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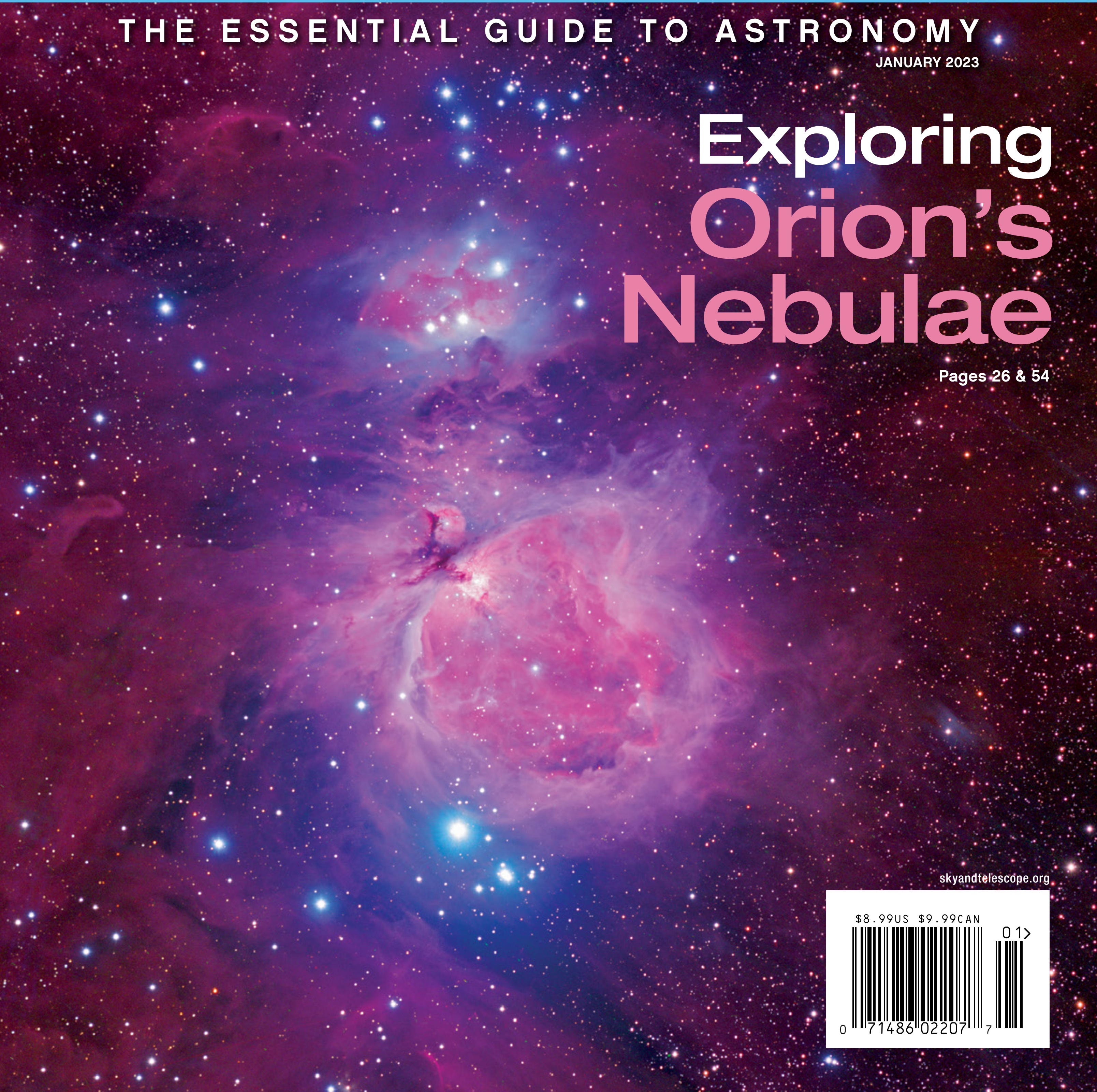
# SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

JANUARY 2023



## Exploring Orion's Nebulae

Pages 26 & 54

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ASTRONOMY'S FAVORITE TRACKING MOUNT — BACK IN STOCK
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Seriously, after everything we've all gone through in the past couple of years, it's nice to have some good news.
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THE ESSENTIAL GUIDE TO ASTRONOMY


January 2023 VOL. 145, NO. 1

NASA / GSFC / ARIZONA STATE UNIVERSITY

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Composite H-alpha and RGB image of the Orion Nebula
MDW SKY SURVEY / S. WALKER

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# Treasures of Orion

**IF YOU HAD TO CHOOSE** one constellation to represent the multifarious wonders of the night sky, you might well choose Orion. The celestial Hunter contains myriad objects you'd want to show a beginner or return to again and again as a serious hobbyist.

For starters, the constellation is one of the most recognizable. How many of us could pick out Orion's Belt even as children? The Hunter is also one of the few star patterns that actually resembles its namesake. With a bit of guidance, most people can discern the mythological giant facing us, with his right arm upraised and his left arm holding a shield towards the charging Bull, Taurus.

If you're just getting into astronomy, Orion offers an ideal way in, particularly at this time of year. Throughout January, the constellation is nicely placed in the evening sky (see Beginner's Space, page 72). Novice observers quickly learn to use asterisms like Orion's Belt to navigate around the sky: Extend that line of three stars left to find Sirius or right to reach Aldebaran.

▲ From red-orange Betelgeuse in upper left to blue-white Rigel in lower right, Orion welcomes endless exploration.

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Orion's stars comprise a diverse stellar sampler. Betelgeuse, the red supergiant and supernova-to-be, blazes from Orion's right shoulder. Rigel, a blue supergiant, shines from his left foot (or left knee, in some depictions). Small telescopes easily split the Belt's rightmost star, Mintaka, into a double, while Sigma Orionis, a multiple star near the left end of the Belt, is a gravitationally bound system of *five* stars.

For larger telescopes, the constellation's nebulae offer limitless investigation. Brian Ventrudo guides you to some of Orion's best in his article about targets in the Radcliffe Wave on page 26. They include the Flame Nebula, the Horsehead Nebula, and Barnard's Loop. (For a sneak peek, see the image on page 30.)

The showpiece, of course, is the Great Orion Nebula, which graces our cover this month. As Ken Hewitt-White writes in his meticulous unsheathing of Orion's Sword on page 54, the Orion Nebula is "arguably the finest deep-sky object visible from northern latitudes." For astronomers, it's a cornucopia of captivating marvels: newborn stars and bow shock waves, brown dwarfs and protoplanetary disks — all of which have been and continue to be objects of intense scientific study.

In sum, one could spend a lifetime — and many do — investigating this storied constellation and its myriad gems. Why not dive in this month?

Peter
Editor in Chief

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**The Essential Guide to Astronomy**

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

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Introducing the HEM27 and the HEM27EC, iOptron's revolutionary hybrid harmonic drive mounts. These lightweight, high payload tiny titans will deliver an astronomy experience like never before. Imagine a mount head weighing in at 8.15lbs with a payload capability of 29.74lbs, without needing a cumbersome counterweight or shaft. Applying iOptron's multi decade experience creating precision mounts, the HEM27 brings this vision to reality. Utilizing state-of-the-art harmonic-drive technology for the RA movement in tandem with a lightweight backlash free DEC worm/belt drive design, the HEM27s deliver unparalleled weight-to-payload efficiency. Its black anodized all-metal CNC-machined body is not only appealing to the eye, it's a rugged platform that will perform at the highest level for many years to come. Unique features such as an electronic friction break and power-down memory allow the mount to safely stop and resume a GoTo slew or continue tracking even after an abrupt power loss (no need to realign and start from the beginning). The HEM27EC features a high-precision RA axis encoder that delivers incredible tracking accuracy, enough that many will choose to image "sans" guiding.
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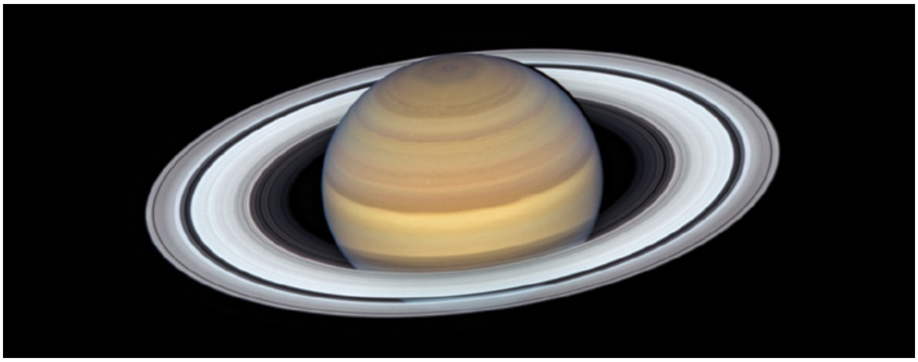


▲ Every year, astronomers use the Hubble Space Telescope to image Saturn in order to monitor the gas giant and its rings. This image is from 2019.

## What's In a Discovery?

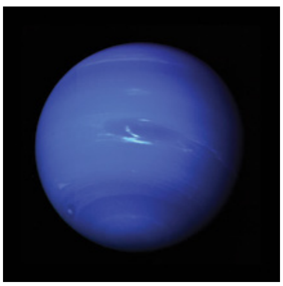
The caption at the bottom of page 29 in "Seeing Saturn's Ring Spokes" (*S&T:* Aug. 2022, p. 28) states, "Galileo Galilei was the first to see the rings [of Saturn], in 1610 . . ."

Galileo certainly saw something unusual about the appearance of Saturn, but I don't believe his telescope was good enough for him to recognize what he saw as rings or a ring. At first, he thought there were two stationary spherical bodies, one on either side of Saturn. A few years later, the rings appeared to him as two handles or "ansae" attached to Saturn.

It wasn't until nearly half a century later that Christiaan Huygens clearly saw, recognized, and described, in Latin, what he saw as a ring around Saturn: "Annulo cingitur, tenui, plano, nusquam cohærente, ad eclipticam inclinato" ("It [Saturn] is surrounded by a thin, flat ring, nowhere touching, inclined to the ecliptic").

**Jeremy Tatum • Victoria, British Columbia**

## Neptune Takes the Stage



◀ September 23, 2021, was the 175th anniversary of the discovery of Neptune. Voyager 2 captured this image nearly one month before the discovery's 143rd anniversary in 1989.

Thank you for Trudy Bell's article "Discovering Neptune: What *Really* Happened?" (*S&T:* Sept. 2022, p. 32). I have been doing 18th-century reenacting for some years. Living in the Brandywine Valley in Pennsylvania, I volunteer at several 18th-century sites. Some years ago, Caroline Herschel became my 18th-century persona.

Bell perfectly put in words the role of a reenactor: "[T]he practice of historical research continued to evolve. Instead of judgmentally viewing events in hindsight, the role of the historian came to be understood as (in the words of the historian Angus Macintyre) 'seek[ing] an empathy with the actors of the past . . . by diligently finding all surviving evidence, then immersing ourselves in their milieu, their circumstances.' The object is to understand events *as the people then would have experienced them* [Bell's emphasis], without foreknowledge of the future, as well as to consider the social context in which the people lived and the obstacles they faced."

We have been saying this for years. We ask people to leave their 21st-century brains and come back with us to the 18th century. I am passing on the above quote to all my reenacting friends.

**K. Lynn King**
**Wilmington, Delaware**

In "Discovering Neptune," Trudy Bell overlooks an important point. Both Urbain Jean Joseph Le Verrier and John Couch Adams assumed that the mean distance of Neptune from the Sun was about 38.8 astronomical units, whereas it is, in fact, about 30.1 a.u. This is because they assumed the correctness of Bode's Law (actually due to J. D. Titius), which approximated the distances from the Sun of all the planets from Mercury to Saturn and had been confirmed by the discoveries of Uranus and the first four asteroids.

It fails for Neptune.

**Lisa Budd**
**London, England**

**Trudy E. Bell replies:** *You are correct in pointing out that Neptune, at 30.1 a.u. from the Sun, turned out to be far closer than the 38.8 a.u. astronomers expected from Bode's Law. In fact, there is a lot to this, and the details are described in* Neptune: From Grand Discovery to a World Revealed, *edited by William Sheehan et al. The complicated problem of inverse perturbations, which Adams and Le Verrier set out to solve, would have been utterly intractable were not some simplifications introduced at the outset. Thus, Adams assumed (just to get started) the Bode's Law distance, circular orbit, and no inclination to the plane of the ecliptic in his first very rough calculation, and by the time he completed what were actually his fourth and fifth calculations, though the Bode's Law distance was retained, he was working with a quite high eccentricity. This eccentricity is much greater than the actual low eccentricity of Neptune, but it is clear in retrospect that the too great Bode's Law distance and the excessive eccentricity balanced each other out, and so the planet's calculated longitude, which was what was needed to reveal the position of the planet, was close enough to the truth at the time to allow discovery.*

*Adams himself wasn't satisfied with the large eccentricity and recalculated everything again, so that his final result the summer before the planet was found at Berlin on September 23rd had a mean distance of 37.25 a.u.*

SATURN: NASA / ESA / A. SIMON (GODDARD SPACE FLIGHT CENTER) / M.H. WONG (UNIVERSITY OF CALIFORNIA, BERKELEY) / THE OPAL TEAM; NEPTUNE: NASA / JPL-CALTECH

I very much enjoyed Trudy Bell's article "Discovering Neptune: What *Really* Happened?" She mentions Benjamin Pierce and Sears Cook finding pre-discovery observations as far back as 1795. In 1980, Charles Kowal and Stillman Drake discovered that Galileo observed Neptune on December 28, 1612, and January 28, 1613, when it was in conjunction with Jupiter. Galileo's notes for his January 28, 1613, observation indicate that he noted that Neptune was farther away from a nearby star than it had been the previous night, and thus was aware of its apparent motion.

She raises the question, "Were pre-discovery sightings actually themselves discoveries?" Despite making the first known recorded observations of Neptune, Galileo is not generally recognized as its discoverer, as there is no evidence that he followed up his observations or that he identified it as a planet. Uranus was observed and mistaken for a star many times before William Herschel identified it as a planet, so astronomers credit him with the discovery.

**Alson Wong**
**Rancho Cucamonga, California**

## Roger F. Griffin (1935–2021)

In Roger W. Sinnott's 75, 50 & 25 Years Ago column on page 7 of the September issue, there was a quote from Roger F. Griffin (about what one could see visually in Palomar Observatory's 200-inch telescope). I had the good fortune to meet Roger Griffin while I was at the University of Cambridge some years later. We lost him last year. I won't attempt to describe his unique career here, with several hundred papers presenting orbits of binary and multiple stars. But I will note he was rigorous in his handling of data, as exemplified in this quote I've retained from a 2013 paper: "There are some unusually bad residuals in Table XII; it is not possible to distinguish between stellar and instrumental origins for them, and it seems better to retain them in the solution of the orbit than to reject them for no better reason [than] we don't like them and wish that they were not there." We can hope that this attitude survives in current scientists.

**Alan Whiting**
**Alexandria, Virginia**

### FOR THE RECORD

- On page 12 of the October 2022 issue, the description of Kepler's third law of planetary motion omitted the word "root" from the cubed-root phase of the equation.
- In the sidebar on page 37 of the October 2022 issue, the most common elements in the universe are hydrogen, helium, oxygen, carbon, and neon.

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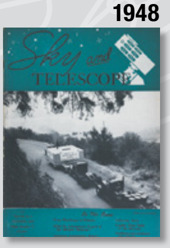
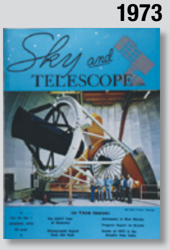
## 75, 50 & 25 YEARS AGO by Roger W. Sinnott

1948




1973




1998


**January 1948**

**Moving a Mirror** "At Rincon, where we had stopped . . . , the truck-men removed a large section of the trailer to shorten the length for the curves ahead. Once started up the mountain, there was no turning back, and the 20-foot crate which held the largest eye in the world sometimes straddled the entire road, even in places where the mountainside dropped a sheer 1,000 feet.

"But in spite of the bad weather, we were up to the observatory by 11 o'clock and the mirror was unloaded by 12. The building was completely breathtaking and equally freezing, for the summit temperature was 29° Fahrenheit. . . . Reporters from many papers and wire services, newsreel camera and radio men were all there, so this trip of the century was well covered for the general public."

S&T *staffer Nancy R. Bolton was there as the 200-inch mirror arrived on Palomar Mountain.*

**January 1973**

**Sidewalk Astronomers** "For a week early last July, I accompanied [this group] on one of their frequent visits to Yosemite National Park, where 7,200-foot Glacier Point provides an observing site that is among the best in California. The largest telescope in our caravan was the 24-inch Newtonian they call Delphinium — the one with which I did most of my observing.

"These active amateurs have been showing the heavens to the public for many years, not only on the sidewalks at Fisherman's Wharf in San Francisco, but also at campsites and scenic high-elevation spots around the state. They have a host of large reflectors, each with its own name. There is 10-inch Heliotrope for solar observing, a pair of 16-inch reflectors called Cyclops and Magnificat, . . . and many more.

"The key to the society's success is telescope maker John Dobson's skill in figuring and mounting mirrors made from one-inch-thick porthole glass."

*Lee McDonald described a novel but counterculture approach to amateur astronomy. It would come to be known as the Dobsonian revolution.*

**January 1998**

**Exoplanet Mystery** "One of the many confounding aspects of the newly found planets around other stars is why some of them are in highly eccentric orbits. When planets coalesce from a disk surrounding the protostar . . . they should wind up in nearly circular orbits — just like those in our solar system. However, the paths of three stars' companions . . . are [noncircular.]

"Jonathan I. Katz (Washington University) examined whether two planets in nearly circular orbits could have a sufficiently close encounter that would result in one planet being ejected from the system and the other settling into an orbit more akin to those of comets and asteroids. . . . In his assessment, [this won't work]."

*This puzzle persists.*

◀ The ATLAS project captured stills of the DART mission's impact on Dimorphos. (See the animation at **https://is.gd/DARTphotos**.)

SOLAR SYSTEM

# NASA's DART Mission Successfully Impacts Asteroid

**AS EARTH BARRELS** along its orbit around the Sun, it's peppered by impacts from near-Earth objects. While large collisions are rare, the fossil record demonstrates that once in a while, large asteroids have dug out craters, spawned tsunamis, caused climate changes, and wiped out life.

But with enough warning, a small change in an asteroid's orbital velocity could turn a certain future impact into a certain miss. The first test of such a mechanism happened on September 26th, when NASA's Double Asteroid Redirection Test (DART) smashed nearly head-on into Dimorphos, the satellite of asteroid 65803 Didymos. If the crash changes the velocity of Dimorphos' orbit by a detectable amount, the mission will validate the notion that we can use a kinetic impactor to nudge a hazardous asteroid's path, keeping Earth out of harm's way.

DART streamed photos from its Didymos Reconnaissance and Asteroid Camera for Optical navigation (DRACO) down to Earth in real time, about one per second. Fed into an onboard computer with software descended from anti-missile technology, those images helped DART autonomously guide itself to impact. On its approach, it resolved Dimorphos and its larger companion Didymos into worlds with fascinating surfaces covered with gullies and angular blocks. DART initially targeted the binary system, then it differentiated the larger and smaller member of the binary pair, and finally it steered toward the smaller Dimorphos.

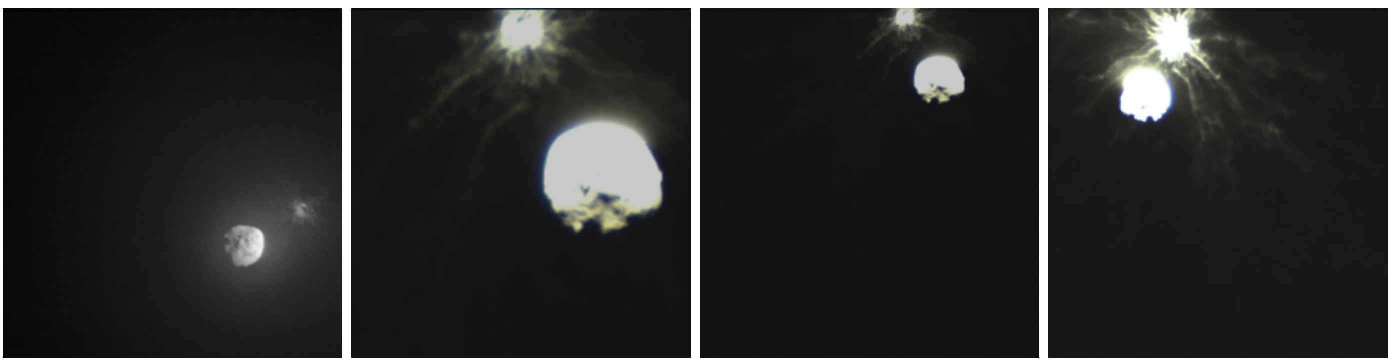
While the DRACO camera feed ended upon impact, the Italian-built minisatellite LICIACube (pronounced "lee-chee-ah kyoob"), separated from DART on September 11th to establish a viewpoint on the carnage. LICIACube used two cameras (the high-resolution, monochrome LEIA and wider-angle, color LUKE) to shoot photos of Dimorphos throughout the approach, impact, and afterward. It passed about 55 kilometers (34 miles) away from the moon 165 seconds after the impact.

Meanwhile, observers throughout space and across Earth watched the immediate and long-term effects of the crash. Other in-space observers include the Lucy spacecraft, currently cruising toward its Jupiter Trojan asteroid mission, as well as the Hubble and James Webb Space Telescopes. Along with Earth-based observers, the telescopes saw the plumes of dust that rose off the surface of Dimorphos in response to the crash. At least two separate plumes were visible: One, crescent-shaped, spread out in the direction opposite the impact, while another, fainter one jetted at an angle behind Didymos' apparent motion across the sky.

The key result from the mission — detecting a significant decrease in Dimorphos' orbital period — will take days to weeks to achieve. Observers across Earth will look for the telltale dimming of the Didymos system's light as the asteroid pair mutually eclipse each other throughout the rest of 2021. The period will need to decrease by at least 70 seconds for the change to be detectable above the uncertainty in the orbit. Didymos is fainter than 14th magnitude, out of reach of typical backyard scopes, so the mission organized no formal amateur observing campaign.

■ EMILY LAKDAWALLA

**See more impact follow-up observations at https://is.gd/DARTphotos.**



▲ The CubeSat LICIACube separated from DART on Sept. 11th to photograph the impact on Sept. 26th from a safe distance. The spacecraft swung closest to the asteroid 165 seconds after impact (second frame) and captured asymmetric plumes of dust coming from Dimorphos.

DART IMPACT FROM GROUND-BASED TELESCOPE: IMAGES: ATLAS PROJECT (UNIVERSITY OF HAWAI'I / NASA); IMAGE PROCESSING: EMILY LAKDAWALLA; LICIA CUBESAT PHOTOS OF IMPACT: ASI / NASA (4)

MARS

## Perseverance Finds Habitable Conditions (But Not Yet Life)

**ON SEPTEMBER 15TH** NASA announced a status update on the Perseverance rover trundling through Jezero Crater on Mars. Some 3.5 billion years ago, rivers broke through the crater rim to fill a lake there. Now, the mission team has revealed the first results from investigations of the delta deposits that the rivers left behind.

In contrast to the crater floor, where the rover found igneous evidence of ancient volcanic activity, the new findings focus on the sedimentary layers of the delta front.

The team took two samples each from two ridges: Skinner and Wildcat. The two ridges are quite different, says David Shuster (University of California, Berkeley). Skinner Ridge has a mixture of sedimentary rocks, some of which the river carried to the delta from a long way away. Wildcat Ridge, on the other hand, hosts sulfate-rich mudstone that would have formed in place in salty brines as the lake water evaporated.

Unlike igneous rocks, sedimentary rocks easily preserve organic matter. So if biological activity were present when the sedimentary layers formed, the rock core samples could reveal it, Shuster explains. But any signs of life would be ancient; the surface of Mars is inhospitable today.

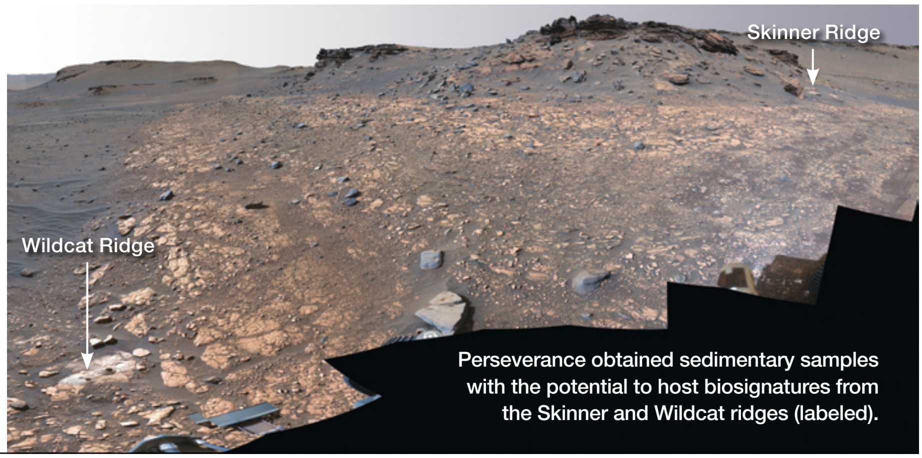
◀ Perseverance at work near a rocky outcrop called Skinner Ridge. The rover abraded a circular patch to analyze a rock's composition.

Although definitive signs of life await future sample analyses, Perseverance's SHERLOC instrument found organic matter, likely ring-shaped aromatic compounds, tied to sulfate minerals in the rocks, says Sunanda Sharma (JPL).

But it isn't clear yet whether life produced these compounds or if it was a purely chemical process, Sharma cautions.

As of press time, Perseverance has collected 13 samples (12 rock cores and one containing Martian atmosphere). The current sample-return plan has samples coming to Earth by 2033. And then the fun will really begin!

■ MONICA YOUNG




Perseverance obtained sedimentary samples with the potential to host biosignatures from the Skinner and Wildcat ridges (labeled).

EXOPLANETS

## Webb's Exoplanet Data Are Almost Too Good

**GOOD SCIENCE TAKES TIME.** That's not a popular refrain when there's a new space telescope sending down crystal-clear views of the infrared universe nearly every day. But astronomers drinking from the firehose that is the James Webb Space Telescope need time to interpret some of their most anticipated data: the spectra of exoplanet atmospheres. A study published September 15th in *Nature Astronomy* urges caution in interpreting the chemical fingerprints of these alien worlds.

While molecule detections to date aren't in question, determining their abundance is trickier, says Julien de Wit, who led the study with graduate student Prajwal Niraula (both at MIT). Niraula, de Wit, and colleagues found that the models astronomers use to decode spectra become imprecise when faced with high-quality Webb data. For example, one group of astronomers might conclude that an exoplanet's atmosphere is 5% water, while another group might find it's 25% water, and it would be difficult to say who's right.

"To date, no studies have been published regarding the interpretation of Webb exoplanet spectra, so our study is timely," de Wit says. Just how long it will take to get models up to speed depends on the molecule in question.

"For instance, for carbon monoxide (CO), there's not much work needed at the level of accuracy required by JWST," says team member Iouli Gordon (Center for Astrophysics, Harvard & Smithsonian). For water measurements in deep atmospheres, though, lab measurements and theoretical calculations will take a few years to catch up to Webb's observations. Some molecules, like ethane, will need a lot more work.

Caroline Morley (University of Texas, Austin), who wasn't involved in this study, thinks we might not need to wait if we use brown dwarfs for comparison. These "failed stars" share many characteristics with giant planets, and past studies comparing lab-based measurements with brown dwarf spectra have shown good agreement.

"My instinct is that the conclusions are therefore a bit overstated," Morley says. "Nonetheless, the paper is a nice contribution to the field." Hopefully, she adds, it will bring needed attention to "under the hood" modeling work.

■ MONICA YOUNG

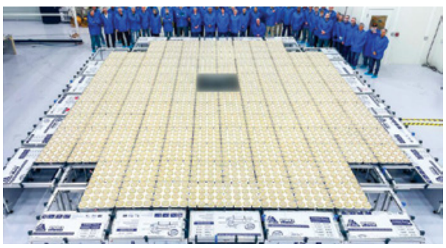
NASA / JPL-CALTECH / ASU / MSSS (2)

SPACE & SOCIETY

## Bright New Satellites to Join a Crowded Sky

**BLUEWALKER 3,** a prototype of a new constellation of extremely bright Earth-orbiting satellites, launched successfully on September 10th. The AST SpaceMobile company plans to orbit more than 100 of these spacecraft by the end of 2024. Astronomers at the Vera Rubin Observatory and the International Astronomical Union's Centre for the Protection of Dark and Quiet Skies from Satellite Constellation Interference (IAU CPS) are concerned because these new spacecraft will interfere with celestial observations, adding to the problems already caused by other satellite constellations.

BlueWalker 3 features a giant antenna array covering an area of 64 square meters (693 square feet). Observers on the ground will see bright sunlight reflected from this structure. After on-orbit tests of BlueWalker 3 are completed, operational satellites called BlueBirds will be launched. BlueBirds may be more obtrusive since they will be significantly larger.



▲ The BlueWalker 3 satellite's phased array antenna (which also functions as a solar panel) covers 64 square meters.

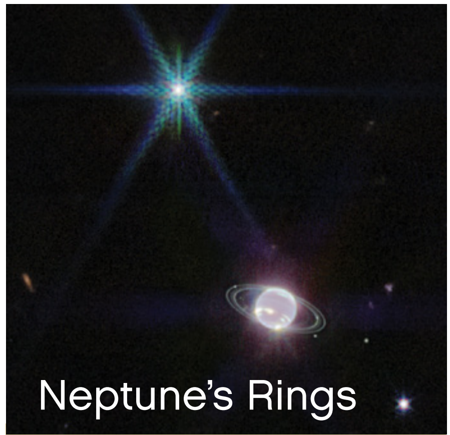
The satellites' commercial appeal is that they'll link directly to cell phones without needing a tower. AST SpaceMobile has already secured a license from the Federal Communications Commission (FCC) to test the prototype.

The satellites will be stored as compact objects on their launch vehicle and will unfold the large antennas after being released into space. The back side of each antenna has solar cells for power. As of press time, BlueWalker 3 hasn't unfolded its panel yet.

Other bright satellites are waiting in the wings: 30,000 second-generation Starlink satellites are currently awaiting FCC approval. Like the BlueBirds, the new Starlinks may carry antennas for direct connection to cell phones; the antennas are slightly smaller at 25 square meters, but the satellites would be far more numerous than the BlueBird constellation.

BlueWalker 3 is expected to be among the brightest objects in the night sky after the antenna unfolds. Amateur astronomers and astrophotographers can help record BlueWalker 3's brightness; see **https://is.gd/BlueWalker3** to learn more.

■ ANTHONY MALLAMA




The James Webb Space Telescope has imaged Neptune and its gossamer rings. We haven't detected some of these rings since Voyager 2's flyby of the planet in 1989. Neptune itself appears dark in the image because trace amounts of methane in its atmosphere absorb the near-infrared wavelengths Webb was observing. However, high-altitude clouds appear bright because their methane ice crystals reflect sunlight before they can absorb it. A thin line at the equator also appears bright, because this is where the atmosphere warms and sinks. The image also shows seven of Neptune's 14 known moons, including the brilliant Triton, surfaced in highly reflective frozen nitrogen, at upper left. Triton is much brighter than Neptune and carries Webb's characteristic diffraction spikes.

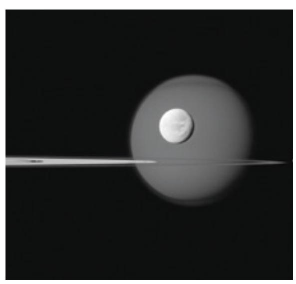
■ MONICA YOUNG

SOLAR SYSTEM

## Lost Moon Might Solve Saturn Riddles

**A ROGUE MOON** might be responsible for Saturn's spectacular rings: In the September 16th *Science*, Jack Wisdom (MIT) and colleagues propose that tidal forces tore apart this moon, dubbed Chrysalis, some 100–200 million years ago. The scenario could also explain other curiosities of the Saturnian system. "It's quite an innovative hypothesis," says Jack Lissauer (NASA Ames), who wasn't involved in the study.

Wisdom and collaborators note that Saturn's *precession* — the slow wobble of its spin axis — has almost but not quite the same period as the precession of Neptune's orbit. The researchers thus suggest there was once a true *spin-orbit resonance* between the two planets. After the resonance locked in hundreds of millions of years ago, Saturn's spin axis would have tilted, explaining its current unexpectedly high *obliquity* of 26.7°.



◀ Saturn's rings slice through the center of this image. The largest moon, Titan, is in the background; in the foreground is the icy moon Dione.

Saturn escaped the spin-orbit resonance thanks to Chrysalis, an icy moon that orbited between Titan and Iapetus. As Titan drifted outward toward Chrysalis over time, simulations show that the moon would have entered a 3:1 resonance, orbiting Saturn once for every three times Titan swung around. But Chrysalis's trajectory eventually

BLUEWALKER 3'S LARGE SOLAR PANEL: AST SPACEMOBILE; NEPTUNE: IMAGE: NASA / ESA / CSA / STSCI, IMAGE PROCESSING: JOSEPH DEPASQUALE AND ANTON M. KOEKEMOER (STSCI); SATURN'S MOONS NEAR RINGS: NASA / JPL-CALTECH / SPACE SCIENCE INSTITUTE

OBITUARY

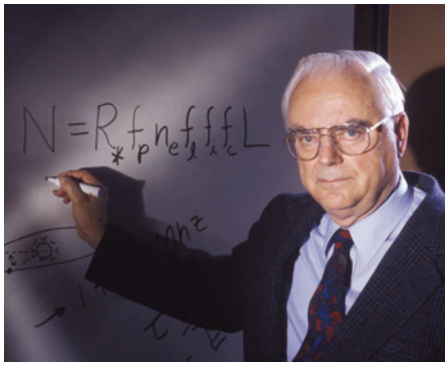
## Remembering Frank Drake, 1930–2022

**FRANK DRAKE,** a pioneer in the search for extraterrestrial intelligence (SETI), died on September 2nd at the age of 92.

Born in 1930 in Chicago, Drake first thought about alien life at the age of eight, when his father told him of other worlds. After earning an engineering physics degree at Cornell University, Drake served three years as an electronics officer on a Navy cruiser before completing graduate studies in astronomy at Harvard University, working with stellar astronomer Cecilia Payne-Gaposchkin.

At his first position after graduation, at the National Radio Astronomy Observatory in Green Bank, West Virginia, Drake was finally able to pursue his boyhood dream of searching for alien life. For two months in 1960, he pointed the observatory's 85-foot Tatel dish alternately at two nearby Sun-like stars, Tau Ceti and Epsilon Eridani, searching for transmissions along particular frequencies. Dubbed "Project Ozma," this first study shaped SETI efforts for decades to come (*S&T:* Jan. 1960, p. 140).

The project found no real signals but drew public attention and, one year later, the U.S. National Academy of Sciences funded the organization of a SETI-themed conference. Drake organized the agenda, breaking down



SETH SHOSTAK / SETI

the probability of finding alien intelligence into several factors, items that turned into what is now known as the Drake Equation (*S&T:* Dec. 1998, p. 36). This equation has shaped SETI efforts as much as if not more so than Project Ozma did.

Drake was also instrumental in sending out signals of our own, including the plaques bolted to Pioneer 10 and 11 and the Golden Record sent out with Voyager 1 and 2. Even before these, as director of the Arecibo Observatory between 1971 and 1981, he used the 300-meter dish to send a coded message in the direction of globular cluster M13.

In 1984, Drake moved to California for positions at the University of California, Santa Cruz, and the SETI Institute. He continued SETI work for the rest of his life. Drake is survived by his wife, two daughters, three sons by a previous marriage, a brother, a niece, a nephew, and four grandchildren.

■ MONICA YOUNG

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became chaotic, undergoing multiple encounters with Titan, Iapetus, and other satellites. Those encounters might be responsible for Titan's slightly elongated orbit today.

If the moon ended up grazing near Saturn, the planet's tidal forces would have torn it apart to create the bright and icy rings. The timeline fits in nicely with the young age some researchers have previously suggested for the rings (*S&T:* Sept. 2021, p. 14).

Regardless of whether it created the rings, the icy moon's elimination would have changed Saturn's precession and broken the resonance with Neptune.

Luke Dones (Southwest Research Institute, Boulder) is impressed the team has reproduced so many aspects of the Saturnian system. But he notes, "They take for granted that the rings are young, which is not established."

For his part, Lissauer says he is "not convinced that it's correct, nor that it's wrong," adding that the idea has "surprisingly, many potential pluses."

A better measurement of Saturn's interior, gravity field, and precession rate might test parts of the Chrysalis scenario, Lissauer says, but "it's really difficult to confirm."

■ GOVERT SCHILLING

# IN BRIEF

## New Authority for Mauna Kea

New stewardship of Mauna Kea, which hosts some of the world's largest telescopes, could change the face of astronomy at the summit. The University of Hawaii has overseen the construction of 13 telescopes at the peak over the past 50 years, but new construction often occurred over the protest of Native Hawaiians. Now, management will transition to an 11-member Mauna Kea Stewardship and Oversight Authority that includes a broad spectrum of voices. After a transition period of five years (starting July 1, 2023), this group will have jurisdiction over all state-leased lands on Mauna Kea, including the 550-acre astronomy precinct that hosts 12 of the 13 telescopes, the Hale Pōhaku complex that hosts visiting astronomers, and the access road that takes visitors up to the summit. The new authority will oversee the telescopes' subleases, up for renewal in 2033, and make decisions about the in-limbo construction of the Thirty Meter Telescope (TMT).

■ MONICA YOUNG

**Read details at https://is.gd/Mauna.**

## First Inter-Venusian Asteroid

The discovery of an asteroid inside Venus's orbit might be the first of a new population in the inner solar system, suggests a study published August 13th in the *Monthly Notices of the Royal Astronomical Society*. A team of astronomers spotted the asteroid on the night of January 4, 2020, using the 48-inch Samuel Oschin telescope at Palomar Observatory. Later measurements showed it's always within Venus's orbit. At the discovery team's request, the Pauma band of indigenous peoples have named the worldlet 594913 ʻAylóʼchaxnim, (pronounced ai-LOH-chakh-nym), meaning "Venus Girl" in the group's Luiseño language. It's as red as asteroids in the main belt, indicating its possible origin, and it spans 2 kilometers (1.2 miles), surprisingly large for an inner-solar-system object. Team lead Bryce Bolin (Caltech) notes that seeing a large object early on suggests there might be more asteroids within Venus's orbit than previously thought. But ʻAylóʼchaxnim's orbit isn't stable: It's probably a recent arrival, and simulations show that in the next 10 million years or so it has a high chance of smashing into Venus.

■ DAVID DICKINSON

# Worlds Apart

*Can a newly found exoplanet help explain why Earth and Venus diverged so radically?*

▲ Like the seven-planet Trappist-1 system, pictured here in an artist's concept, the red dwarf LP 890-9 system may host at least one planet bearing liquid water on its surface.

MARK GARLICK / SCIENCE PHOTO LIBRARY

**IN COMPARATIVE PLANETOLOGY** we can't run controlled experiments, altering factors such as initial composition or distance from a star and then seeing what happens over billions of years. We can only study the random experiments nature has chosen to run and try to piece together the overall story.

The closest we may ever get to a controlled experiment for Earth's evolution is a comparison with Venus. Our sister world seems to have started with similar ingredients and conditions as our planet — though about a third closer to the Sun — yet it evolved into such an utterly different planet. We're still trying to work out the timing and mechanisms for this divergence, and to find evidence for or against past oceans on our neighboring world. These questions are a major motivation for the fleet of Venus missions we'll launch in the next decade (*S&T:* May 2022, p. 12).

They are tough problems to solve because there are so many variables. Did Earth and Venus actually form out of different stuff? How do rotation rates and magnetic fields affect planetary evolution? How did the massive collision that formed the Moon change our planet? Also, how could we possibly answer these questions by studying only two Earth-size planets?

Fortunately, help is arriving in patterns of photons from distant stars that reveal previously hidden planetary companions. Exoplanets can rescue comparative planetology from the curse of too few examples. It goes both ways: Solar system planets give us ground truth for filling in the vague clues we can gather from a growing harvest of exoplanets, and in turn this multitude will provide context for our home system, teaching us which characteristics are widespread and which are just local quirks.

An exciting new discovery illustrates the complementary nature of these efforts. An international team led by Laetitia Delrez (University of Liège, Belgium) was using a telescope in Chile to verify a planet found by the TESS mission around LP 890-9, a red dwarf star 100 light-years distant, when it found another planet orbiting the same star.

This lucky find, dubbed SPECULOOS-2c, is slightly larger than Earth and located just at the inner edge of that system's habitable zone. Orbiting its star at only a tenth of Mercury's distance from the Sun, SPECULOOS-2c receives about 90% of the starlight that Earth receives from the Sun. This means that — depending on evolutionary details that are still poorly understood — the planet might be something like an exo-Earth, or it may instead resemble an exo-Venus. How can we tell?

Its atmosphere would give us a clue. The James Webb Space Telescope could observe starlight passing through its atmosphere, and the mix of gases seen would be very different for a watery Earth than for a parched Venus.

Of all stars known to have planetary systems, LP 890-9 is now the second coolest, in both meanings of the word. Such relatively dim red dwarf stars can host planets that orbit very close by but nonetheless may be habitable, in the sense of having stable liquid water on their surfaces. And having nearly Earth-size planets in this zone, which as far as we know might have inhabited oceans — well, that's just *cool*.

What makes a planet become like Earth, with stable oceans and a surface biosphere, as opposed to a scorching, desiccated world like Venus? The next decade of exploration with spacecraft, aided by continuing exoplanet discoveries, should reveal the answers.

■ **DAVID GRINSPOON** is a senior scientist at the Planetary Science Institute.

 by Melinda Soares-Furtado & Sarah Kubiak

# AGING *Ungrac*


As stars grow older, they and their planets can affect each other in strange and violent ways.

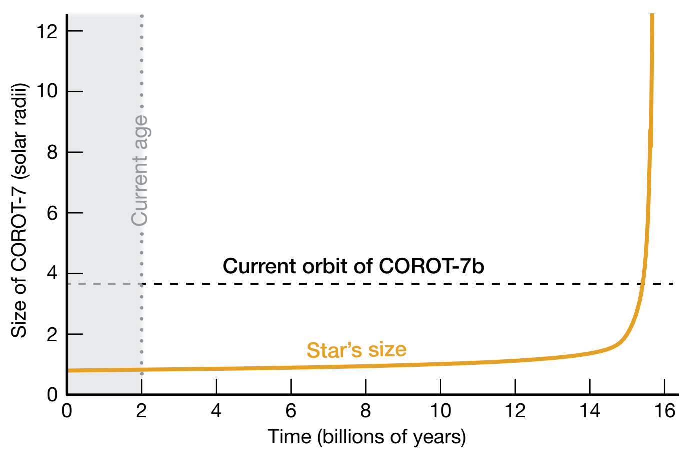
Astronomers have confirmed the existence of more than 5,000 exoplanets to date. The vast majority of these — approximately 95% — orbit stars in an evolutionary stage akin to that of our Sun, a stage known as the *main sequence*. Main-sequence stars actively fuse hydrogen into helium in their dense, hot cores. Stars spend the vast majority of their nuclear-burning lives in this stage: In the case of a Sun-like star, the main sequence comprises 90% of the total stellar life cycle.

But what about the 5% of known exoplanets found around aging stars? These stars bear exotic names like *subgiants*, *red giants*, and *white dwarfs*, and they have evolved to have vastly different sizes, temperatures, and luminosities than they did when they were young. Any planets around these stars have therefore experienced a dramatic change in circumstances, which in many cases leads to their destruction.

With so few examples of these mature planetary systems in hand, it's difficult for us to know how late-stage planetary evolution unfolds. Nevertheless, the systems we do have serve as critical benchmarks in our quest to trace the complete planetary life cycle. These systems are teaching us that the evolutionary process is in some ways a symbiotic one: Not only do aging stars affect their planets, but the planets also affect their stars.

## Red and Puffy

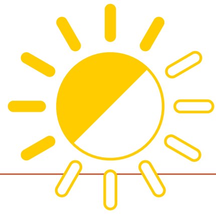
A star's birth mass largely determines how its evolution proceeds; there isn't a "one size fits all" pattern. But of stars confirmed to have at least one exoplanet, the average mass is essentially that of the Sun, and nearly all those host stars (99%) weigh in at less than two solar masses. So the life cycle




◀▲ **COROT-7B** This illustration *(left)* shows the roasted surface of a super-Earth that closely orbits the Sun-like star COROT-7. The star will swell and engulf the planet's orbit in 13 billion years *(above)* — but the star will likely eat the planet much sooner than that, depending on how quickly tidal forces make the planet spiral closer. (Age is approximate.)

ARTWORK: ESO / L. CALÇADA, PLOT: GREGG DINDERMAN / S&T, SOURCE: M. SOARES-FURTADO

**Half**
Fraction of its mass the Sun will lose as it ages



of a Sun-like star provides an informative evolutionary trajectory for the current census of known exoplanets.

During the main sequence, a star remains in a state of *hydrostatic equilibrium*, whereby the inward pull of gravity is counterbalanced by the outward pressures of heat and light produced by nuclear fusion. However, the star's core hydrogen reserves are not limitless. Once a star has exhausted its supply, fusion ceases. Without a supply of central energy, the star's inert helium core begins to contract under its own gravity. The outer regions of the star, still rich with unprocessed hydrogen, also contract, causing the star's interior to heat up. Eventually, a thin layer of hydrogen around the core reaches a critical temperature, and nuclear fusion recommences.

Once hydrogen-shell burning begins, the star enters a new evolutionary stage known as the *subgiant branch*. Fusion slowly moves outward into higher sections as it depletes the shell's hydrogen, adding new layers of helium ash to the stellar core. A subgiant star produces more energy than its main-sequence counterparts. The increased radiation pressure pushes on the star's outer layers, causing the star to expand. By the end of the subgiant phase, a Sun-like star will have doubled in size.

The star grows even more during the next evolutionary stage, known as the *red giant branch*. Stars like the Sun will swell to become 100 times their original size. The internal and external changes will cause the star to brighten by a factor of 1,000, and the distance at which a planet can sustain liquid surface water will change significantly. In the case of our own solar system, the habitable zone will sweep outward, briefly baking the gas giants and their icy moons with an unfamiliar warmth. (Earth's atmosphere and oceans will have long since boiled away, perhaps during the subgiant phase.)

A far bleaker fate awaits the companions that closely orbit their evolving stellar hosts. Such planets are doomed to be engulfed by the expanding star at this stage. Mercury and Venus will suffer this end. Earth might as well, but our planet's future depends upon things like how the Sun's mass loss will affect the planets' motions, which we don't know precisely (*S&T:* Oct. 2017, p. 22). Assuming Earth does survive, by the end of the Sun's red giant phase, average temperatures on our planet will top 1000°C (2000°F).

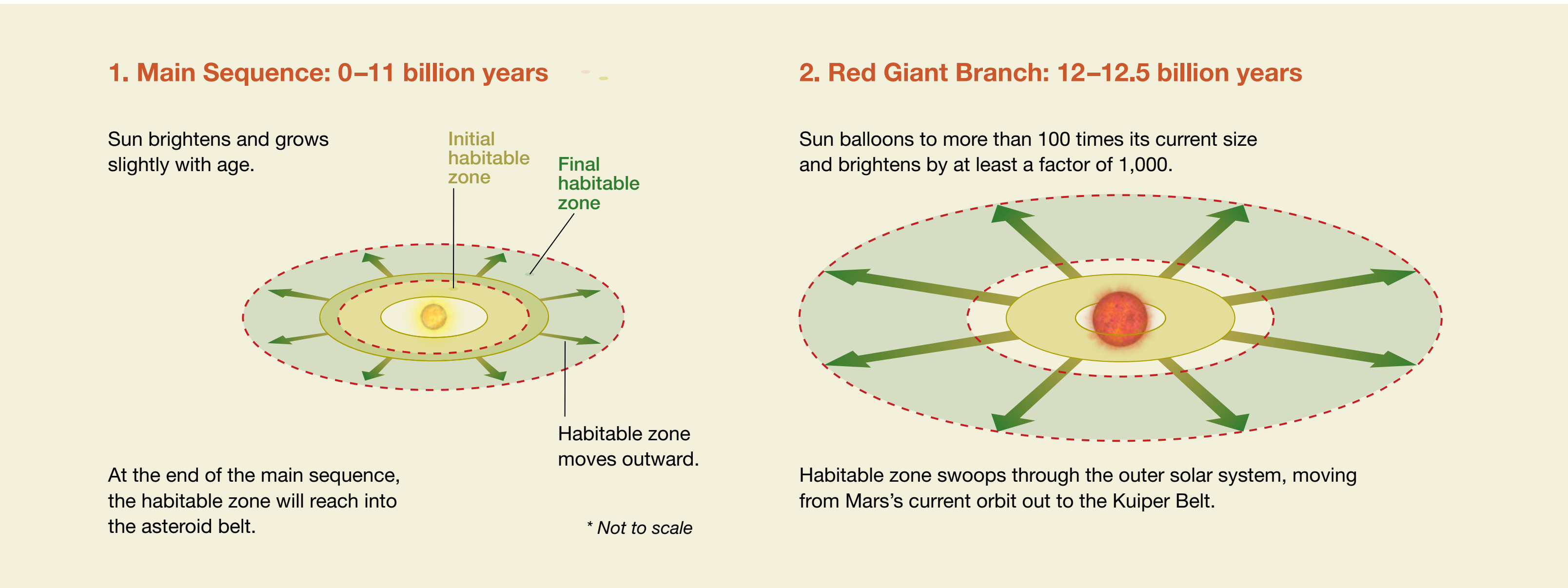
Planetary-engulfment events at these late evolutionary stages are common. Observations indicate that exoplanetary engulfment will accompany the evolution of 30% of *all* Sun-like stars. It's also the fate awaiting some 90% of the confirmed exoplanet population. This is because we've detected the vast majority of these alien worlds (95%) using techniques that more easily find companions in close orbits. Astronomers have seen signs of orbital decay in some planetary systems, with the exoplanets' orbital periods decreasing over time. These planets appear to be spiraling inward toward their hosts on million-year time scales.

## Stellar Indigestion

While exoplanet ingestion is not a rare phenomenon, there is

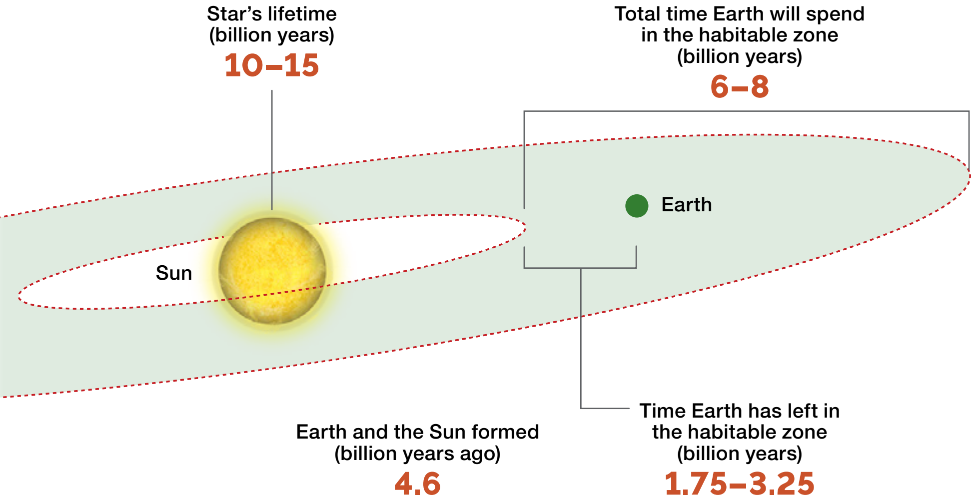
▼ **LIFE OF THE SUN** The Sun is slowly brightening as it ages, pushing its habitable zone out. Once core hydrogen fusion ceases at the end of the main sequence, the star will undergo several evolutionary stages, three of which appear here. Each brings extreme changes to the Sun's size and luminosity and shifts the habitable zone's location. Orange numbers are the star's age during each stage (the AGB stage lasts about 20 million years).

LIFE OF THE SUN: GREGG DINDERMAN / *S&T*



## How much time does Earth have left in the habitable zone?

Sun-like stars will spend more than 10 billion years fusing hydrogen in their cores, but that doesn't mean Earth-like planets have 10 billion years of clement conditions: The liquid-water zone moves outward through the planetary system as the star ages. Earth has only a couple billion years left in the Sun's habitable zone, and it might even start to lose its atmosphere 1 billion years from now, as the planet's core cools and our global magnetic field weakens.




much we astronomers still have to learn about this important stage of star-planet evolution, especially regarding the effects on the star itself. Although a planet is tiny compared with its star (Jupiter contains 0.1% as much mass as the Sun does), it could still affect its host in observable ways.

For example, stars may occasionally swallow a world more or less whole. How deep will the planet penetrate the star before it fully falls apart? Does this depth change the details of the star's fate? Might dense companions avoid disassociation altogether, surviving inside the bloated star? Preliminary work suggests that in rare cases, the planet might go so deep that it passes into the star's inner layers and triggers the ejection of the star's outer envelope of gas, which we'd see as a boost in infrared light from the aging star.

The decay of the planet's orbit could also affect the star. The planet's angular momentum has to go somewhere, because the laws of nature require that the angular momentum be conserved. A likely recipient is the star's spin. Calculations suggest that a Jupiter-mass world could increase a Sun-like star's spin by 60%. Even a Neptune-size planet could spin up its star by 10%.

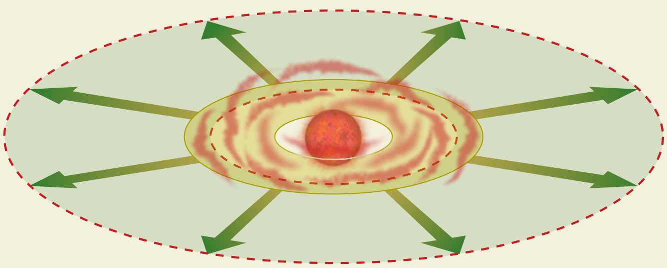
One effect we already have evidence for is on the star's surface chemistry. Theory shows that an engulfed planetary body leaves long-standing, telltale chemical fingerprints on the star's surface — even in cases in which the companion is not fully disassociated. We can only detect such contamination signatures if we have a good idea of the host star's original composition. Luckily, nature is generous, providing environments like wide-orbiting binary stars, co-moving groups, and stellar clusters where such constraints are possible.

One particularly useful engulfment tracer is the lithium-7 isotope, which, on average, is 60 times more abundant (per unit mass) in planets than in stars. Astronomers have detected strong signatures of lithium enrichment in some

AGING HABITABLE ZONE: TERRI DUBÉ / *S&T*

### 3. Asymptotic Giant Branch: 12.7 billion years

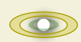
Sun shrinks and expands again, shedding half its mass.



The habitable zone, which had shrunk down to cover Jupiter and Saturn's orbits, expands again out to the Kuiper Belt.

### 4. White Dwarf: >12.7 billion years

Sun becomes a white dwarf. After 2 billion years, its cooling rate slows, enabling a long-lived habitable zone.



The white dwarf has a surface temperature similar to the current Sun, but it's about 1/10,000 as luminous. The habitable zone lies roughly 0.01 a.u. from the star. Over many billions of years, it slowly shrinks.

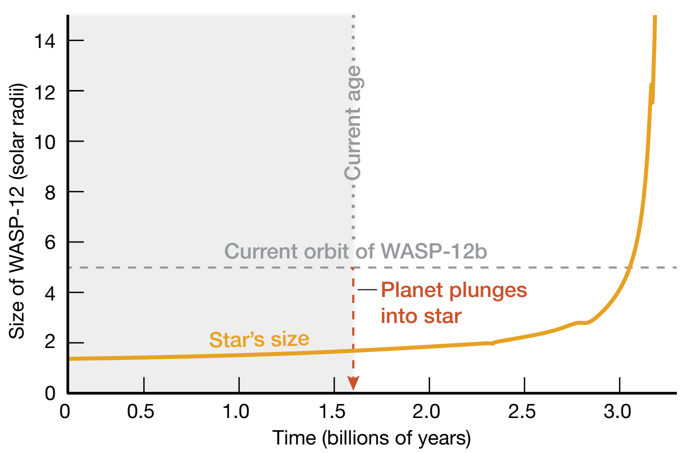
star-planet systems. These observations indicate that 1% of all *G*- and *K*-type giant stars have substantial levels of lithium-7; of those, 6% exceed the pristine levels of their birth, based on our expectations from meteoritic studies. A star should easily destroy its lithium as it ages, so something is enriching these giants, and disrupted planets likely play an important role. Enhancements of *refractory metals* — elements with exceptionally high boiling temperatures — offer additional engulfment indicators.

Perhaps most interesting of all is the fact that planetary-engulfment sites offer a rare and valuable opportunity to probe the bulk composition of the engulfed planets. We might be able to tell what a destroyed planet's crust or core was made of. Other kinds of exoplanet observations — say, of starlight passing through a planet's cloud deck — only tell us about a world's atmosphere.

## Ember Star

What about the planets that *do* survive? What is the fate of gravitationally bound planets that were not engulfed by their hosts, or of the planets that were swallowed whole but are so dense that they're impervious to digestion? The future of these planets is intimately connected to the final stages of stellar evolution.

Taking a solar twin as our primary example once again, we consider such a star billions of years in the future. At this evolutionary juncture, the star has endured additional phases of internal and external transformation, and all stellar fusion processes have finally ceased. The star has shed its outer layers, and the core has become an Earth-size remnant known as a *white dwarf*, held up against further collapse by the pressure of electrons refusing to pack any tighter. An extraordinary 97% of all the stars in the Milky Way Galaxy will end their lives as white dwarfs, slowly cooling with time as energy radiates from their surfaces.




▲ **IMMINENT DEMISE** If planets stayed put until their stars swelled to engulf them, then the hot Jupiter WASP-12b would have about 2 billion years in its future. But observations reveal that the planet's orbit is decaying rapidly — in only 3 million years, it will plunge into the star.

GREGG DINDERMAN / S&T, SOURCE: M. SOARES-FURTADO

White dwarfs may be similar in size to Earth, but the similarities end there. These dense remnants are more than 200,000 times more massive than our world. The resulting surface gravities are more than 100,000 times what we experience. This leads to a stratified composition, as heavy elements sink from the stellar surface to the deep interior and light ones rise up. The outer layers of the white dwarf comprise the lightest elements, hydrogen and/or helium. The resulting spectrum is near-featureless, which makes contamination from any planetary material rather conspicuous!

**These dense remnants are more than 200,000 times more massive than our world.**

One of the most exciting advances in the field of exoplanetary science has been the discovery of exoplanets around white dwarfs. In most cases, observations reveal that these companions have long been torn asunder by the star's strong tidal forces, creating a planetary debris disk. In fact, to date, only one intact exoplanet has been confirmed in orbit around a white dwarf host.

The world, coined WD 1856b, is 14 times more massive than Jupiter and orbits its white dwarf every 1.4 Earth days. The small orbital separation, which is 20 times closer than the distance between Mercury and our Sun, is rather puzzling. If we rewound the clock on the host's evolution, leaving the orbital separation fixed, we would find the planetary companion embedded within the host's stellar envelope during the red giant phase — a situation it shouldn't have survived.

It could be that the planet originally orbited much farther away. Theoretical models that include stellar evolution, tidal effects, and the dynamical effects from stellar companions indicate that it is possible for planets to appreciably change their orbital configurations. In such circumstances, the planet would have eventually migrated inward to its current, tight orbit *after* the host evolved into a white dwarf. It is remarkable that an exoplanet orbiting a dense stellar corpse provides observational evidence of a rich migration history.

Planetary migration can also end in annihilation. We've seen pieces of disrupted planetary companions orbiting white dwarfs, as well as lots of debris littering stars' surfaces. We often observe these dismembered bodies by their spectral signatures. In fact, at least 25% of *all* white dwarfs should bear signs of accreted debris in their spectra, and to date we've measured about two dozen distinct atomic species. The most recent additions to this growing list of pollutants are the elements lithium, potassium, and beryllium. And since the gravitational sinking in white dwarfs occurs relatively quickly (on time scales ranging from a few days to 10,000 years, for the most common type of white dwarfs), such signs of contamination provide evidence of recent or even ongoing planetary disruptions. These offer another important opportunity to directly measure the bulk composition of the planetary companion, placing constraints on theories of planet formation and evolution.

## Searching the Haystack

At the moment, we only know of a couple hundred exoplanets around aging stars. Future and newly commissioned surveys have the potential to significantly enhance our exoplanet census, enabling us to examine the entire life cycle of planetary systems in more detail. The Nancy Grace Roman Telescope will play a major role in this work. Roman is a space-based observatory set to launch in 2026. Among its many scientific contributions will be the ability to directly image giant planets at a wide range of distances from their host stars — a technique astronomers could leverage to find exoplanets in orbit around white dwarf hosts. Direct imaging also will make it possible to reveal true analogs of our own gas giants.

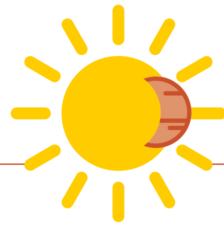
More immediately, the exoplanet community is eager to explore data from the recently launched James Webb Space Telescope. JWST is well positioned to explore late-stage planetary systems. For example, as close-orbiting planets break up, the telescope's Mid-Infrared Instrument (MIRI) could identify specific minerals in the resulting debris. JWST can also perform direct imaging, and it has the potential to search for widely separated, intact exoplanets around white dwarfs, probing planets as cool as 100 kelvin (similar to Jupiter). MIRI can also search for exoplanets around white dwarfs using novel techniques, such as by looking for "extra" infrared emission in the star's light from a planetary companion.

Perhaps most exciting of all is JWST's potential to answer a burning open question: Might there be life on the exoplanets orbiting long-dead stars? While this may sound far-fetched, an Earth-like planet orbiting an older white dwarf at 1% Earth's distance from the Sun could hypothetically sustain liquid surface water, and the habitable zones of white dwarfs should be stable for billions of years. This has led some theorists to speculate that life might arise during these late evolutionary stages — a scenario far removed from the early stages of Earth's biogenesis. Like the early Sun, white dwarfs also emit high levels of ultraviolet radiation. Scientists suspect that exposure to UV radiation is necessary for the emergence of prebiotic molecules (*S&T:* Dec. 2022, p. 34).

Regardless of where we place our bet on the likelihood of late-stage biogenesis, white dwarfs' relatively clean spectra make their exoplanetary systems extremely amenable to the detection of biosignatures, such as methane and ozone. It could be that, *if* life is present in these late-stage exoplanetary systems, they will be the first place we detect it.

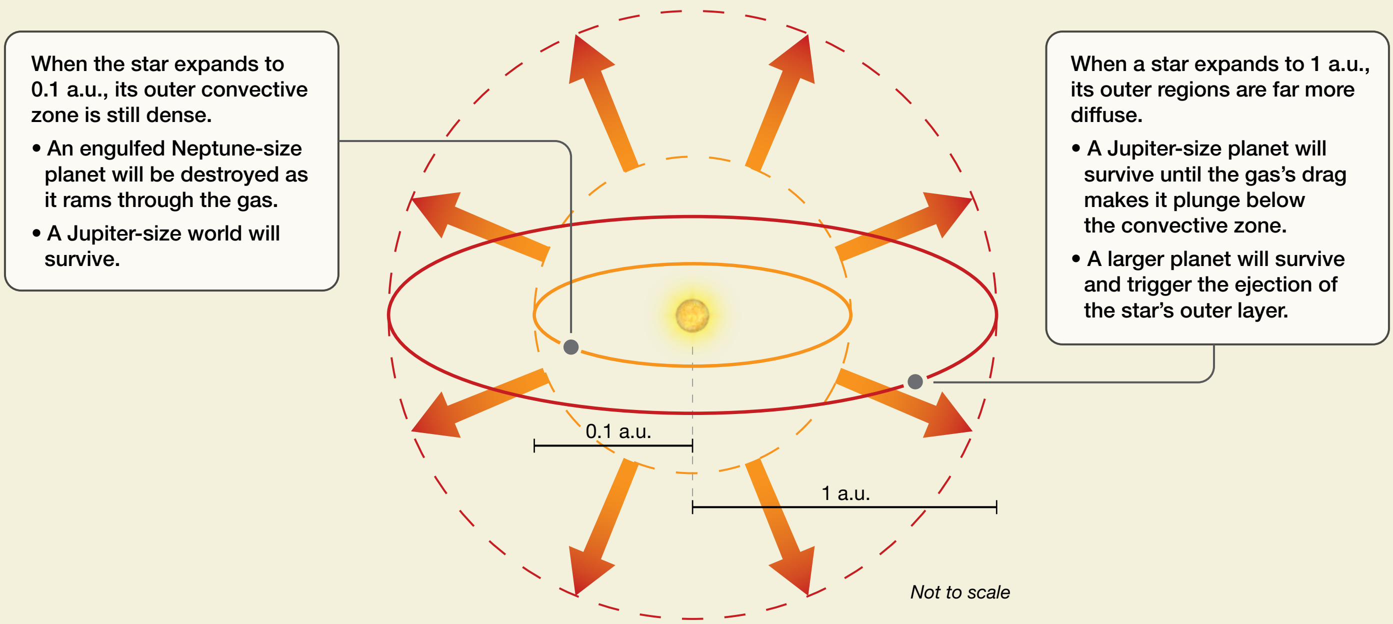
### Every 1 to 10 years

Frequency at which a star engulfs a planet somewhere in the Milky Way



■ **MELINDA SOARES-FURTADO** is a NASA Hubble Postdoctoral Fellow at the University of Wisconsin, Madison. She studies star-planet systems at early and late evolutionary stages. **SARAH KUBIAK** is a science communication master's student at Colorado State University with a bachelor's in astrophysics from the University of Wisconsin, Madison.

GREGG DINDERMAN / *S&T*




▲ **ENGULFMENT** As a star expands, it can engulf inner planets. The planet's orbit will decay with time as the world tries to shove its way through the surrounding gas.

 by Karen Masters

# The Neverending Survey

The decades-long Sloan Digital Sky Survey project has transformed how astronomers do astronomy.

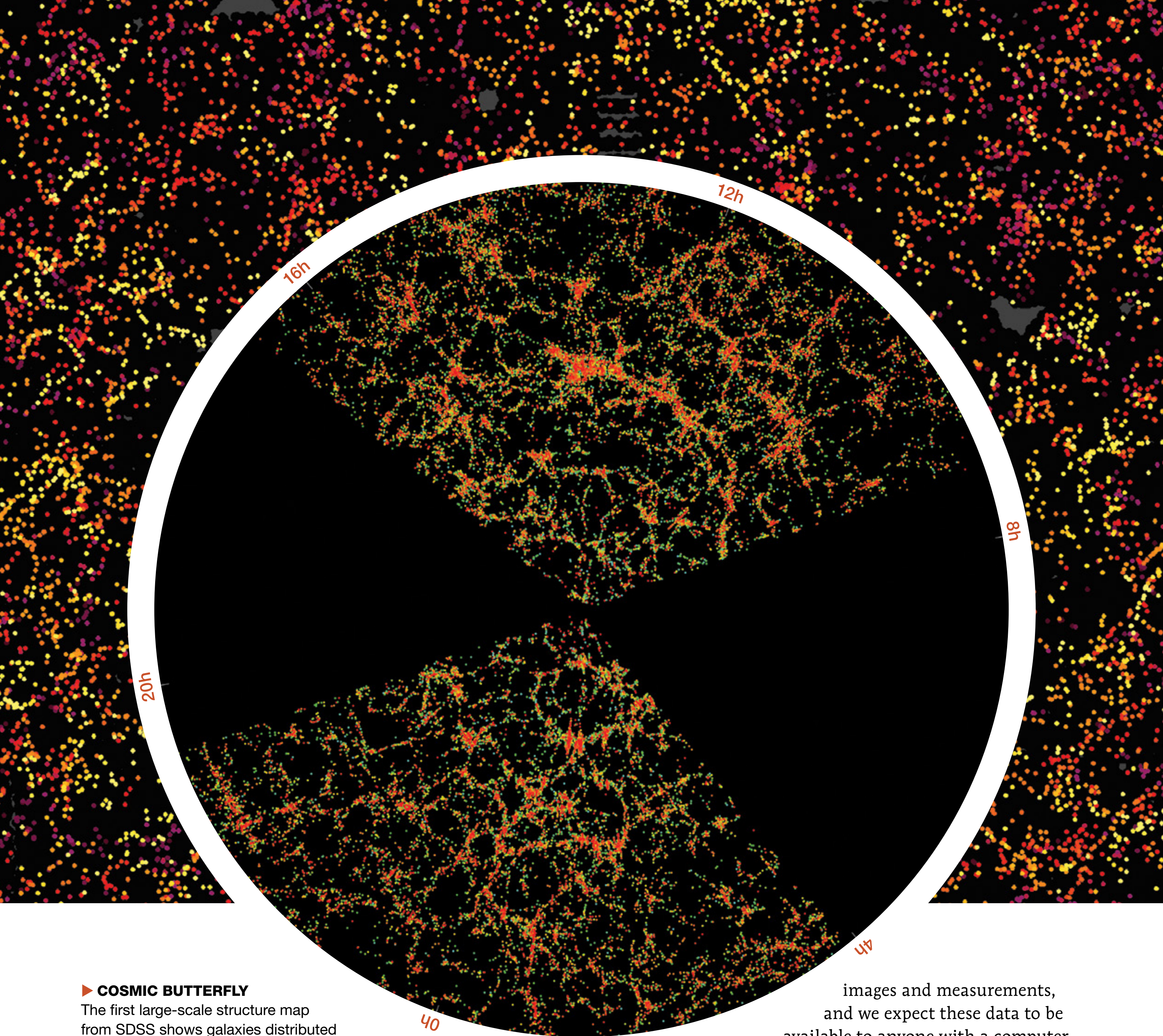
The telescope used most across professional astronomy isn't the biggest or the newest, and it isn't in space. It's a modest telescope on a mountain in New Mexico. The images and spectra from this facility, the Sloan Foundation 2.5-meter Telescope at Apache Point Observatory, are so ubiquitous that many astronomers don't even think about where the data come from. But this unassuming telescope and the (so far) five phases of its Sloan Digital Sky Survey (SDSS) have revolutionized how astronomers work.

The original idea behind the SDSS was to make an enormous map of the universe. To do this, the collaboration developed a huge digital camera, which held the record for the largest camera in the world for well over a decade. Before megapixel smartphones became our pocket cameras, this 126-megapixel imager was scanning the night skies from its first light in 1998 until 2009, stitching together a detailed view of a third of the sky visible from New Mexico. Meanwhile, researchers developed computer codes to process these images, calibrate the images' colors, scan them to identify galaxies and stars, and pick some to measure spectra. In all, the first SDSS efforts cataloged more than 1 billion objects.

▲ **SLICE THROUGH THE UNIVERSE** Every colored pixel in this picture is a galaxy, mapped by the Baryon Oscillation Spectroscopic Survey (BOSS) out to a distance of 6 billion light-years. The color indicates each galaxy's distance, from near (yellow) to far (purple).

After the imaging camera's retirement in 2009, SDSS projects refocused on collecting celestial objects' spectra in a series of acronym-titled surveys. Each SDSS observation from these surveys measured hundreds of spectra at once. Decoding these detailed rainbows of light enables us to track how fast galaxies are moving away from us due to the universe's expansion, to measure the types of stars in those galaxies, to find the locations and sizes of supermassive black holes, and to learn more about our own galaxy's stars and their planets.

ALL IMAGES COURTESY OF SDSS UNLESS OTHERWISE NOTED




▶ **COSMIC BUTTERFLY**
The first large-scale structure map from SDSS shows galaxies distributed along bubbles and filaments out to 1.8 billion light-years from Earth (at center). Each point on the map is a galaxy. Parts of the map are missing because those areas are blocked from view by our own Milky Way Galaxy. This map is dwarfed by later phases of SDSS.

SDSS / MIKE BLANTON

With an alphabet soup of different projects across more than two decades, and now with a second facility in the Southern Hemisphere, the SDSS is arguably one of the most successful and influential astronomy projects in the world.

## Astronomy as Data Science

Today, it seems normal that professional astronomers would work together across international borders to create large surveys of the night sky. We're used to collecting and storing images and measurements, and we expect these data to be available to anyone with a computer. But until SDSS became the massive success it is, many astronomers didn't believe this model would work. Astronomers were used to keeping their data private — fair enough, given that building professional telescopes and obtaining observing time on them are costly and difficult endeavors. In fact, when team members in the early 1990s first talked about plans to measure the spectra of hundreds of thousands of objects, other astronomers thought they were joking. It took visionaries to realize that by working together instead of apart, by collaborating to both collect and process the data from telescopes, and (crucially) by releasing these data for the entire community to use, astronomers could map much more of the universe than would ever have been possible if they were working as individuals.

▶ **LEGACY CAMERA** This camera collected all the imaging data of SDSS's first decade. The camera read the CCDs while the sky drifted by the field of view of the telescope in great circles, so images of objects moved along the CCD columns at the same rate that the CCDs were being read.

**After being retired, the original SDSS imaging camera was moved to the basement of the Smithsonian in Washington, D.C., where it is stored for its significance to scientific history.**

It takes great effort to make "open and accessible data" a reality. Scientists working within the project commit to releasing data regularly, typically about a year after it comes off the telescope. This time gives the team time to do necessary processing, to check and double-check for mistakes, to write supporting documentation — and to benefit from early access before releasing the data to the rest of the world.

## Mapping the Universe

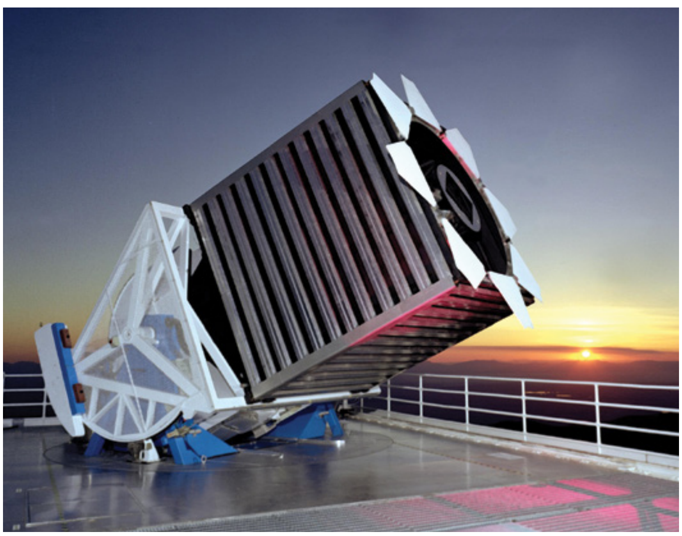
SDSS is probably best recognized by its maps of the distant universe. If you've been to a planetarium, you may well have "flown through" one of these. The videos look like how movies imagine jumping to hyperspace, flying past endless galaxies. Eventually, they zoom out to show all that SDSS has surveyed: a butterfly-shape slice of the cosmos.

Across SDSS's first four phases, measuring *cosmological redshifts* was a main goal. Astronomers first calculate how quickly distant galaxies appear to be moving away from us due to the universe's expansion; this *recessional velocity* is proportional to a galaxy's distance from us (*S&T:* Oct. 2022, p. 12). We can then use these distances to map galaxies in 3D.

These first maps of large-scale structure showed galaxies outlining bubbles and filaments in the local universe. Other, smaller surveys had seen evidence for this cosmic web, but SDSS made such a leap in scale that there was no longer any doubt of the web's existence. Later phases of SDSS have dwarfed that first look, measuring galaxy distances out to a redshift of 1.1 (a lookback time of 8.2 billion years). For galaxies with intense beacons powered by supermassive black holes, called quasars, the measurements extend even further, to a redshift of 3.5 (11.9 billion years).

From these maps we learned that as the universe evolves, it becomes clumpier: Gravity pulls matter into a vast network over time. The detailed patterns in the network tell astronomers about the content and expansion history of the universe. We've even identified reliable (albeit very large!) rulers in those patterns. The imprint of ancient soundwaves shows up as a slightly preferred distance between any two pairs of galaxies. SDSS scientists measured this *baryon acoustic oscillation* (BAO) scale for the first time in 2005. The BOSS survey, later extended as eBOSS, improved on this work by obtaining millions of galaxies' and quasars' redshifts.

The BAO scale has enabled astronomers to make some of the most precise measurements of the universe's expansion rate over a wide range of cosmic times. The result favors the lower of two hotly contested values for the universe's *current* expansion rate (*S&T:* Mar. 2022, p. 14). SDSS BAO data haven't yet solved the puzzle of the mysterious dark energy that's accelerating this expansion, but they are an important step toward an answer.



▲ **THE TELESCOPE** Sunset falls at the SDSS 2.5-meter telescope at Apache Point Observatory in New Mexico.

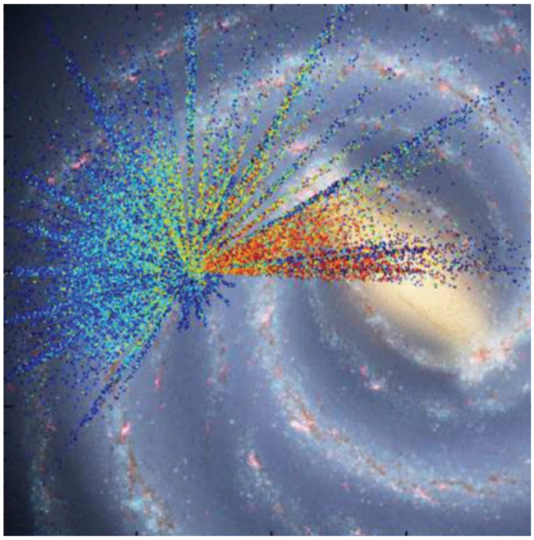
## So Many Galaxies, So Little Time

Along the way to creating cosmic maps, SDSS's observations gave astronomers physical information about almost 1 million galaxies. Besides measuring their distances, we can also "weigh" galaxies by probing the motions of their constituent stars, and we can gauge how many baby stars they are forming. Chemical elements leave fingerprints in the detailed spectra that tell us about both the types and ages of stars and about the history of how past stars have enriched the gas with heavy elements. All of this together helps us reconstruct each galaxy's life story.

While we can only ever see an instantaneous snapshot in the life of an individual galaxy, from data on hundreds of thousands, or even millions, of galaxies, we can piece together how they change over time. That wasn't possible before SDSS: "Big samples" of galaxies had previously numbered up to a couple thousand.

The advance to much larger samples meant astronomers had to become data scientists: Instead of examining a handful of galaxies, they started looking for big-picture correlations. For example, SDSS data showed that larger galaxies tend to be redder. Their ruddy hue reveals that they are past their peak of star formation, because all the young, massive bluish stars have died. These larger and redder galaxies are more likely to be elliptical in shape (rather than spiral), and they're richer in heavy elements from past starbirth and -death. Such galaxies also tend to crowd more closely with their neighbors.

Such studies showcase the connections between galaxies, and that many galaxies' properties depend on their location within the cosmic web. Astronomers had seen a lot of these trends earlier on, but SDSS data confirmed the relations with a clarity and precision that revolutionized extragalactic astronomy.



◀ **STAR BY STAR** The APOGEE survey targets individual stars, taking spectra to determine how chemically enriched each one is. Stars marked blue have fewer heavier elements and are likely older; stars marked red have more heavier elements and are likely younger. Data are overlaid on an artist's illustration of the Milky Way.

This immense success from the first phase guaranteed that galaxy science would continue to be a big theme in SDSS. The original Main Galaxy Survey measured just a single spectrum per galaxy, but in SDSS IV the Mapping Nearby Galaxies at Apache Point Observatory (MANGA) survey used a technique called *integral field spectroscopy* to measure tens to hundreds of spectra per galaxy, for a total of 10,000 galaxies. These spectra enabled MANGA to map star formation across different parts of a galaxy, revealing beautiful complexity. Internal structures like bars and spirals mix things up and change how stars and gas move. We see that galaxies stop forming stars from the inside out, and we are beginning to put together how internal processes combine with a galaxy's environment to impact its evolution.

## Stars in Our Galaxy

Another unexpected side benefit of SDSS's early days was spectral observations of a large number of individual stars. These images and spectra resulted in a number of serendipitous findings. For example, astronomers discovered numerous stellar streams littering the Milky Way's halo. We now know these are the drawn-out remains of smaller galaxies that our own gobbled up.

This initial serendipity led to planned surveys targeting our galaxy's stars, first using the telescope's optical spectroscope but then moving to near-infrared with the Apache Point Observatory Galactic Evolution Experiment (APOGEE). Observing infrared wavelengths has several benefits for stellar astrophysicists. For one, it allows them to observe during bright moonlit nights, opening up the amount of time available on the telescope. But it also helps them peer deeper through the interstellar dust that obscures the Milky Way's central parts.

APOGEE has given us a more complete picture of the galactic ecosystem, revealing patterns in the ages, motions, and chemical compositions of its stars, including the amount of carbon, iron, and other elements important to life as we know it. When combined with stellar distances, such as those provided by the European Space Agency's Gaia mission, APOGEE spectra help us pick apart the substructures of the Milky Way, revealing details about how our galaxy came together over cosmic time.

However, this analysis is complicated by the fact that our galaxy stretches into a giant circle all around the sky from our perspective, and not all of it is visible from New Mexico. Inspired by a wish to observe stars at the galactic center, the APOGEE team led the charge to bring SDSS to the Southern Hemisphere. The group built a twin spectrograph to send to

### Why *Sloan* Digital Sky Survey?

SDSS as an overarching project has always been eponymously linked to the Alfred P. Sloan Foundation. This organization, which leverages the wealth generated by industrialist Alfred P. Sloan, Jr., during the early part of the 20th century, seeks to support innovative scientific research and the diversification of the scientific workforce. Across five phases of SDSS, the Sloan Foundation has provided essential seed funding, contributing more than $70 million across three decades. However, each phase of SDSS has also been strongly supported by institutional buy-in: Academic institutions pay a "joining fee" for early access to data and the right to direct the surveys' scientific priorities. In the fourth phase, a cosmological analogy was sometimes used to talk about the funding sources: The Sloan Foundation was the dark matter (around a quarter of the total funds), institutions provided the dark energy (most of the rest), while grants from government agencies like the Department of Energy provided the baryons (less than 5%). All parts were essential to make the survey work.

Las Campanas Observatory in Chile, which hosts a telescope that to astronomers is almost identical to the Sloan Foundation Telescope. Now, we enjoy a full-sky view of stars in the Milky Way. SDSS V continues this work with the Milky Way Mapper, which is measuring spectra using either the infrared spectrograph from APOGEE or the optical one from BOSS — or both — for more than 4 million stars.

## The Changing Universe

Over the years, SDSS has sometimes surveyed the same regions of sky again and again. In these data, astronomers can look for sources that change with time, either because they move or because their brightness changes. Repeated measurements thus turned out to be crucial to studying the changing universe.

Even individual SDSS images are carried out over a period of time: During imaging, the telescope is fixed, purposefully letting the sky drift by while its set of five filters consecutively transmit a specific part of the spectrum, from the ultraviolet to the infrared. These monochrome images are stitched together to make color images, but they're actually taken at slightly different times. Anything that's moving across the frame ends up looking like a little traffic light in the composite image, with blue, green, and red light slightly spread out. Astronomers have used this signature to discover more than 100,000 asteroids as they move across the sky.

SDSS began making more deliberate movies of the sky by repeatedly imaging narrow stripes of sky in an effort to discover and measure the light from Type Ia supernovae, which astronomers can use to measure large distances. SDSS has also run programs that take multiple spectra of objects, such as a *reverberation mapping* survey of distant quasars. Astronomers gauge how quickly these spectra vary — and, thus, how long it takes light to travel across the quasar's domain — to reveal the mass of the supermassive black hole and the size of the gaseous disk around it. This technique powers another

**Are you a teacher interested in incorporating SDSS into your astronomy curriculum? Check out sdss.org/education. In addition to providing various activity ideas, SDSS distributes its old plug plates for free (while supplies last) for use in education.**

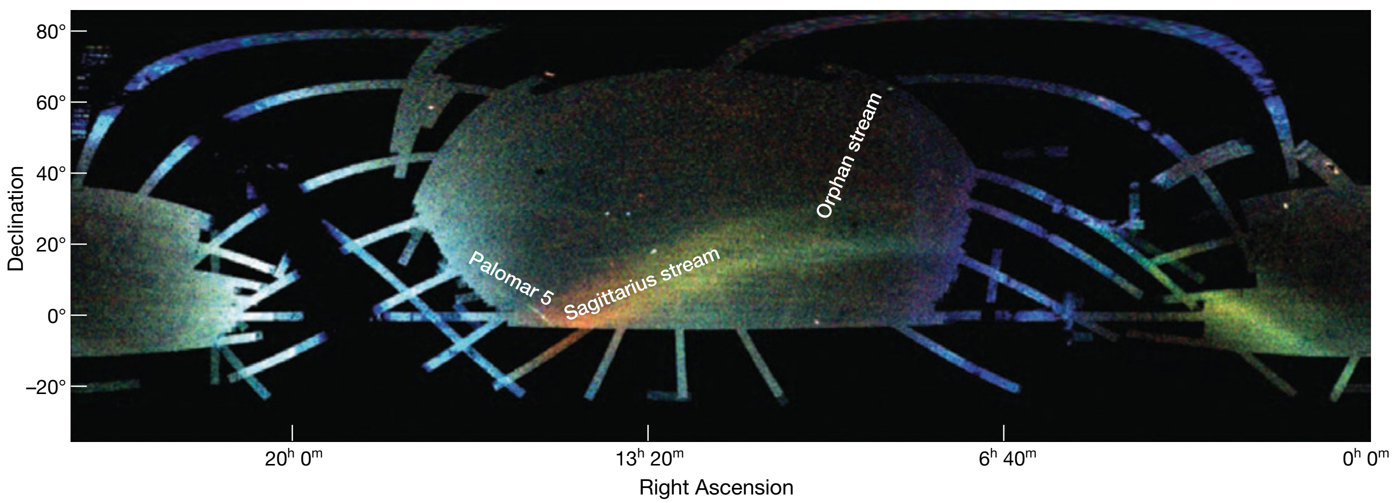
core component of SDSS V, Black Hole Mapper, which will make this kind of measurement for 300,000 quasars (a big leap over the not-quite-1,000 done to date).

## The Robots Are Taking Over

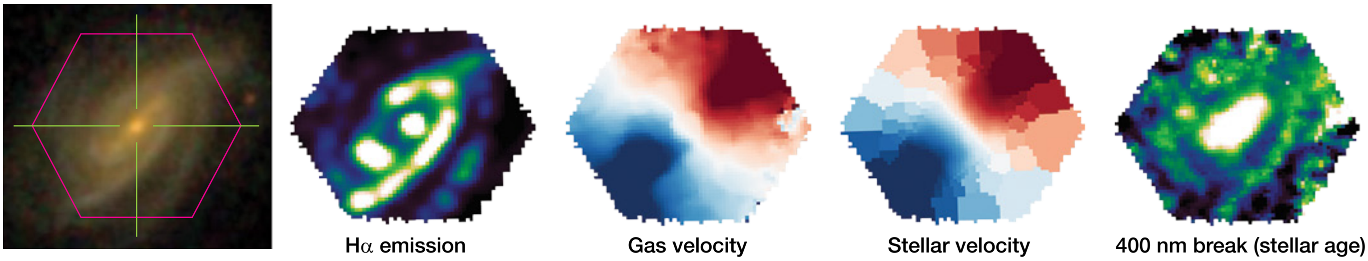
I've been working within the SDSS collaboration for more than a decade now, and one of my pet peeves has been incorrect descriptions of SDSS as a "robotic" or "automated" telescope. I presume this idea comes from thinking that SDSS data are so vast and perfect that only an automaton could have produced them. It's flattering in that way. But I also feel it diminishes the vast scale of the human effort that went into SDSS.

Two human observers have run every single night of spectroscopic data-taking: one "warm" in the control room and one "cold," venturing outside periodically to change over the *plug plates*. Those plates are flat metal circles about the size of a coffee table, each of which is custom-drilled with holes to hold up to about 1,000 fiber-optic cables. Celestial light travels through each cable to the spectroscopes. To prepare for a night's observing, multiple people throughout a dayshift load these plates into cartridges and then plug in the hundreds of fiber optics by hand. The all-time record was nine plates in a single night, representing 10,000 fiber optics plugged during the day — ouch. I once tried to plug just one plate by myself, and it wasn't an easy job!

The funny thing about my pet peeve is that the future of SDSS actually *is* robots, and the future is now. The last observation with a plug plate at Apache Point Observatory




▲ **FIELD OF STREAMS** In this all-sky image, which contains SDSS data through 2011, the brightness indicates the density of certain types of stars. Color indicates distance, with blue marking stars out to 50,000 light-years away, green for stars out to 60,000 light-years, and red for stars out to 88,000 light-years. The several stellar streams visible were once dwarf galaxies or globular clusters but were torn apart by the Milky Way's gravity.




▲ **PICKED APART** MANGA spectra across the face of this spiral galaxy reveal (from left to right) ongoing star formation, gas motions, star motions, and the size of a characteristic break in the spectrum at 400 nanometers, an indicator of stellar age. In this classical spiral galaxy, the stars and gas are rotating in an orderly way about a central bulge of older stars. New stars are forming in clumps along the spiral arms.

happened on June 26, 2021. SDSS V has graduated to using robotic positioners: 500 little robots now guide fiber-optic cables to their positions. But learning to control hundreds of robots to move in sync — and never collide — has been a significant challenge. The transition was made all the more impressive by happening during a global pandemic, with some engineers even building cardboard mockups at home. It was worth it, though: This technological shift enables much higher efficiency, and the number of spectra SDSS V anticipates measuring will dwarf the rest of SDSS.

## The Impact of SDSS

Summarizing SDSS's impacts on science is a neverending task. While I have been writing this article, even more papers have come out using SDSS data, and more astronomers are figuring out more ways to get more science out of our vast archive. That SDSS has impacted science in areas as diverse as understanding asteroids in our own solar system to the overall scale of the universe is simply astonishing.

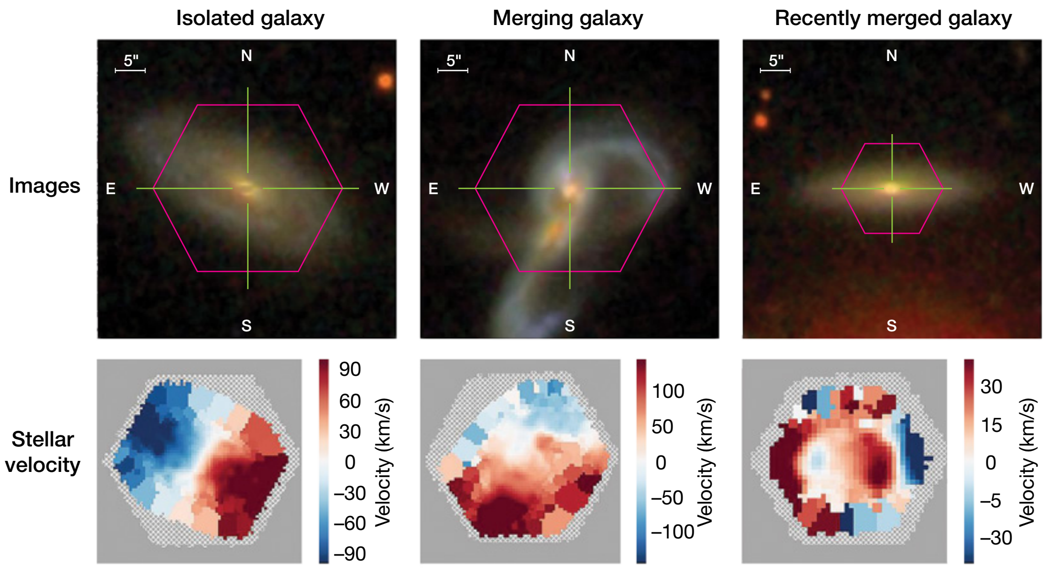
If I had to pick one important impact, though, it would be the change in how astronomers work and share data. Open data have fueled the huge volume of science results. They have also enabled highly successful spin-off projects such as Galaxy Zoo (**galaxyzoo.org**), which invites members of the public to help classify the galaxies in SDSS images by shape and type. Galaxy Zoo inspired a massive expansion of citizen science, with a "Zooniverse" of similarly designed projects (see **zooniverse.org**). Open and accessible data also make SDSS available for use in teaching, or as a check for other observations. As one astronomer I talked to about this article said, "If I want to know about the optical properties of my object of interest, I check the SDSS first."

Ironically, this is the greatest evidence of the transformation wrought by SDSS: The data it has collected are now so ubiquitous that they have become part of the background of how we do astronomy.

■ **KAREN MASTERS** is an astronomer at Haverford College near Philadelphia but originally comes from the UK. She has worked with SDSS data since she was a graduate student and serves as the spokesperson for SDSS IV, as well as Principal Investigator for Galaxy Zoo.

**SDSS MOVIES:** Fly through the universe, see SDSS-discovered asteroids of the solar system, and watch a night of observing at **https://is.gd/sdssmovies**.

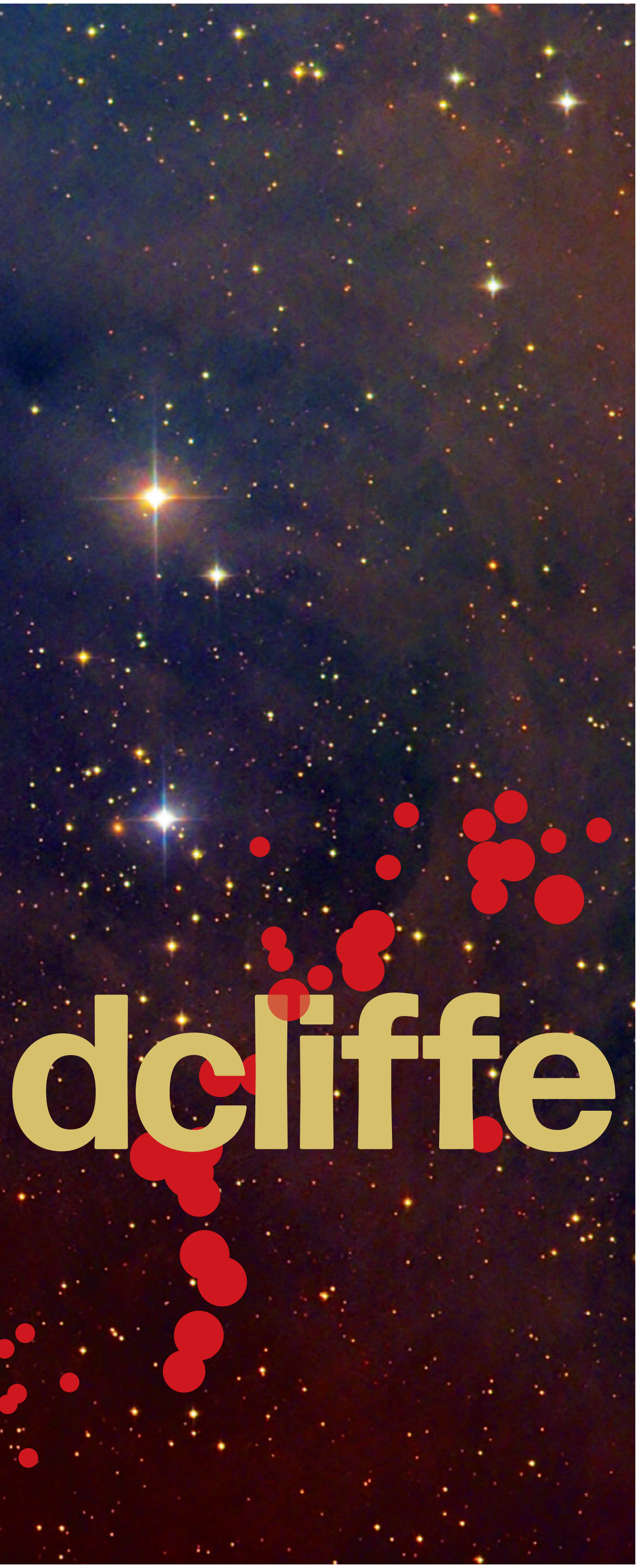
▶ **ROTATION REVEALS** MANGA spectra across the face of these spiral galaxies show the disturbance another galaxy can cause. The leftmost image shows an isolated spiral galaxy. Half of its stars are moving toward us (blue) and half away (red) due to its rotation. When two galaxies merge, as in the second panel, chaos ensues, mixing up the rotational motions. MANGA can reveal such disturbances to stars' orbits long after the merger has happened, as in the case of the third panel. The image shows an isolated galaxy, but the spectra reveal the effects of a recent merger.



**PRIZE IN PERSEUS** The stunning reflection nebula NGC 1333 is a sight not to miss. You'll find it close to the southern border of Perseus, the Hero. Infrared observations show 150 new stars have formed in NGC 1333 in the past million years.

# Riding the Ra

VOLKER WENDEL / JOSEF PÖPSEL / STEFAN BINNEWIES / CAPELLA OBSERVATORY



# dcliffe Wave

By observing this selection of targets, you can trace a newly discovered structure in the Milky Way.

The Gould Belt holds a special place in the hearts of deep-sky observers. Distinct from the Milky Way and tilted by 20° to our galaxy's plane, this starry ring spans 3,000 light-years and intersects the galactic equator in the richest regions of Scorpius and Centaurus on one side of the sky and in Orion on the other. The Belt offers stargazers a lavish bounty of blue-white stars, stellar nurseries, and rich open star clusters along its circumference. There's just one problem with the Gould Belt — it doesn't actually exist.

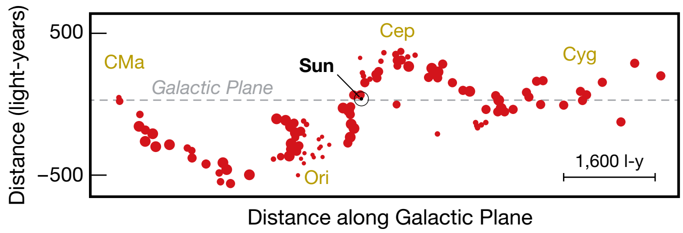
Or at least, it doesn't exist as a coherent physical structure. That's according to a landmark 2020 study in *Nature* in which a team of astronomers mapped the positions to local gas clouds that serve as star-forming regions in the Local Arm of the Milky Way and along the Gould Belt. Using an ingenious approach, the team parsed data from the European Space Agency's Gaia satellite to measure precise distances to hundreds of stars along 380 lines of sight towards dense and dark gas clouds and the more tenuous gas bridges between them. For each cloud, they used photometric measurements to distinguish foreground stars from background stars. The latter appear redder as their bluer light gets preferentially scattered passing through the cloud (the same reason a setting Sun appears red). With this approach, the team bracketed the distance to each cloud to an accuracy of about 5%, far better than any previous survey.

With advanced visualization software (**glueviz.org**), the scientists mapped each cloud across the Local Arm and expected to see the Gould Belt in "high definition." Instead, they discovered something astonishing — a thin, interconnected, wavelike structure about 8,800 light-years long and 400 light-years wide that undulates up to 500 light-years above and below the plane of the galaxy and stretches nearly halfway across the sky from Cygnus to Canis Major. Our Sun lies as close as 450 light-years from this structure near its middle and some 5,000 light-years away from either end. The team named this structure, which holds the mass of some three million Suns, the "Radcliffe Wave" after Harvard's Radcliffe Institute for Advanced Study.

And the Gould Belt? It simply doesn't fit the data. One section of the Belt intersects with the Radcliffe Wave at Orion, while another passes through gas clouds in Scorpius and Centaurus, a section designated the "split." But a ring can pass through any two points, and the rest of the Belt seems to be a projection of the Wave onto the sky as it rises from Orion through Taurus, Perseus, and Cepheus — a length of sky that's at an angle of about 20° to the plane of the Milky Way. The Gould Belt, according to this study, is finished.

The dark clouds surveyed in the 2020 study don't offer much appeal to amateur astronomers. But can we see blisters of star formation along the Radcliffe Wave to help us trace it across the sky?

That's the question I put to João Alves (University of Vienna, Austria) and Catherine Zucker (now at the Space Telescope Science Institute), lead authors of the study. With their generous help and a trusty star atlas, I assembled a tour of sights along the Wave within reach of visual observers. Most are associated with emission and reflection nebulae emerging from these dark gas clouds. Distances to stars, clusters, and stellar associations that lie along the Wave are less certain, at least until astronomers digest more data from Gaia. This list of sights isn't comprehensive, and in time more deep-sky sights will fall into place along the Radcliffe Wave. Most clouds along its length coalesced 50 million years ago, and its stars and star-forming regions are less than 30 million years old — this helps us weed out objects that are in the line of sight of the Wave but aren't physically associated with it.




▲ **UNDULATION IN THE MILKY WAY** The Radcliffe Wave stretches all the way from Cygnus (at right in the plot above) to Canis Major (at left). Along the way it rises up into Cepheus before plunging down into Orion. All in all the Wave spans nearly 9,000 light-years.

Late autumn and early winter shortly after nightfall offer the best time to trace the entire Radcliffe Wave, with Cygnus low in the northwest at one end and Orion and Canis Major rising in the southeast at the other. So, let's get busy in Cygnus before it sets, then work our way eastward.

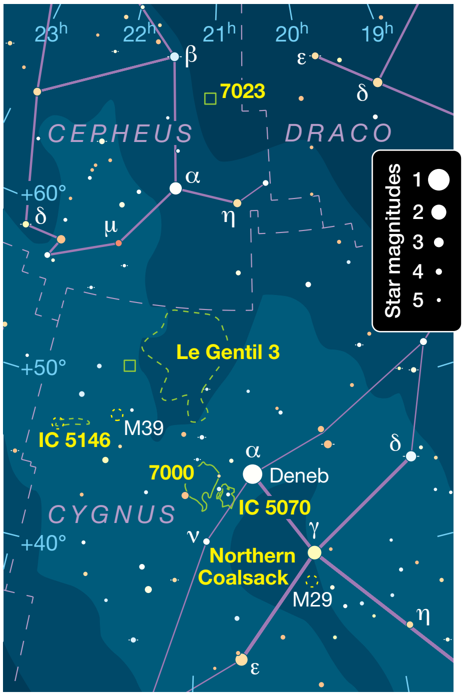
## Star Factories in Cygnus

The western terminus of the Radcliffe Wave lies in the Cygnus X star factory, a massive region of stellar associations and

**BRIGHT AND DARK CLOUDS OF CYGNUS** This wide-field view of the region around Deneb (the bright star near the center of the image) shows the dark clouds of Le Gentil 3 (or, as *S&T* Contributing Editor Alan Whitman dubbed it, the Funnel Cloud) trickling in from top left. The Northern Coalsack lies just right of the colorful North America and Pelican Nebulae.

CHART: GREGG DINDERMAN / *S&T*, SOURCE: JOÃO ALVES / *NATURE* 578: 237 (2020); CYGNUS CLOUDS: ALAN DYER molecular clouds at the heart of the Celestial Swan. At a distance of 5,000 light-years, this region harbors hundreds of luminous stellar nurseries. Unfortunately, we can't see them at visual wavelengths because they're hidden behind the dark Cygnus Rift. The first hint of the Wave comes in the form of the Snow Angel Nebula (Sh2-106), about 3,500 light-years away. It's a challenging object for imagers and all but out of reach for visual observers with amateur instruments.

We get our first visual glimpse of the Wave at the famed **North America Nebula** (NGC 7000), just 3° east of Deneb. In a wide-field scope or binoculars it presents a pale sheet of light spanning 120′ × 100′, with dozens of embedded 9th- and 10th-magnitude stars. A 3° or larger field of view frames it nicely. The North America Nebula and the fainter **Pelican Nebula** (IC 5070) next door constitute small sections of an H II region set aglow by a hot young star, which is obscured from sight by intervening dust. Both nebulae lie some 2,600 light-years away. (See page 58 in the September issue for further observing tips.)




In pristine observing conditions, some of the Wave's dark clouds emerge to the unaided eye against the background Milky Way. The **Northern Coalsack**, nestled between Alpha (α) Cygni (Deneb), Gamma (γ) Cygni (Sadr), Nu (ν) Cygni, and Epsilon (ε) Cygni, spans 7° × 5° and lies at the near edge of Cygnus X. Another dark nebula, the sprawling **Le Gentil 3**, is situated about 7.5° north-northeast of Deneb and stands out prominently against a brighter and more uniform stellar background.

The **Cocoon Nebula** (IC 5146) features a photographically reddish emission nebula overlapping with a fainter blue-white reflection nebula, with the clearly etched dark cloud Barnard 168 extending about 2° to the west. The luminous portion of the Cocoon spans around 10′ and has an integrated magnitude of 7.2. An 85-mm refractor and an Ultra High Contrast (UHC) filter at 24× tease out its circular glow under suburban skies, and I can make out two 10th-magnitude stars within. With 12×36 binoculars I can just spot the Barnard dark cloud. This three-in-one gem also harbors Collinder 470, a loose and relatively sparse open star cluster.

If you're looking at a star chart of the region, you'll see that more star clusters abound in northern Cygnus and neighboring Lacerta, but all of them either lie in front of or behind the Radcliffe Wave, or they're simply too old and predate it. Over in Cepheus the sprawling nebula IC 1396 lies slightly behind the Wave. However, 3.5° southwest of Beta (β) Cephei, we find the **Iris Nebula** (NGC 7023), a small reflection nebula embedded in a larger dark cloud about 1,300 light-years away. At magnitude 7.2 and 10′ across, the Iris Nebula looks lovely in a small telescope. I can spot it with my 85-mm refractor at 24×. It takes magnification well: At 67× the nebula displays a complex structure reminiscent of an irregular spiral galaxy. A central 7th-magnitude blue-white star illuminates this small patch of interstellar dust. An inky-black nebulosity, about 0.5° across, surrounds the Iris.

## Expansive Dark Nebulae

Invisible bridges of tenuous gas lie eastward on the Radcliffe Wave and thread through Cassiopeia and Camelopardalis. Coming to Perseus, though, we find denser clouds and a pair of visible tracers. Look about 3.3° west-southwest of Omicron (ο) Persei (Atik) to spot **NGC 1333**, a reflection nebula in a much larger dark cloud. German astronomer Eduard Schönfeld discovered it in 1855 with a 3-inch refractor, so it's an easy object in dark sky. This tiny, 5.7-magnitude oval looks like a fuzzy star at low magnification in my 10-inch Dobsonian, but its nebulous form emerges at 92× along with its central 10th-magnitude star.

Just ¼° southeast of Atik sits **IC 348**, another tiny cluster of blue-white stars some 1,000 light-years away just flickering to life. Its designation refers to the cluster itself and to

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▲ **TRIPLE DELIGHT** The Cocoon Nebula presents three types of nebulae in one spot in space: emission, reflection, and dark. You'll find it in a fairly empty bit of sky in the far eastern reaches of Cygnus by slewing some 12½° slightly north of due east of Deneb.

the dim reflection nebulosity surrounding it. The cluster contains hundreds of stars in an area 10′ in diameter, but only a dozen lie within reach of my 10-inch reflector. The most conspicuous is Struve 439, a wide double star with components of magnitudes 8.8 and 10.3 separated by 23″. The brightest nebulosity surrounds this double. While a challenging visual object, the tiny cluster presents a taste of things to come: In the next several million years, many more clusters will emerge from the dense clouds in this Perseus section of the Radcliffe Wave.

Now on to Taurus to see the major feature of the Radcliffe Wave closest to the Sun: the striking **Taurus Molecular Cloud**. At a distance of just 450 light-years, this inky-dark archipelago presents a worthy challenge for visual observers with ideal conditions. The complex spans about 20°, and its darkest region lies some 10° northeast of the midpoint of a line connecting the Pleiades and Hyades star clusters. In Bortle 2 skies and with the help of a pair of 2.1×42, wide-angle constellation binoculars, I can barely glimpse its darkest fingers adjacent to the Milky Way lacing through Taurus and Auriga. When observing such challenging dark nebulae, success comes when you see the absence of stars against an otherwise rich, stellar background.

Taurus offers only a glimmer of visible light along the Wave. **Hind's Variable Nebula** (NGC 1555, also known as Sh2-238), lies near the Hyades about 4.5° northwest of Aldebaran. With a magnitude ranging from 8.5 to 13.5, this inconspicuous reflection nebula spans just 1′ × 1′ and is illuminated by 10th-magnitude T Tauri just to the east. The nebula presents a serious challenge and requires at least a 12-inch telescope to spot it (see *S&T:* Feb. 2018, p. 22). But astronomers consider T Tauri especially interesting as a proto-typical star still sputtering in brightness and yet to settle onto the main sequence.

## The Brightest Section of the Radcliffe Wave

We arrive at the richest part of the Radcliffe Wave, which is found in the Orion Molecular Cloud. Here the Wave plunges some 500 light-years below the plane of the Milky Way to rise back toward the galactic plane in Canis Major. The Orion Molecular Cloud holds some of the brightest and best-known groups of newborn stars and star-forming regions.

Even naked-eye observers can see the fruits of the Radcliffe Wave in the bright, blue-white stars of the **Orion OB 1 association**. This encompasses the region just north and west of Orion's Belt (OB 1a), the Belt itself (OB 1b), and the Sword of Orion (OB 1c), which includes the **Orion Nebula** (M42 and

▼ **BRIMMING WITH TARGETS** *Below right:* Orion, the Hunter, presents a wealth of observing opportunities. Enjoy the fruits of this constellation during the long winter nights.

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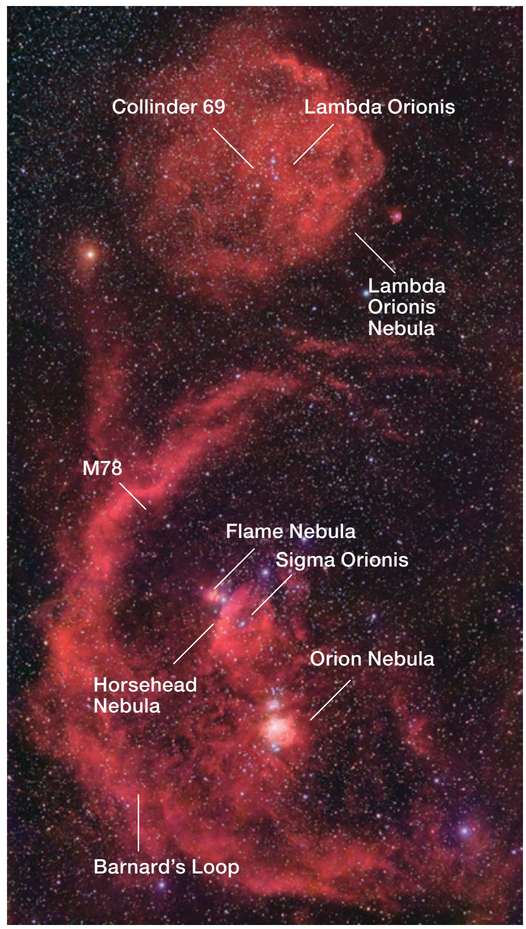


▲ **INTRICATE SIGHT** Western Cepheus holds the marvelous Iris Nebula, a reflection nebula illuminated by the 7.4-magnitude star HD 200775, the whole surrounded by a dark cloud. The best of it is you only need a small telescope to snag it.

▲ **MAGNIFICENCE IN ORION** As you sweep from top left to bottom right in this image you'll encounter the hint of a swirl of Barnard's Loop, the Horsehead and the Flame Nebulae, and the clouds that form the spectacular Orion Nebula.

▲ **DON'T BE FOOLED** The photogenic California Nebula (NGC 1499) just 5° northeast of Atik is a lovely object, but precise measurements show it's unconnected to the rest of the Wave. The pretty but tiny cluster IC 348 (at bottom right) *is* part of the Radcliffe Wave, though.

IRIS NEBULA: NASA / ESA / DIGITIZED SKY SURVEY 2; IC 348: STEFAN BINNEWIES / RAINER SPARENBERG / CAPELLA OBSERVATORY; ORION: FRANK SACKENHEIM

▲ **WITCH HEAD** IC 2118 is a delightful — but challenging — target that you'll find in Eridanus just across the border from Orion's blue supergiant Rigel. The nebula's dust grains reflecting the star's light make it appear grayish blue (scattering also contributes to this effect).

▲ **SEAGULL IN SPACE** IC 2177 is one of those objects that truly seems to represent its nickname. If you look closely, you'll note that multiple open clusters, smaller bright nebulae, and dark patches all contribute to shaping the Seagull.

M43) and a spray of young star clusters. All lie around 1,350 light-years away. Point an 80-mm or larger telescope just northeast of Zeta (ζ) Orionis (Alnitak) to catch a view of the **Flame Nebula** (NGC 2024), a 30′-wide glow bifurcated by a dark dust lane. About 1° southwest of the center of the Flame lies the fine multiple star **Sigma (σ) Orionis**, a gravitationally bound system of five stars, four of which split nicely in my 85-mm refractor at 133×. About 2.5° northeast of Alnitak, you'll find the reflection nebulae **M78** and **NGC 2071**, challenging targets in a small scope even in good conditions.

Orion offers fainter sights for sharp-eyed observers. About 4° northeast of Alnitak, look for NGC 2112, a foreground cluster that points the way to the immense **Barnard's Loop**. Visual observers can spot the brightest portions of this emission nebula with binoculars under ideal conditions. Its 14°-long arc is an easy target for wide-field imagers. About 1° south of Zeta Orionis you'll come to the **Horsehead Nebula**, which consists of the emission nebula IC 434 and the dark cloud Barnard 33 (the Horsehead itself). Only larger instruments equipped with a hydrogen-beta filter and ideal skies will reveal this notoriously difficult object. At Orion's head, binoculars show the star cluster **Collinder 69** and the fine double star **Lambda (λ) Orionis**. With components of magnitudes 3.5 and 5.4 separated by 4.3″, Lambda Orionis splits easily in my 85-mm refractor at 133×. The **Lambda Orionis Nebula**, about 5° across, envelops the cluster and appears in wide-field images of the area, but it's too faint to spot visually.

For wide-field optics, the Radcliffe Wave includes the faint, smoky **Witch Head Nebula** (IC 2118), a reflection nebula that you'll find about 3° west of Rigel in neighboring Eridanus. It extends northeast-southwest and spans 3° × 1°. This nebula makes Barnard's Loop seem easy. I've barely glimpsed it — after considerable effort — on a crystal-clear (but freezing cold) winter night with my 85-mm refractor and a 35-mm Panoptic eyepiece with a 4° field of view. I saw no structure, just an ethereal smudge at its brightest section about 1.2° south-southwest of Beta Eridani.

Monoceros and Canis Major present an oblique glance towards the eastern end of the Radcliffe Wave. About 2,900 light-years away, the giant Monoceros R2 molecular cloud emerges into view at **NGC 2170**, a small reflection nebula some 1.5° west of Gamma (γ) Monocerotis. Just 2′ across, this featureless glow is within reach of a 6-inch reflector.

And so we come to our last stop on the Radcliffe Wave, the **Seagull Nebula** (IC 2177). It's a large and faint emission nebula that lies 4,050 light-years away embedded in the Canis Major OB 1 cloud and is a favorite of imagers. Visual observers can spot it with a telescope that captures its 20′ × 20′ size. I've only been able to glimpse it in my 10-inch Dobsonian at 35× with a UHC filter in black skies.

As you've seen on this tour, there's still plenty to see along the Radcliffe Wave's 8,800-light-year length. Perhaps most remarkable is the physical connection among the many deep-sky sights along the Wave. The North America Nebula, the Taurus Molecular Cloud, and the bright nebulae of Orion and

IC 2118: RAINER SPARENBERG / STEFAN BINNEWIES / CAPELLA OBSERVATORY;
IC 2177: STEFAN BINNEWIES / RAINER SPARENBERG / CAPELLA OBSERVATORY

## Ride the Radcliffe Wave

| Object | Name | Type | Mag(v) | Size/Sep | Dist. (l-y) | RA | Dec. |
|---|---|---|---|---|---|---|---|
| NGC 7000 | North America Nebula | Emission nebula | — | 120′ × 100′ | 2,600 | $20^h$ $59.3^m$ | +44° 31′ |
| IC 5070 | Pelican Nebula | Emission nebula | — | 60′ × 50′ | 2,600 | $20^h$ $51.0^m$ | +44° 24′ |
| | Northern Coalsack | Dark nebula | — | 7° × 5° | 1,800 | $20^h$ $20.2^m$ | +36° 24′ |
| | Le Gentil 3 | Dark nebula | — | 7° × 5° | 1,800 | $21^h$ $05.0^m$ | +52° 30′ |
| IC 5146 | Cocoon Nebula | Emission/Reflection/ Dark | 7.2 | 10′ × 10′ | 2,470 | $21^h$ $53.4^m$ | +47° 16′ |
| NGC 7023 | Iris Nebula | Reflection nebula | 7.2 | 10′ × 8′ | 1,300 | $21^h$ $01.6^m$ | +68° 10′ |
| NGC 1333 | | Reflection nebula | 5.7 | 6′ × 3′ | 950 | $03^h$ $29.3^m$ | +31° 25′ |
| IC 348 | | Open cluster/ reflection nebula | 7.3 | 10′ | 1,000 | $03^h$ $44.6^m$ | +32° 10′ |
| | Taurus Molecular Cloud | — | — | 14° × 9.5° | 450 | $04^h$ $41.0^m$ | +25° 52′ |
| NGC 1555 | Hind's Variable Nebula | Reflection nebula | 8.5–13.5 | 1′ × 1′ | 650 | $04^h$ $21.8^m$ | +19° 32′ |
| | Orion OB 1 association | — | — | 14° | 1,040–1,600 | $05^h$ $36.0^m$ | –01° 12′ |
| M42/M43 | Orion Nebula | Emission nebula | 4.0 | 40′ × 35′ | 1,350 | $05^h$ $35.3^m$ | –05° 23′ |
| NGC 2024 | Flame Nebula | Emission nebula | — | 30′ × 30′ | 1,350 | $05^h$ $41.9^m$ | –01° 51′ |
| Sigma Orionis | | Multiple star | 4.1, 5.3 | 0.3″ | 1,070 | $05^h$ $38.7^m$ | –02° 36′ |
| M78 | | Reflection nebula | 8.3 | 8′ × 6′ | 1,350 | $05^h$ $46.7^m$ | +00° 05′ |
| NGC 2071 | | Reflection nebula | — | 7′ × 5′ | 1,300 | $05^h$ $47.2^m$ | +00° 18′ |
| | Barnard's Loop | Emission nebula | — | 14° × 1° | 1,400 | $05^h$ $35.0^m$ | –03° 00′ |
| IC 434 | | Emission nebula | — | 60′ × 10′ | 1,380 | $05^h$ $41.0^m$ | –02° 24′ |
| B33 | Horsehead Nebula | Dark nebula | — | 6′ × 4′ | 1,380 | $05^h$ $40.9^m$ | –02° 28′ |
| Collinder 69 | | Cluster | 2.8 | 70′ | 1,100 | $05^h$ $35.0^m$ | +09° 56′ |
| Lambda Orionis | | Double star | 3.5, 5.4 | 4.3″ | 1,100 | $05^h$ $35.1^m$ | +09° 56′ |
| Sh2-264 | Lambda Orionis Nebula | Emission nebula | — | 270′ × 240′ | 1,340 | $05^h$ $35.0^m$ | +10° 00′ |
| IC 2118 | Witch Head Nebula | Reflection nebula | — | 180′ × 60′ | 950 | $05^h$ $06.9^m$ | –07° 13′ |
| NGC 2170 | | Reflection nebula | — | 2′ × 2′ | 2,900 | $06^h$ $07.5^m$ | –06° 24′ |
| IC 2177 | Seagull Nebula | Emission nebula | — | 20′ × 20′ | 4,050 | $07^h$ $05.3^m$ | –10° 38′ |

Angular sizes and separations are from recent catalogs. The data for Sigma Orionis include only the A and B components. 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.

Canis Major all owe their formation to this vast conglomeration of gas and dust.

But what caused the Radcliffe Wave to form? How do its constituent parts move with respect to one another and the Milky Way? And are there similar structures in the Milky Way and other galaxies? Astronomers have plenty of work ahead to answer these questions. And as data from Gaia and other surveys continue to arrive, we look forward to more surprising discoveries about the structure and dynamics of our little corner of the galaxy.

■ Contributing Editor **BRIAN VENTRUDO** is a writer, scientist, and longtime amateur astronomer. He tries to make sense of nearby structures in the Milky Way under the relatively dry and clear skies of Calgary, Canada. Brian writes about astronomy and stargazing at his website **CosmicPursuits.com**.

# The Night Skies of Georgia O'Keeffe

This famed artist often included astronomical subjects in her remarkably distinctive works.

Born in Wisconsin in 1887, Georgia O'Keeffe's enjoyed a career that spanned nearly the whole of the 20th century. Her innovative, modernist paintings of intensely sculptural flowers, skyscrapers, and mountainous deserts simultaneously opened the world's eyes to artistic experimentation while also presenting America's vast beauty. Of special interest to readers of this magazine are her many portrayals of the heavens.

Evocative morning twilight skies are shown in a series of watercolors titled *Light Coming on the Plains* (1917). Her painting *Starlight Night, Lake George* (1922) includes both stars above the lake and their reflections in the water. Starry skies appear above the terrestrial scenes of *Black Cross with Stars and Blue* (1929) and *The D. H. Lawrence Pine Tree* (1929). Both *Little House with Flagpole* (1925) and *Ladder to the Moon* (1958) feature the first-quarter Moon. There are many more examples, but one is especially striking and spectacular.

## A Luminous Manhattan Night

Georgia O'Keeffe's *New York Street with Moon* is rich in celestial and topographical details. Lines of dramatic clouds partly obscure a full or nearly full Moon high in the sky above Manhattan, with the scene framed by tall buildings that stretch heavenward. The light from a nearby lamppost glows in the bottom half of the canvas, and a lofty church spire appears in the background. But what is the location of this scene, and when exactly did O'Keeffe paint it? I, along with colleagues from Texas State University, wondered if there were enough clues in the painting to answer these basic questions.

O'Keeffe created the painting in late 1924 or early 1925. The work first figures in biographical studies of the artist in connection with the Seven Americans exhibition that opened at Manhattan's Anderson Galleries on March 9, 1925. Famed American photographer Alfred Stieglitz organized the show but didn't include *New York Street with Moon*, wanting instead to focus on O'Keeffe's paintings of flowers.

Hunter Drohojowska-Philp's biography of the artist describes her reaction to the show, which opened only three months after her marriage to Stieglitz: "O'Keeffe was annoyed on opening night. She had spent the last few months hurriedly completing her first urban nightscape, *New York with Moon* . . . but when she arrived, the painting was not on view. Stieglitz's first official act as husband had been to censor what she considered to be a good painting. More than fifty years later, she was still irate. 'I was furious,' she recalled" (*Full Bloom: The Art and Life of Georgia O'Keeffe*, 2004, p. 243).

Half a century later, O'Keeffe recalled the excitement of her first attempt to paint a New York scene, her subsequent disappointment at the March 1925 show, and her eventual triumph the following year:

> *. . . I began talking about trying to paint New York. Of course, I was told that it was an impossible idea — even the men hadn't done too well with it. From my teens on I had been told that I had crazy notions so I was accustomed to disagreement and went on with my idea of painting New York.*
>
> *My first painting was a night scene of 47th Street, "New York with Moon." There was a street light in the upper foreground at about the Chatham Hotel . . . five of us* [five painters, along with two photographers] *had a group show on the top floor of the Anderson Galleries. My large flowers were shown for the first time. At the end of the hall just outside the door of the show was a perfect place for my first "New York." It carried well and would have been seen when you stepped out of the elevator to go toward the show. But the "New York" wasn't hung — much to my disappointment.*

▲ **YEARBOOK PORTRAIT** This photograph of Georgia O'Keeffe (1887–1986) appeared in *Le Mirage*, the 1917 yearbook of West Texas State Normal College (now West Texas A&M University), where she taught art.

▶ **BOLD NEW VIEW** *New York Street with Moon* by Georgia O'Keeffe is a 1925 oil-on-canvas painting (measuring 122 by 77 centimeters, or 48 by 30 inches) that the artist was particularly pleased with. However, uncertainty about exactly when she created the work and the location it depicts remained unresolved until now.

*The next year Stieglitz had a small corner room at the Anderson Galleries. There were three large windows. As you entered you saw my first "New York" between two windows . . . My large "New York" was sold the first afternoon. No one ever objected to my painting New York after that.*

*(Georgia O'Keeffe,* Georgia O'Keeffe*, 1976: text accompanying catalogues 17 and 18)*

## Illuminating Clues

The foreground of *New York Street with Moon* features an ornate lamppost of the type known as a Bishop's Crook, so named because the shape resembles the staff carried by high-ranking clerics. Ornamental curlicues and filigree fill in the curve at the top of the crook.

These fixtures began appearing on New York City streets around 1900 and were common by the 1920s. An internet search for "Bishop's Crook lamppost" will bring up numerous historical Manhattan photographs, locations of surviving examples, and websites devoted to these nostalgic reminders of a bygone time. An excellent and somewhat surprising place to see them is Universal Studios Florida in Orlando. Several blocks of the studio backlot recreate New York streets from the 1920s, with Bishop's Crook lights installed throughout this part of the park.

Georgia O'Keeffe herself, in the passage above, gave the location as "a night scene of 47th Street." Not unreasonably, given the artist's statement, the unanimous consensus of later authors accepted that the canvas showed 47th Street. In her O'Keeffe biography, Drohojowska-Philp described this as a work "in which highrises from Forty-seventh Street are silhouetted against a dusky sky; clouds embrace the moon." Alicia Inez Guzmán's 2017 monograph mentioned a "vantage point between 46th and 47th Street. With an upward gazing view, we see the vertical red-hued buildings cut sharply into a turquoise sky . . . the moon peeking out of the clouds" (*Georgia O'Keeffe at Home*, p. 65). The catalog for a recent exhibition at the Wallraf-Richartz Museum in Cologne, Germany, likewise asserted that "Georgia O'Keeffe created *New York Street with Moon* in 1925 . . . from a location on 47th Street" (Ashley E. Lazevnick, *Es war einmal in Amerika*, 2018, p. 488; translated from the German). The online collection of the

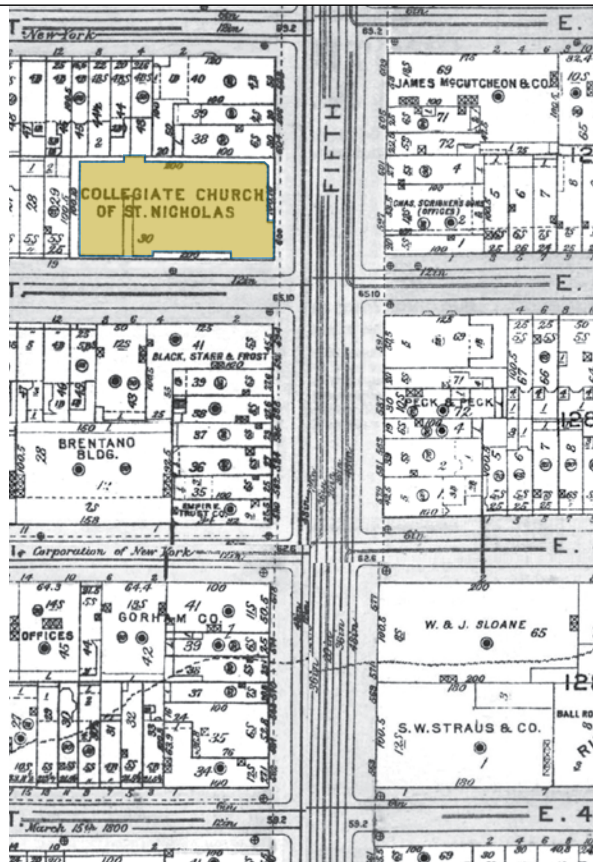

◀ **CHATHAM LAMPPOST** This photograph from a Hotel Chatham brochure shows the same Bishop's Crook lamppost depicted by Georgia O'Keeffe in the foreground of her *New York Street with Moon*. The marquee over the hotel entrance on the left wasn't present in the 1920s.

COLLECTION OF DON OLSON (4)

▶ **INSPIRING SPIRE** This postcard from 1905 shows the lofty, 275-foot (84-meter) spire of the Collegiate Church of Saint Nicholas, on the northwest corner of 48th Street and Fifth Avenue. This same spire appears in the background of *New York Street with Moon*.

▶▶ **MIDTOWN LANDMARKS** The location of *New York Street with Moon* appears on this map segment from the Bromley *Land Book of the Borough of Manhattan* for 1927. Georgia O'Keeffe stood near the intersection of 48th Street and Vanderbilt Avenue. Her view from this position (indicated with a blue arrow) near the Hotel Chatham (highlighted), looked generally west along East 48th Street, with the spire of the Collegiate Church of Saint Nicholas (also highlighted) in the distance, on the north side of the street.

▶▶▶ **SCENE SETTING** The setting of *New York Street with Moon* can be recognized in this vintage postcard. The view looks generally to the west along 48th Street. In the foreground, a Bishop's Crook lamppost stands at the street corner by the Hotel Chatham. The tall spire of the Collegiate Church of Saint Nicholas is visible in the distance, on the north side of the street.



Thyssen-Bornemisza National Museum in Madrid, Spain, names the same street: "This depiction of 47th Street at night was her first New York painting."

My colleagues and I wondered whether we could find the precise location shown. In addition to the artist's mention of 47th Street, the streetlight, and Hotel Chatham, we noticed that the painting includes another clue: a tall church spire in the distance, with ornamental projections along the sides of the spire and a cross at the top.

### Steeple on the Skyline

With help from Margaret Vaverek, a research librarian at the Alkek Library of Texas State University, we located three sources covering Manhattan churches: David W. Dunlap's 2005 book, *From Abyssinian to Zion: A Guide to Manhattan's Houses of Worship*; Richard Panchyk's 2016 compilation, *Manhattan Churches*; and a book of detailed maps published by G. W. Bromley & Co. in the 1920s. The Bromley maps show every building on every city block along all the streets and avenues. We found two candidate churches on 47th Street: Church of the Holy Family and Saint Boniface's Roman Catholic Church.

Today, the Church of the Holy Family occupies a modern building constructed in the 1960s on East 47th Street, not far from the United Nations complex. Planning for the original church at this site began at a fundraising dinner in April 1925, one month after the Seven Americans show had already opened. Because there was no formal church at that location in 1924 and early 1925, the Church of the Holy Family can't be the one portrayed in the painting.

St. Boniface's Roman Catholic Church, on the southeast corner of the intersection of East 47th Street and Second Avenue, was completed in 1869 and wasn't demolished until 1950. However, vintage drawings and photographs from the 1920s show that it had no spire, and so it, too, can't be the church that Georgia O'Keeffe painted.

It was clear that no church on 47th Street matched the one in *New York Street with Moon*. However, we noticed that O'Keeffe's own account mentioned the Hotel Chatham. This hotel was definitely not along 47th Street but stood instead on the block between 48th and 49th Streets, adjacent to Vanderbilt Avenue. A photograph from a hotel brochure shows a Bishop's Crook lamppost next to the hotel entrance. We found no churches on 49th Street like the one in the painting, but we did identify two candidates along 48th Street: the Svenska Kyrkan (Swedish Seamen's Church) and the Collegiate Church of Saint Nicholas.

The Svenska Kyrkan still stands on the north side of 48th Street, near Fifth Avenue. However, this building can definitely be ruled out because it never had a spire.

The Collegiate Church of Saint Nicholas stood on the northwest corner of 48th Street and Fifth Avenue. The church was built between 1869 and 1872, and wasn't demolished until 1949. Panchyk's compilation emphasized that "the most prominent feature of the church was its tower-


ing 265-foot-high steeple" (*Manhattan Churches*, 2016, p. 78). Architectural drawings note a slightly greater height (275 feet, or 84 meters) for the tower. The lofty spire of this church and its location on the north side of the street combine to make it a perfect match for the church in *New York Street with Moon*.

We also found a vintage postcard that captures almost the same scene that O'Keeffe painted. The postcard shows the view looking west along 48th Street, with the Bishop's Crook lamppost on the northwest corner of the intersection of 48th Street and Vanderbilt Avenue, Hotel Chatham next to the lamppost, other buildings on the north side of 48th Street, and the spire of Collegiate Church of Saint Nicholas in the distance.

In the description given in her 1976 book published more than 50 years later, O'Keeffe correctly recalled the Hotel Chatham and the lamppost, but she mistakenly identified the location as 47th Street. Later authors simply repeated the error.

Unfortunately, both Hotel Chatham and the specific lamppost depicted in the painting no longer stand. Interested readers can still head to the south side of 48th Street and 49th Street, between Park and Lexington Avenues, to find other Bishop's Crook examples (or use Google Street View).

Having established the "where" of *New York Street with Moon*, we directed our attention to the question of "when?" Returning to the astronomical content of the painting, we noted the Moon's location high in the sky above Manhattan.

### A Clouded Moon Runs High

When the Sun or Moon "runs high," it rises in the northeast, passes high overhead, and remains above the horizon for many hours before finally setting in the northwest. The Sun or Moon "runs low" when it rises in the southeast, skims at a relatively low altitude across the sky not far above the southern horizon, and remains in view for a relatively short time before setting in the southwest.

Skywatchers recognize seasonal variations in the behavior of the Sun and the full Moon, which lie opposite each other in the sky. As a result, around the summer solstice the Sun "runs high" overhead, providing many hours of abundant sunshine, while summer full Moons "run low." Near the winter solstice, however, the situation is reversed and the Sun "runs low" over the southern horizon, providing fewer hours of weak sunlight, while winter full Moons "run high." Because *New York Street with Moon* shows a full or nearly full Moon high above the foreground buildings, we can infer that the painting represents a full Moon period on a date not far from the winter solstice.

The painting also includes a meteorological clue. Both the pattern of the clouds and their opaque quality, obscuring the lower part of the lunar disk, suggest that O'Keeffe depicted lines of altocumulus clouds. Fortunately, records from the New York Meteorological Observatory in Central Park recorded both the types of clouds and the fraction of the sky covered.

## O'Keefe's Evening Star

In addition to paintings like *New York Street with Moon*, Georgia O'Keeffe created many abstract works that included the night sky. While teaching art at West Texas State Normal College, in Canyon, Texas, she produced at least eight watercolors, each known as *Evening Star*. Inspired by sunset walks west of the town, O'Keeffe apparently started work on the series by mid-March of 1917. The first example featured a normal evening twilight scene with a white dot in the sky at the upper left, while subsequent versions made the transition to abstraction.

Calvin Tomkins, writing for the *New Yorker* magazine, interviewed the artist and noted, "Although much of the new work looked wholly abstract, it was always based on something she had seen in the landscape." ("Profiles: Georgia O'Keeffe," *New Yorker*, March 4, 1974, p. 42).

What was it that O'Keeffe saw in the evening twilight sky? Important clues are present in her writing:

> We often walked away from the town in the late afternoon sunset . . . The evening star would be high in the sunset sky when it was still broad daylight. That evening star fascinated me. It was in some way very exciting to me . . . I had nothing but to walk into nowhere and the wide sunset space with the star.
>
> (O'Keeffe, 1976: text accompanying catalogue 6)

She explained her transition to abstraction:

> . . . I began painting the evening star. And my first painting was just the horizon and the sky and a little star. Well, that didn't give you any idea of the painting; it had to be more exciting than that.
>
> (Ann Prentice Wagner, "Living on Paper," PhD dissertation, University of Maryland, 2005, p. 293)

Art historian Amy Von Lintel observed that some of O'Keeffe's letters from March 1917 appear to describe the origin of the *Evening Star* series. As O'Keeffe wrote to Alfred Stieglitz:

> Tuesday night [March 13, 1917] . . . worked awhile till supper — and after that walked into the sunset till it was gone . . . about three miles I guess . . . then back in the dark.
>
> (letter postmarked on Wednesday, March 14, 1917; quoted by Amy Von Lintel, *Georgia O'Keeffe's Wartime Texas Letters*, 2020, p. 83)

In a letter from the next day, O'Keeffe dramatically emphasized her artistic breakthrough:

> Wednesday night [March 14, 1917]: I've worked — today — even painting in my spare time — it's big and it looks like Hell let loose with a fried egg in the middle of it — and I'm

▲ **MYSTERY EVENING STAR** O'Keeffe's series of twilight paintings includes *Evening Star No. V*. It was long thought to depict the planet Venus, but the real identity of O'Keeffe's "evening star" turned out to be another planet entirely.



crazy about it . . . I feel as though I've burst and done something I hadn't done before . . . It's terribly red — and such fun — And I walked into the sunset again till it was dark . . . Then back in the starlight.

(Letter postmarked on Thursday, March 15, 1917; quoted by Amy Von Lintel, 2020, p. 84)

Von Lintel suggested that in this letter the artist was probably referring to her *Evening Star* series and was describing "how she had figuratively exploded with creativity to create this series of abstract forms . . . in March 1917" (Von Lintel 2020, p. 28).

Unsurprisingly, previous authors unanimously assumed that Venus was the subject of the *Evening Star* series. For example, Michael Fallon's 2011 book referenced "the planet Venus, which usually appears in the western sky after the sun has set. O'Keeffe was fascinated and excited by this spot of light. She would walk and watch the sunset and the bright evening star" (*How to Analyze the Works of Georgia O'Keeffe*, 2011, p. 28). We found several other similar analyses, all mentioning Venus.

However, our astronomical calculations revealed a problem. When Georgia O'Keeffe arrived in Canyon, Texas, on September 3, 1916, Venus was actually the Morning Star. The planet remained in the morning sky between September 1916 and March 1917, and so could not have been the celestial object that inspired the *Evening Star* series.

However, any bright planet can serve as the Evening Star. And there was such a planet visible at dusk in the weeks and months before the middle of March 1917.

Princeton University astronomy professor Henry Norris Russell wrote a monthly column about the heavens for *Scientific American* in 1917. For February and March, Russell advised his readers that "Venus is a morning star" and that "Jupiter is an evening star . . . the chief ornament of the evening sky."

Calculations for Canyon, Texas, in February and the first half of March 1917 show that Jupiter indeed was a prominent sight, always standing higher than 35° above the western horizon during civil twilight in those weeks. The inspiration for O'Keeffe's colorful *Evening Star* paintings turns out to be Jupiter after all.

The Seven Americans show opened on March 9, 1925, so we searched for dates in late 1924 and early 1925 that would satisfy three criteria: a full or nearly full Moon; a Moon "running high"; and the presence of altocumulus clouds. Four full Moon periods occurred within that timespan.

*November 1924:* As was their custom, Georgia O'Keeffe and Alfred Stieglitz spent the summer and much of the autumn of 1924 at Lake George, in upstate New York. We can determine the precise date of their return to Manhattan thanks to a meteorological allusion in a letter that O'Keeffe sent from Lake George to the author Sherwood Anderson. Previous scholars have dated this letter to November 1924, without knowing the exact day. O'Keeffe described bitterly cold weather near 0°F, gale-force wind, and packing up for the impending return to Manhattan after two more days at the lake (Jack Cowart, Juan Hamilton, and Sarah Greenough, *Georgia O'Keeffe: Art and Letters*, 1987, pp. 178–179).

The weather archives at the National Oceanic and Atmospheric Administration make it clear that this letter must have been written on November 17th — a day of extreme cold and strong winds recorded at Albany in New York, Burlington in Vermont, and other locations in and near upstate New York. On the next day, the *New York Times* ran a front-page story that described an "Icy Gale" that came down from the north. According to our astronomical calculations, a full Moon occurred on November 11th, and the Moon "ran high" on dates near the 15th. Because O'Keeffe was still at Lake George until after November 17th, we can rule out this full Moon period as the one that inspired *New York Street with Moon*.

*December 1924:* During December 1924, O'Keeffe and Stieglitz resided in New York City. A full Moon occurred on December 11th, and the Moon "ran high" on dates near December 12th. However, for evenings during this full-Moon period, the weather observatory in Central Park reported skies that were either completely clear or contained stratus clouds in featureless horizontal layers. Because none of these nights had altocumulus clouds, the meteorological evidence allows us to rule out the full-Moon period nearest the winter solstice, which occurred on the evening of December 21st for time zones in the United States.

*January 1925:* Our research identified an excellent candidate at the next full Moon. All three important factors — the lunar phase, the Moon's position high in the sky, and the correct type of clouds — came together just as depicted in the sky of O'Keeffe's painting.


JANUARY, 1st month—Begins on Thursday 1925

**Moon's Phases**

| | | |
|---|---|---|
| ☽ | First Quarter, 1st day, 6h. 26m. evening | S. |
| ☺ | Full Moon, 9th day, 9h. 47m. evening | S. E. |
| ☾ | Last Quarter, 17th day, 6h. 33m. evening | S. |
| ● | New Moon, 24th day, 9h. 45m. morning | S. E. |
| ☽ | First Quarter, 31st day, 11h. 43m. morning | E. |

| D M | D W | Aspects, Holydays Weather, Etc. |
|---|---|---|
| 1 | 5 | ☽ on equator. ☌ ♂ ☽. |
| 2 | 6 | Low tides. *A cold spell* |
| 3 | 7 | ⊙ in perigee. ☿ g. h. l. N. |
| 4 | D | 1*st Sabbath. seems to be* |
| 5 | 2 | ♀ rises 5h. 17m. morn. |
| 6 | 3 | ☿ stationary. *in order.* |
| 7 | 4 | Legislature meets. |
| 8 | 5 | ☽ in apogee. *Signs of* |
| 9 | 6 | ☽ runs high. *snow* |
| 10 | 7 | Medium tides. *or* |
| 11 | D | 2*nd Sabbath. rain.* |
| 12 | 2 | ☽ in ☊. ☌ ♆ ☽. |
| 13 | 3 | ♂ sets 11h. 35m. eve. |
| 14 | 4 | ♃ rises 6h. 5m. morn. |

Farmers' Calendar

UNTIL comparatively recently, says House and Garden, the wood shingle was practically the only shingle used. A modern development has been to offer shingles pre-stained by dipping, and hence more impregnated with creosote than shingles to which stain is applied on the building. Considerable added life is given to shingles by dipping in creosote stain, and a great color range is possible. Shingles weather naturally with a certain amount of variation in color, and the makers of pre-stained shingles now offer them in assortments of color and tone. Straight-grain shingles take stain more evenly and retain it longer than shingles sawed in such a way as to expose the hard and impregnable portions of the wood. Creosoting is a general preservative, not only

◀ **HIGH MOON** This detail from the *Maine Farmers' Almanac* for January 1925 includes a date with a perfect match for the lunar phase and position in O'Keeffe's *New York Street with Moon*.

A full Moon occurred on January 9, 1925, and the Moon "ran high" on exactly the same date, reaching its greatest altitude around midnight. The Meteorological Observatory in Central Park recorded that the sky on that evening was 30% filled with altocumulus clouds. For several evenings both before and after that date, meteorological observations indicate either completely clear skies, cirrostratus clouds, or complete overcast — all of which are inconsistent with the conditions shown in the painting. Only January 9th provided a perfect match for the sky depicted in *New York Street with Moon*.

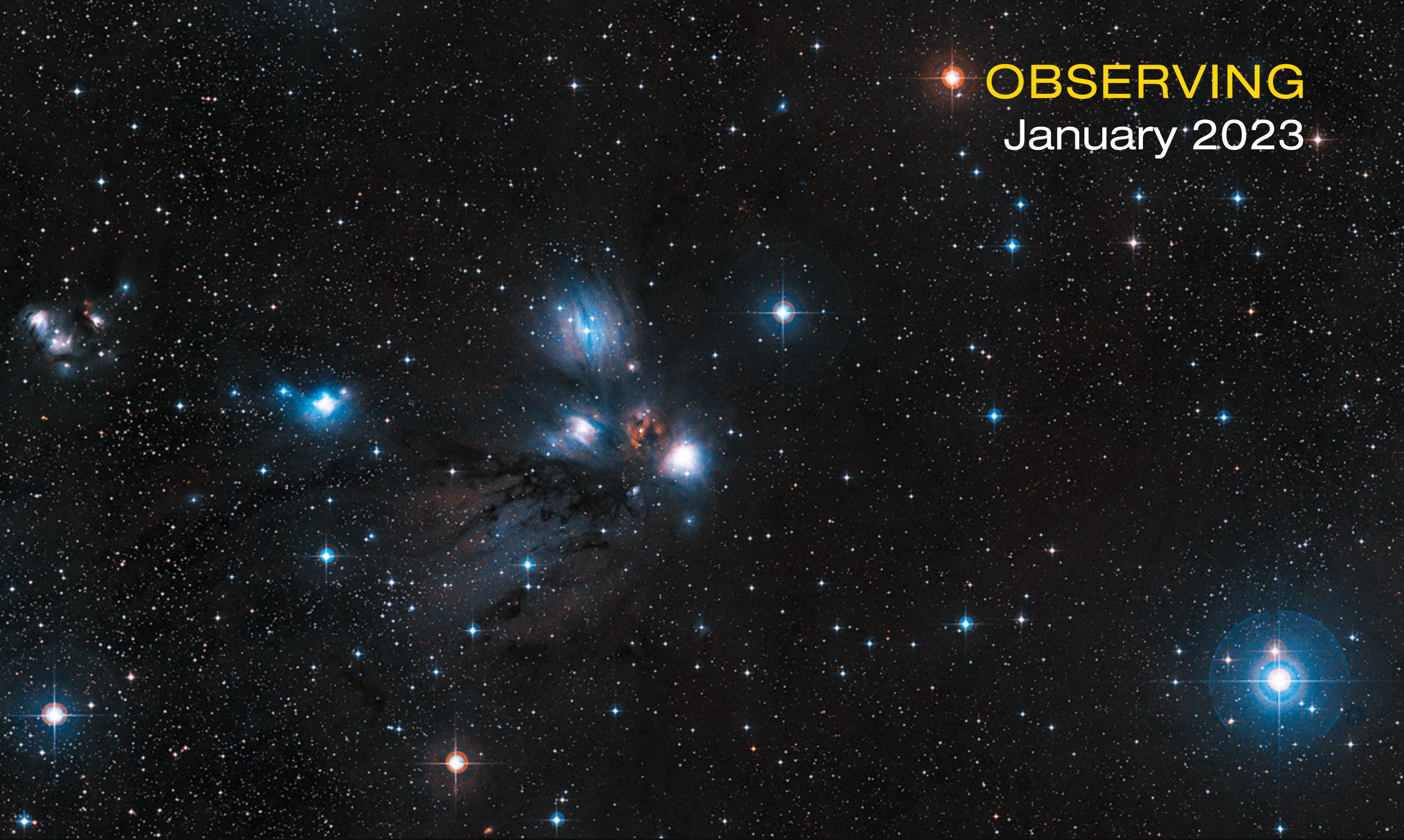
Remarkably, later in the same month a spectacular celestial event took place on a day with clear skies. On January 24th, shortly after 9 a.m., New Yorkers witnessed a solar eclipse with totality visible in uptown Manhattan, north of a line that passed between 96th and 97th Streets (*S&T:* Jan. 2017, p. 66).

*February 1925:* Although the January date looked like the ideal solution, was it the only one possible? Could favorable conditions have also occurred during the next full Moon period? Dates in February may be too close to the Seven Americans show's opening on March 9th for O'Keeffe to have finished her painting in time. However, for completeness, we calculated that the Moon "ran high" on February 5th — three days before the full Moon of the 8th. According to the weather observations around this date, one of the evenings featured cirrostratus clouds, others had completely clear skies, while yet other evenings were plagued by fog — all of which are inconsistent with the scene in the painting.

Based on the lunar phase and the Moon's position in the heavens, along with meteorological evidence, we conclude that on the night of January 9, 1925, Georgia O'Keeffe stood on the corner of 48th Street and Vanderbilt Avenue in front of the Hotel Chatham, looked skyward, and observed the scene that inspired her to paint *New York Street with Moon*, proving she could create spectacular art set in an urban environment.

**DON OLSON** is professor emeritus of physics at Texas State University and the author of *Celestial Sleuth* (2014), *Further Adventures of the Celestial Sleuth* (2018), and, most recently, *Investigating Art, History, and Literature with Astronomy* (2022).

# OBSERVING
## January 2023



**1 EVENING:** Algol shines at minimum brightness for roughly two hours centered at 10:42 p.m. EST (7:42 p.m. PST; see page 50).

**3 EVENING:** Look high in the east-southeast to see the Moon and Mars about 2½° apart above Aldebaran, in Taurus, the Bull. (Turn to page 46 for more on this and other events listed here.)

**4 EARTH** is at perihelion, its closest point to the Sun for 2023, at a distance of 147.1 million kilometers.

**4 MORNING:** The short-lived Quadrantid shower peaks (go to page 50), but the waxing gibbous Moon will interfere with meteor-watching.

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

**6 EVENING:** The full Moon, Castor, and Pollux form a neat triangle in the east.

**10 DAWN:** Before sunup, look toward the west to see the waning gibbous Moon some 4° from Leo's brightest star, Regulus.

**15 DAWN:** The Moon, one day past last quarter, gleams in Virgo, around 6° left of Spica. Face south to catch this sight.

**18 DAWN:** The thin, waning crescent Moon and Antares rise together in the southeast, about 1½° separating them.

**22 DUSK:** Look toward the west-southwest to see Venus and Saturn a mere ½° apart. The pair sink lower as twilight deepens, so make sure you have a clear horizon to enjoy the view.

**22 EVENING:** Algol shines at minimum brightness for roughly two hours centered at 9:27 p.m. PST.

**24 EVENING:** Algol shines at minimum brightness for roughly two hours centered at 9:16 p.m. EST.

**25 DUSK:** High in the southwest, the waxing crescent Moon hangs some 3° below Jupiter.

**28 DUSK:** The first-quarter Moon is positioned about halfway between Mars and Jupiter high in the south, with Venus and Saturn completing the lineup closer to the horizon in the west-southwest.

**30 EVENING:** As the month draws to a close, the waxing gibbous Moon visits Taurus again and sidles up to within ½° of Mars. This time, though, viewers will have to look high in the southwest to take in this sight. (See page 49 for details of the occultation.)
— DIANA HANNIKAINEN

▲ The bright reflection nebula NGC 2170, at the edge of the Monoceros R2 molecular cloud, is at center in this wide-field image. Go to page 26 to read more on how you can observe this object and others like it. ESO / DIGITIZED SKY SURVEY 2 / ACKNOWLEDGMENT: DAVIDE DE MARTIN

## JANUARY 2023 OBSERVING

## Lunar Almanac

## Northern Hemisphere Sky Chart


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

NASA / LRO

### MOON PHASES

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

**FULL MOON**
January 6
23:08 UT

**LAST QUARTER**
January 15
02:10 UT

**NEW MOON**
January 21
20:53 UT

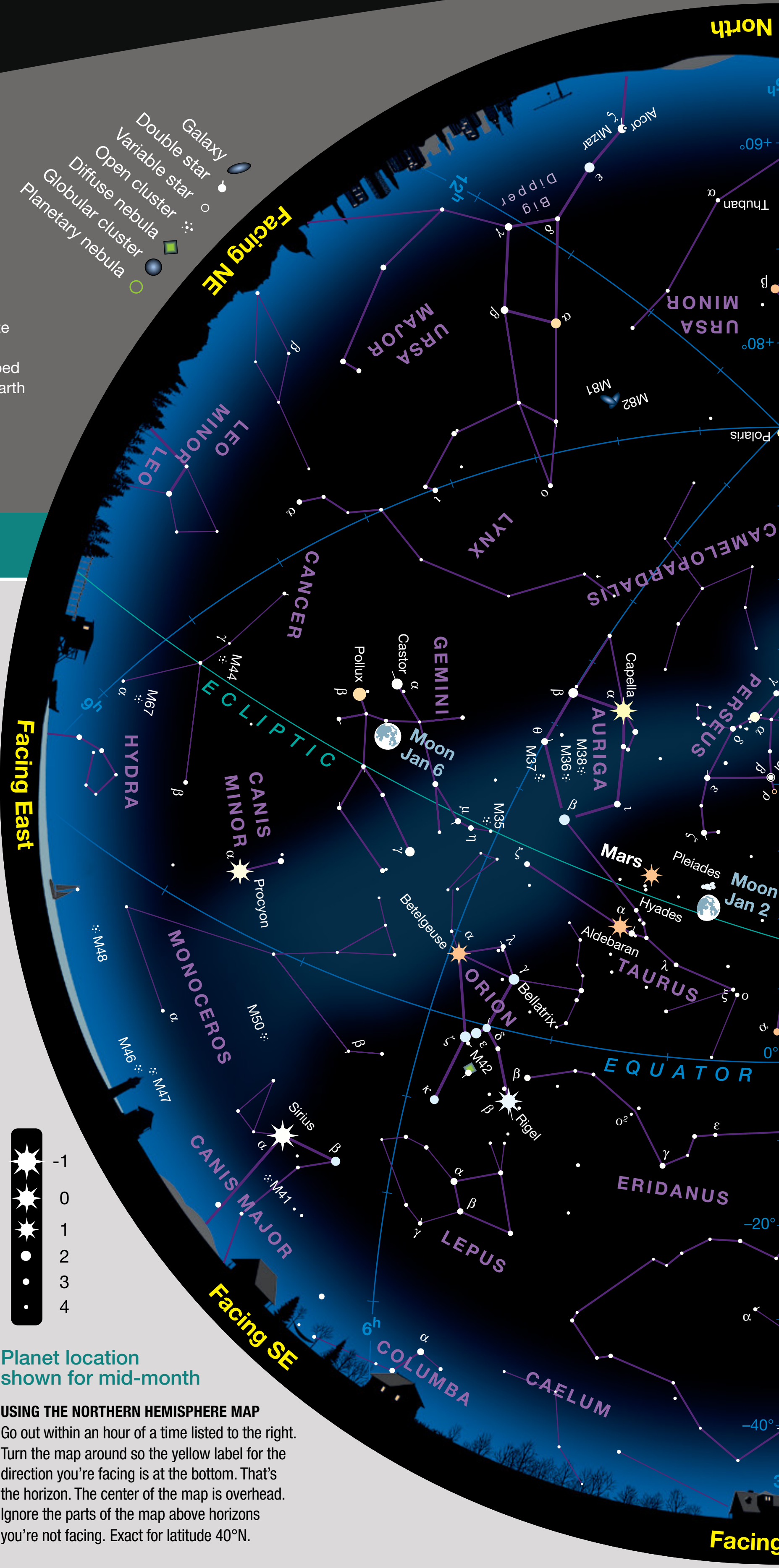
**FIRST QUARTER**
January 28
15:19 UT

### DISTANCES

| | |
|---|---|
| Apogee | January 08, 9$^h$ UT |
| 406,458 km | Diameter 29′ 24″ |
| Perigee | January 21, 21$^h$ UT |
| 356,569 km | Diameter 33′ 31″ |

### FAVORABLE LIBRATIONS

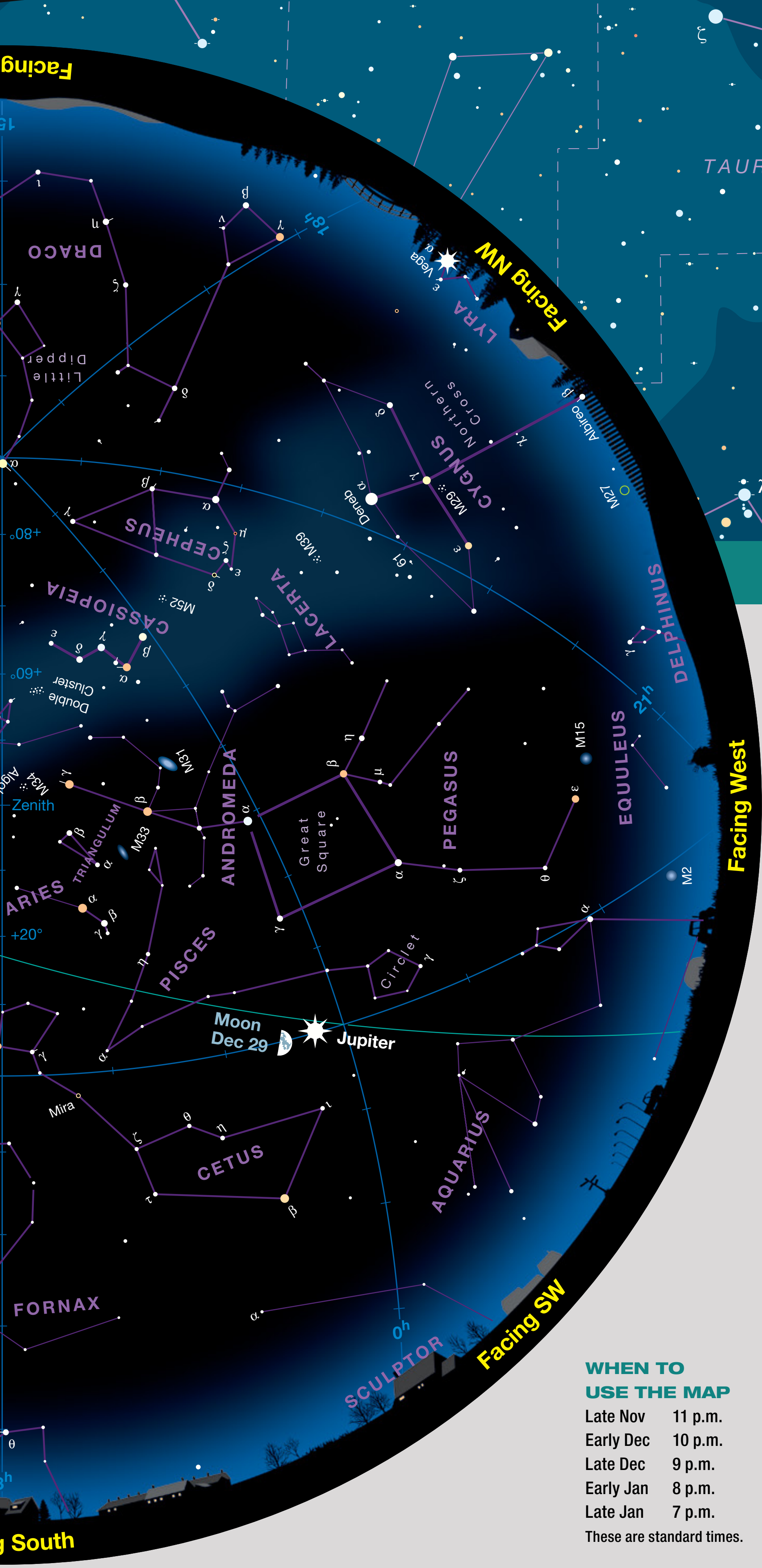
| | |
|---|---|
| • Mare Marginis | January 1 |
| • Bailly Crater | January 10 |
| • Mare Orientale | January 15 |
| • Vestine Crater | January 25 |

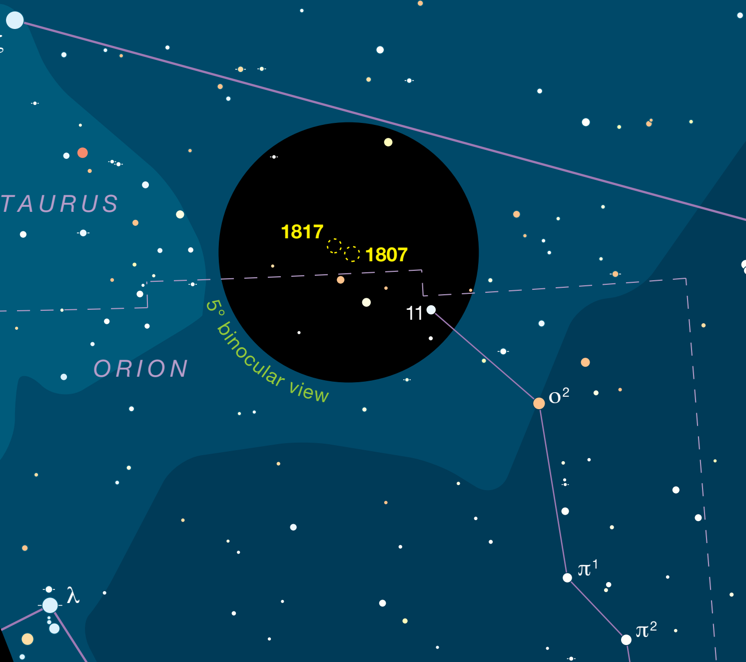



Planet location shown for mid-month

**USING THE NORTHERN HEMISPHERE MAP**

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




**WHEN TO USE THE MAP**

| | |
|---|---|
| Late 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.

**Binocular Highlight** by Mathew Wedel

# A Winter Double Cluster

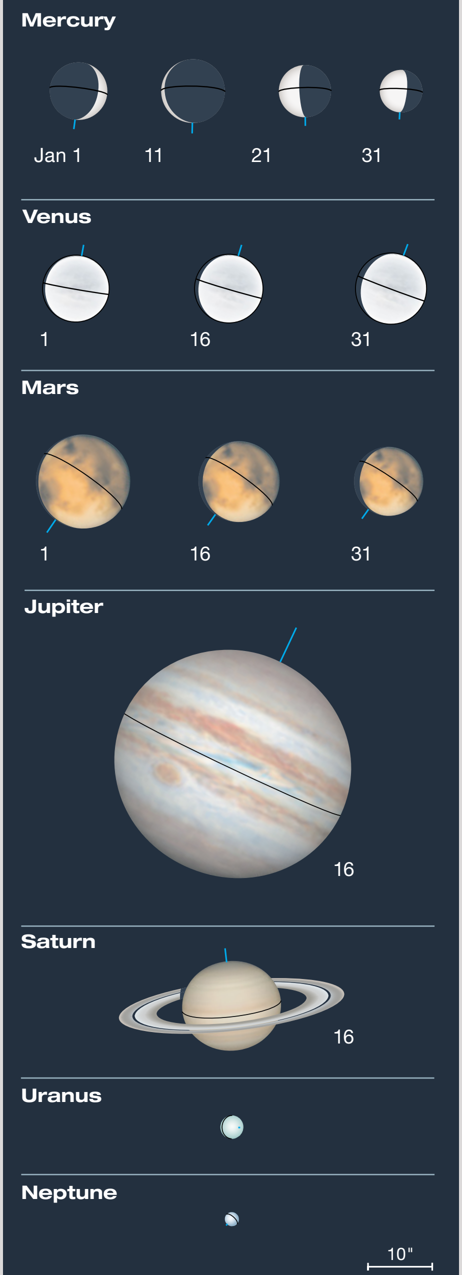
I grew up on the Great Plains of Oklahoma, and on cold, clear nights, the bright stars and clusters of winter remind me of moonlight on snow-covered fields and the warm lights of distant towns. The densest parts of the winter Milky Way are so packed with wonders that the sky seems almost cozy.

Our targets this month are the open clusters **NGC 1807** (magnitude 7.0) and **NGC 1817** (magnitude 7.7), on the southern border of Taurus, the Bull. Or perhaps I should say our target, singular? The two groups of stars are equally distant, at about 5,900 light-years, and astrometric studies suggest that NGC 1807 may be simply a clump of 8th- to 10th-magnitude stars on the western edge of a single extended cluster, NGC 1817. Veteran observer Steve Coe refers to the pair as a double cluster, and that seems like a good solution for amateur observers. The two brighter regions are visually distinct in binoculars, so for convenience I'll refer to them as NGC 1807 and NGC 1817.

To find this double cluster, start in the neighboring constellation of Orion and follow the arc of the Hunter's shield north and east, about 2° past 11 Orionis. At 10× all I see are a couple of fuzzy patches, but at 15× the clusters begin to resolve in averted vision. If you're very keen-eyed, or if you revisit the pair with a telescope, you may be able to detect that each cluster has a backbone of stars running from northwest to southeast. NGC 1817 is richer than NGC 1807, with dozens of faint stars filling in its background. Whatever instrument you use, see what similarities and differences you can find in this winter double delight.

■ Given how often **MATT WEDEL** gets lost in the Milky Way, it's probably a good thing that he lives in a place with mild winters.

**PLANET VISIBILITY** (40°N, naked-eye, approximate) **Mercury** visible at dawn starting on the 15th • **Venus** visible at dusk all month • **Mars** transits the meridian in the evening and sets before dawn • **Jupiter** culminates around sunset • **Saturn** visible at dusk and sets in the early evening.

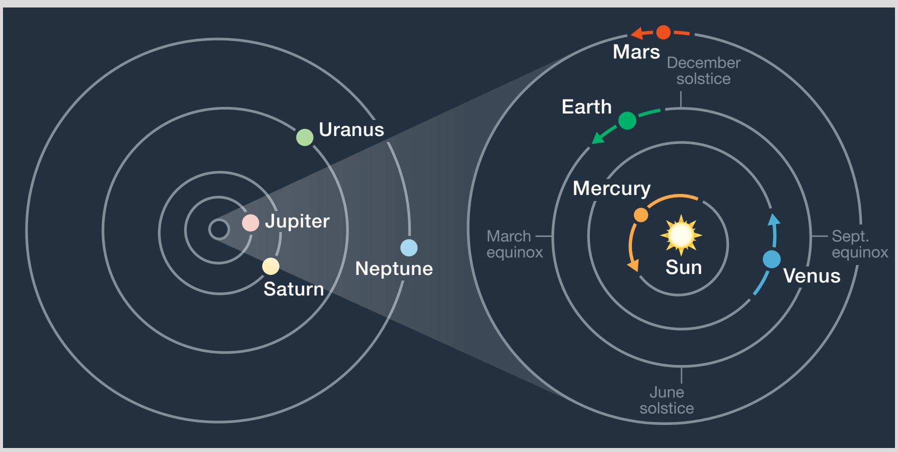



▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

## January Sun & Planets

| | Date | Right Ascension | Declination | Elongation | Magnitude | Diameter | Illumination | Distance |
|---|---|---|---|---|---|---|---|---|
| Sun | 1 | $18^{h}\ 43.4^{m}$ | –23° 04′ | — | –26.8 | 32′ 32″ | — | 0.983 |
| | 31 | $20^{h}\ 51.8^{m}$ | –17° 36′ | — | –26.8 | 32′ 28″ | — | 0.985 |
| Mercury | 1 | $19^{h}\ 40.3^{m}$ | –20° 33′ | 13° Ev | +1.3 | 9.0″ | 16% | 0.749 |
| | 11 | $18^{h}\ 51.8^{m}$ | –19° 36′ | 9° Mo | +3.2 | 9.9″ | 5% | 0.680 |
| | 21 | $18^{h}\ 35.1^{m}$ | –20° 38′ | 22° Mo | +0.1 | 8.1″ | 39% | 0.830 |
| | 31 | $19^{h}\ 07.2^{m}$ | –21° 40′ | 25° Mo | –0.2 | 6.6″ | 64% | 1.013 |
| Venus | 1 | $19^{h}\ 57.6^{m}$ | –22° 06′ | 17° Ev | –3.9 | 10.4″ | 96% | 1.607 |
| | 11 | $20^{h}\ 49.8^{m}$ | –19° 20′ | 19° Ev | –3.9 | 10.6″ | 95% | 1.577 |
| | 21 | $21^{h}\ 39.9^{m}$ | –15° 39′ | 22° Ev | –3.9 | 10.8″ | 93% | 1.542 |
| | 31 | $22^{h}\ 27.8^{m}$ | –11° 16′ | 24° Ev | –3.9 | 11.1″ | 92% | 1.504 |
| Mars | 1 | $4^{h}\ 26.2^{m}$ | +24° 32′ | 149° Ev | –1.2 | 14.7″ | 97% | 0.638 |
| | 16 | $4^{h}\ 22.4^{m}$ | +24° 24′ | 133° Ev | –0.7 | 12.6″ | 94% | 0.741 |
| | 31 | $4^{h}\ 30.6^{m}$ | +24° 36′ | 119° Ev | –0.3 | 10.8″ | 92% | 0.867 |
| Jupiter | 1 | $0^{h}\ 05.3^{m}$ | –0° 50′ | 81° Ev | –2.4 | 39.3″ | 99% | 5.010 |
| | 31 | $0^{h}\ 22.3^{m}$ | +1° 07′ | 55° Ev | –2.2 | 36.2″ | 99% | 5.449 |
| Saturn | 1 | $21^{h}\ 39.5^{m}$ | –15° 19′ | 42° Ev | +0.8 | 15.8″ | 100% | 10.542 |
| | 31 | $21^{h}\ 52.5^{m}$ | –14° 13′ | 15° Ev | +0.8 | 15.4″ | 100% | 10.776 |
| Uranus | 16 | $2^{h}\ 49.1^{m}$ | +15° 54′ | 109° Ev | +5.7 | 3.6″ | 100% | 19.319 |
| Neptune | 16 | $23^{h}\ 35.6^{m}$ | –3° 55′ | 58° Ev | +7.9 | 2.2″ | 100% | 30.428 |

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




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

# The Hare and the Dove

## Two small constellations are nearly overshadowed by their brilliant neighbor.

On clear January evenings it's impossible to ignore the brilliant constellation Orion. But don't overlook two surprisingly bright and interesting characters just below the heavenly Hunter: Lepus, the Hare, and Columba, the Dove.

The Hare's brightest stars are only a little dimmer than Delta (δ) Orionis, the easternmost Belt star and the faintest of Orion's seven main lights. Six additional stars in Lepus exceed magnitude 4.0, making the figure an easy sight under moderately dark skies. The Hare's brightest light is 2.6-magnitude Alpha (α) Leporis. It's also known as Arneb, which appropriately enough is the Arabic name for "hare." Arneb occupies the center of Lepus, about 18° due south of Orion's Belt and more than one hour of right ascension due west of Sirius, the night sky's brightest star.

Arneb is a most distinctive star. It's about 2,200 light-years from Earth and has an *absolute magnitude* of –6.6. What is absolute magnitude? Astronomers use two different figures to describe a star's brightness. The more familiar is *apparent magnitude* — how bright a star appears in the night sky. That's useful, but what if we want to know how luminous a star actually is? That's where absolute magnitude comes in.

It's calculated using a star's apparent magnitude and its distance. Absolute magnitude tells us how brightly a star would shine if it were placed at a standard distance of 32.6 light-years. That might seem oddly arbitrary, but it's based on another unit of distance: the *parsec*. The parsec is determined by observing how a star's position in the sky changes as measured from opposite sides of Earth's orbit, six months apart. If the star shifts 1 arcsecond, it would be at a distance of 1 parsec, which is equal to 3.26 light-years. So, the standard distance of 32.6 light-years is simply 10 parsecs.

If Arneb were at distance of 32.6 light-years, it would easily outshine the planet Venus at its brightest. However, our own Sun at that same distance would glow relatively dimly at magnitude 4.8 — fainter than most of the stars making up Lepus.

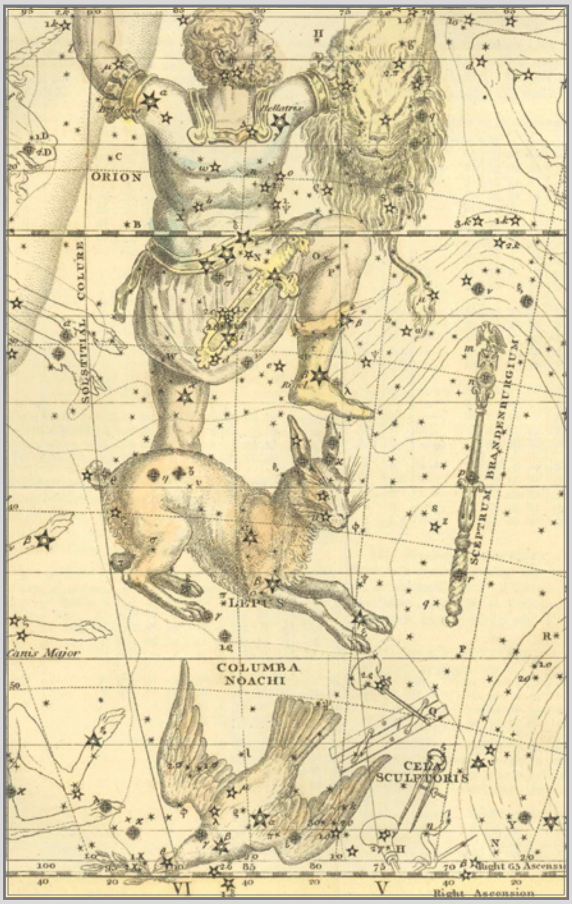
Beta (β) Leporis, also known as Nihal (from an Arabic word for a certain kind of camel), shines at magnitude 2.8 and lies a modest 160 light-years from Earth. That's a lot closer than Arneb but quite a bit farther away than Zeta (ζ), Eta (η), and Gamma (γ) Leporis, which are 70, 49, and 29 light-years away, respectively. Gamma is well known to telescope users as a beautiful, easy double star with 3.6- and 6.3-magnitude components of yellow and red, separated by a generous 96″.

Just south of Lepus is Columba, the Dove. I initially thought that both were among the smallest of the 88 officially recognized constellations. Not so. In fact, 34 constellations occupy less celestial real estate than Columba, which itself is a bit smaller than Lepus.

Lepus is often pictured as being chased by Orion's hound dog, Canis Major, but hares and rabbits have many astronomical connections. One is the "Moon rabbit," in which the lunar feature Mare Crisium serves as the hare's round tail or "scut."

Columba is most often connected with the biblical tale of Noah and the ark. Noah released the dove to seek dry land during the Flood. And indeed, Columba is not far from the huge constellation of the ship Argo, which was broken up into Vela, Puppis, and Carina.

Columba features the creditably bright Alpha Columbae, a 2.7-magnitude star known as Phact (Arabic for "ring dove"). But my favorite Columba attraction lies near its border with Canis Major. That's the location on the celestial sphere that our solar system is flying away from in its journey around the galaxy. A formal name for that point is the *Antapex of the Sun's Way* or the *solar antapex*. But a name for it I like even more is "the Sun's Quit."




ALEXANDER JAMIESON / *CELESTIAL ATLAS* (1822) / UNITED STATES NAVAL OBSERVATORY LIBRARY / PUBLIC DOMAIN

◀ **AT THE FEET OF ORION** Two of the winter sky's lesser-known constellations lie south of mighty Orion, the Hunter. Lepus, the Hare, and Columba, the Dove, may not shine as brightly as their northerly neighbor, but each has its own attractions.

■ **FRED SCHAAF** first identified Orion when he was six years old, Lepus no more than two years later.

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

# A Month of Remarkable Encounters

Venus brushes by Saturn, and the Moon meets Mars.

## SUNDAY, JANUARY 1

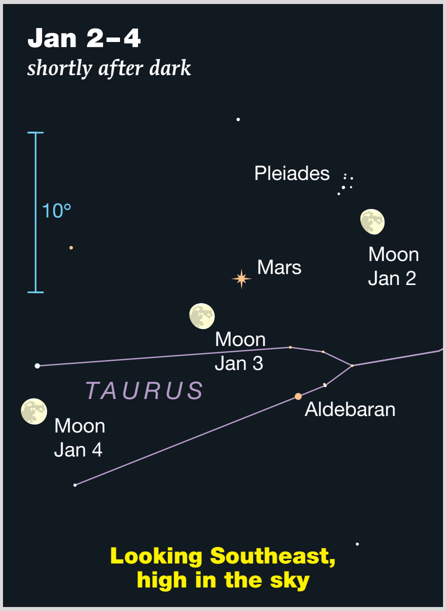
Welcome to a new year — and to a wonderful, celebratory celestial sight that adorns this first evening of 2023. Leave the binoculars and telescope behind, step outside at dusk, and take in the view of five bright solar system worlds spanning 130° across the sky.

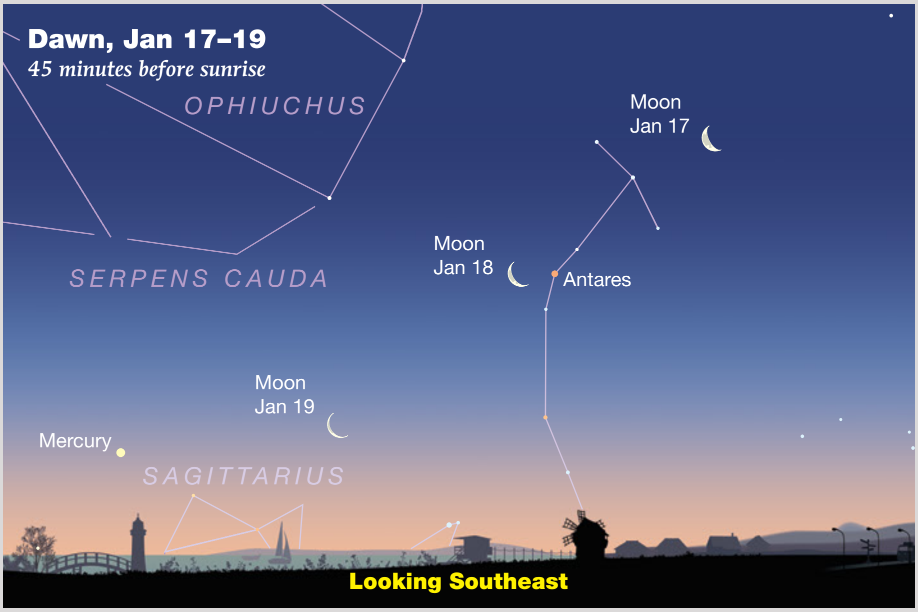
Low in the west-southwest and brightest of all is the reigning Evening Star, **Venus**. A beacon of magnitude –3.9, Venus is in a class of its own and likely the first "star" you see tonight. ("I wish I may, I wish I might . . .") Shift your gaze 24° eastward, and the next planet you encounter will be the relatively subdued **Saturn**, glowing at magnitude +0.8. That's still plenty bright, but given the company it presently keeps, that's not outstanding. Continuing 39° eastward, your eyes will next land on **Jupiter**. Positioned due south, the gas giant, gleaming at magnitude –2.4, is bested only by Venus. Roughly 45° farther east you'll find the waxing gibbous **Moon**, nearly 80% illuminated. Although it's only days away from being full, even the Moon isn't bright enough to overwhelm nearby **Mars**, lying nearly two dozen degrees to its left. The Red Planet has lost a little of its opposition luster but still shines brightly at magnitude –1.2. If you're looking to impress your non-astronomy neighbors and friends with the splendors of the night sky, you could do far worse than by taking a moment to show them this evening's array.

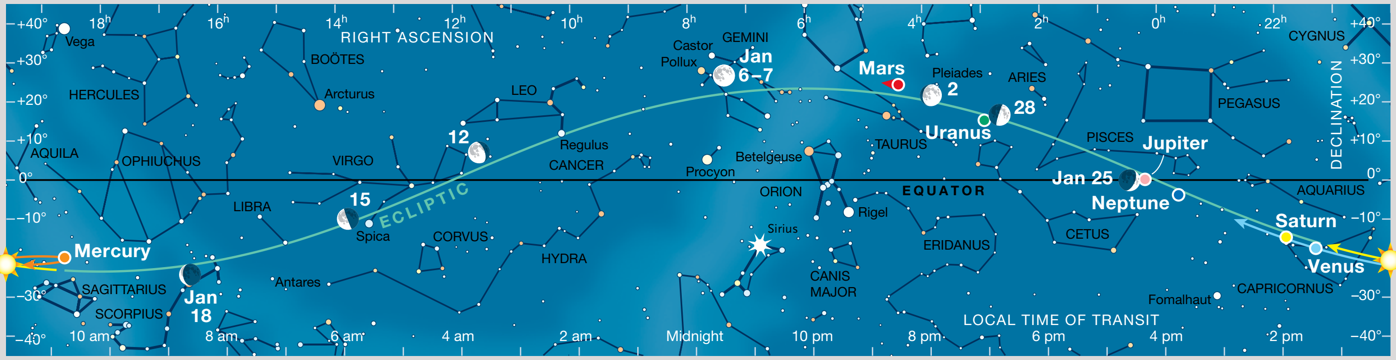
## TUESDAY, JANUARY 3

Compared to the other solar system objects with which it shares the sky, the **Moon** moves relatively swiftly. Indeed, every hour our nearest celestial neighbor shifts slightly more than its own diameter. So, just two evenings after it occupied a no man's land between Jupiter and **Mars**, it's now positioned roughly 2½° left of the Red Planet. I say "roughly" because the exact amount depends on where you are and when you look. If you live in New York, for example, and view the pair as twilight fades, the gap between the two is quite a bit less than 2°. However, if you're in Los Angeles, where nightfall comes later, the Moon's motion has carried it a little more than 3° east of Mars.

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






▲ The Sun and planets are positioned for mid-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.

Regardless, the pair are an arresting naked-eye sight and are even worth a quick look in binoculars, which will emphasize Mars's peachy-orange tinge and the austere, silver-gray of the lunar surface. But as nice as this pairing is, you ain't seen nothin' yet! (Check out January 30th.)

## WEDNESDAY, JANUARY 18

The **Moon** encounters several bright stars as it makes its way along the ecliptic, but this morning's meet-up with **Antares** is the closest of the month. The earthlit, waning lunar crescent rises in the southeast just 1½° left of the flickering ember that is the brightest star in the constellation Scorpius. Once again, binoculars will allow you to get the most out of the scene, enhancing the star's color and the visibility of the "unlit" portion of the Moon. We tend to associate Antares with mild, early-summer evenings. Now, watching it climb higher on a January morning, we're reminded that this season's chilly weather won't last forever. And if you continue viewing as twilight begins to brighten the sky, keep an eye out for **Mercury**, which rises roughly 1½ hours before the Sun. The little planet is at the start of a favorable dawn apparition that reaches its climax on January 30th when it's at greatest elongation.

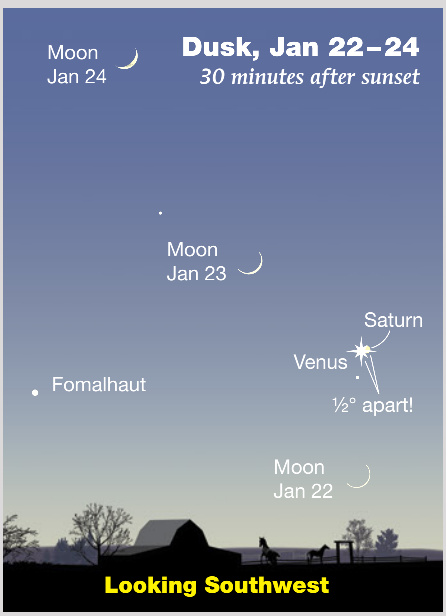
## SUNDAY, JANUARY 22

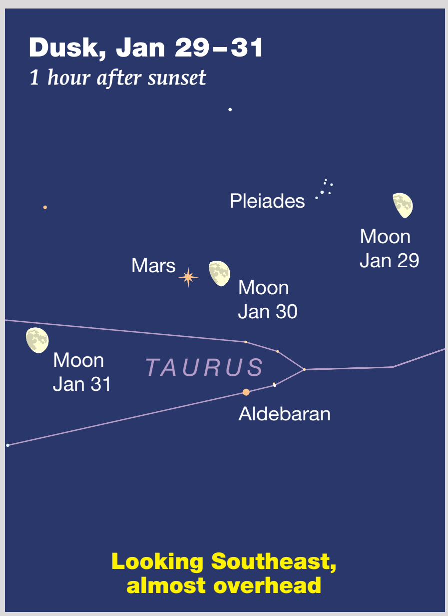
Any time two bright planets are within ½° of each other, it's an exciting and noteworthy sight. And that's what we get at dusk tonight when **Venus** and **Saturn** lie separated by a mere 21′. The brightness mismatch between them, however, is extreme — Venus gleams 76 times brighter than its more distant neighbor! Depending how early in the evening you look, you might need binoculars to see Saturn at all.

This really is a special event as it's the closest observable pairing of naked-eye planets this year — and it happens in the very first month! That said, if you have cloudy skies this evening, don't fret. Venus will approach nearly as close to Jupiter at dusk on March 1st, and the brightness mismatch won't be nearly so dramatic.

## MONDAY, JANUARY 30

As this eventful month winds down, we have one final spectacle to enjoy — a *very* close conjunction featuring the waxing gibbous **Moon** and **Mars**. Indeed, this evening's event is something of a repeat of December's Moon–Mars encounter, during which the lunar disk actually eclipsed the Red Planet for observers at many locations across the U.S. This time, however, the occultation line has shifted south, so most of the country will simply see the Moon slowly pass ever-so-slightly under Mars as the night progresses. (Complete details are presented on page 49.)




■ Consulting Editor **GARY SERONIK** never misses a chance to see two planets in one view.

# Comet ZTF Flies High and Bright

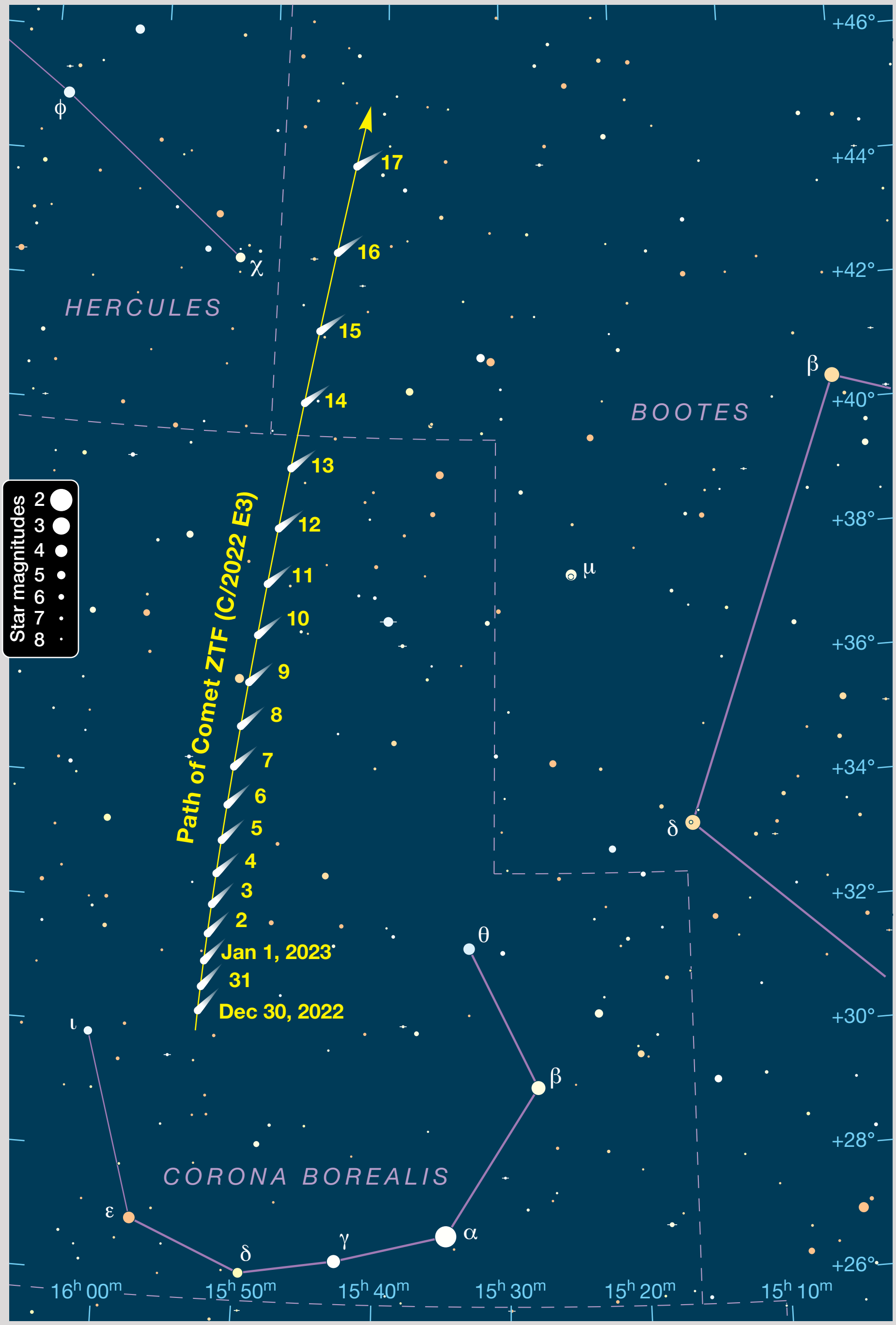
A comet with naked-eye potential dashes across the sky as it swings past Earth.

There's nothing like a bright comet to make gearing up for a night in the frigid cold seem worthwhile. Most of the time I find that once I make the commitment, conditions are never quite as inhospitable as I'd imagined. Besides, a comet that's been slogging toward the inner solar system for close to 50,000 years deserves a warm welcome.

Comet ZTF (C/2022 E3) first came into our ken on March 2, 2022, when the Zwicky Transient Facility (ZTF) discovered a 17th-magnitude asteroidal object on images taken with the 48-inch (1.2-meter) Schmidt telescope at Palomar Observatory. Subsequent observations showed it to have a small, dense coma, and astronomers identified it as a new comet.

I got my first look at ZTF in my 15-inch Dobsonian reflector on June 18th as the comet passed near Albireo, in Cygnus. Although only magnitude 13.8 at the time, its subarcminute coma appeared well-condensed — always a good sign for an incoming comet. Throughout the summer, it gradually brightened to around magnitude 12, sporting a tiny, very dense coma and a short (at most 1′ long) tail extending southeast. Although faint and small, it strikingly had a classic comet form, which I took to be a good omen.

Fast-forward to 2023. Comet ZTF will reach perihelion on January 12th at a distance of 1.11 a.u. (166 million kilometers, 103 million miles) from the Sun. Closest approach to Earth occurs on February 2nd, when the comet passes within 0.28 a.u. (42 million km) of our home world. That's when ZTF could soar to magnitude 5 or 6, making it faintly visible to the naked



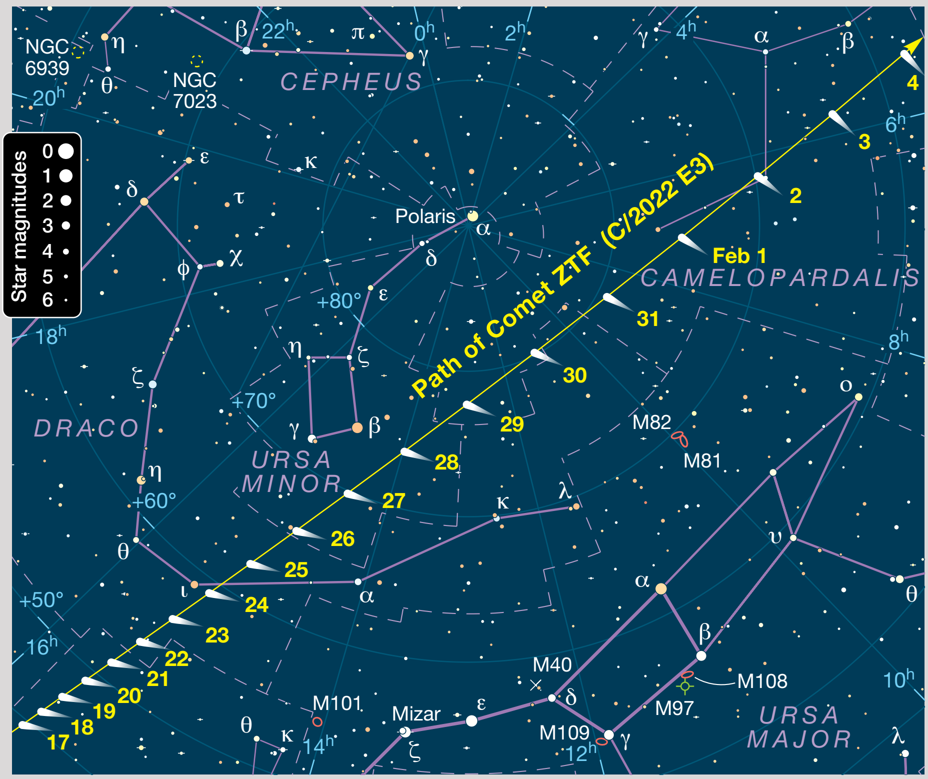
eye from rural skies and an easy catch in binoculars.

The comet begins January in Corona Borealis, where it should glow around 8th magnitude and be beautifully placed at dawn, halfway up the eastern sky. While moving northeast at a little more than ½° each day, ZTF ascends and brightens as it skirts the northeastern edge of Boötes. It may reach magnitude 6 by the third week of the month, when it slips into Draco and becomes a circumpolar object for observers at mid-northern latitudes.

Throughout January, the comet's apparent motion increases rapidly to a pace of more than 6° per day from the 29th through February 4th. That's equivalent to nearly one full Moon diameter every two hours, or 15″ per minute. At that speed, you might be able to detect the comet's movement in real time, using high magnification in your telescope. Peak brightness of around 5.5 is expected at month's end. The Earth-Sun-comet geometry will change quickly from perihelion through early February, so we'll get to see its tail swing slowly about like a wind vane at the approach of fresh weather.

▲ On August 30, 2022, more than four months before perihelion, Comet ZTF (C/2022 E3) exhibited a well-defined dust tail and a bright inner coma. During late January and early February, we may see the distant visitor reach naked-eye brightness.

After sailing within 10° of Polaris on the 29th and 30th, ZTF shoots across Camelopardalis and then zips about 2° northwest of Capella on February 5th, before crossing into Taurus on the 9th. In the predawn hours of February 11th, it passes roughly 1° east of Mars (which shines at magnitude 0.0) for viewers in the U.S. By the time spring begins in the Northern Hemisphere, the icy visitor fades to around magnitude 10 or 11 as it wades across eastern Eridanus, not far from Rigel.




MICHAEL JÄGER

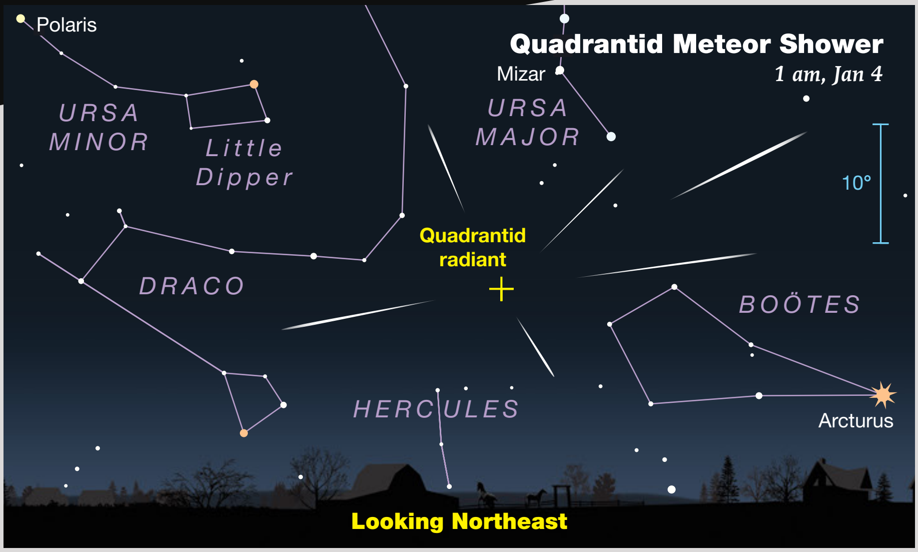
## Moon Occults Mars . . . Again!

**LAST MONTH,** U.S. observers in the southeastern states and along the Atlantic Seaboard missed out as the Moon covered Mars. This month presents a sweet consolation prize. On the night of January 30–31, the Moon will eclipse the Red Planet again, with the event visible across the southeastern U.S., most of Texas, and westward to southern California. It can also be seen throughout Mexico, Cuba, and most of Central America.

Compared to December's occultation, Mars has now faded to magnitude –0.3, but it will still be an impressive sight when the dark limb of the waxing gibbous Moon slowly smothers the ruddy orb and then, later, sets it free. From Albuquerque, New Mexico, the lunar limb contacts Mars at 10:04 p.m. local time on January 30th, taking 68 seconds to completely cover the planet. Mars reappears at the bright limb at 10:45 p.m.

Here are the approximate local times of disappearance and reappearance for several major cities (p.m. times are for the night of the 30th, a.m. refers to the morning of the 31st): Miami, FL (12:37 a.m. to 1:27 a.m.); Jackson, MS (11:32 p.m. to 12:06 a.m.); New Orleans, LA (11:26 p.m. to 12:16 a.m.); Dallas, TX (11:18 p.m. to 12:03 a.m.); Phoenix, AZ (9:45 p.m. to 10:44 p.m.); Los Angeles, CA (8:36 p.m. to 9:29 p.m.); Mexico City, Mexico (10:59 p.m. to 12:27 a.m.).

For more locations, visit **www.lunar-occultations.com**.




# Exercise Your Quads

**THANKS TO SERIOUS** competition from a 12-day-old Moon, this is an off-year for the annual Quadrantid meteor shower. The waxing gibbous won't set until the start of morning twilight, essentially shutting the window on dark skies. Peak activity is predicted to occur on January 4th at around 4 UT (11 p.m. EST January 3rd).

Under ideal, moonless conditions, maximum rates can exceed 100 meteors per hour, making the Quads one of the best displays of the year. The shower appears to radiate from northern Boötes, once home to the obsolete constellation Quadrans Muralis and memorialized in the shower's name. Given that the Quadrantids produce a substantial number of fireballs, you might want to check for an hour or so before dawn on the morning of the 4th. Look halfway up the northeastern sky — and be sure to keep a cup of your favorite hot beverage close at hand.

## Minima of Algol

| Dec. | UT | Jan. | UT |
|---|---|---|---|
| 1 | 14:41 | 2 | 3:42 |
| 4 | 11:30 | 5 | 0:31 |
| 7 | 8:19 | 7 | 21:20 |
| 10 | 5:08 | 10 | 18:09 |
| 13 | 1:57 | 13 | 14:59 |
| 15 | 22:46 | 16 | 11:48 |
| 18 | 19:35 | 19 | 8:37 |
| 21 | 16:25 | 22 | 5:27 |
| 24 | 13:14 | 25 | 2:16 |
| 27 | 10:03 | 27 | 23:05 |
| 30 | 6:52 | 30 | 19:55 |

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 2.7 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

**AS TWILIGHT FADES** on the evening of January 1st, Jupiter will be a prominent sight high in the south. The –2.4-magnitude planet crosses the meridian roughly half an hour after sunset. By month's end, it will do so more than 1½ hours *before* sunset, signifying that the current apparition is starting to wind down. On January 1st, Jupiter sets around 11:30 p.m. local time, and before 10 p.m. on the 31st.

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 on any given date and time. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page.

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

**December 1**: 9:30, 19:26; **2**: 5:22, 15:18; **3**: 1:13, 11:09, 21:05; **4**: 7:01, 16:56; **5**: 2:52, 12:48, 22:43; **6**: 8:39, 18:35; **7**: 4:31, 14:27; **8**: 0:23, 10:18, 20:14; **9**: 6:10, 16:05; **10**: 2:01, 11:57, 21:53; **11**: 7:49, 17:44; **12**: 3:40, 13:36, 23:32; **13**: 9:27, 19:23; **14**: 5:19, 15:15; **15**: 1:11, 11:06, 21:02; **16**: 6:58, 16:54; **17**: 2:50, 12:45, 22:41; **18**: 8:37, 18:33; **19**: 4:28, 14:24; **20**: 0:20, 10:16, 20:11; **21**: 6:07, 16:03; **22**: 1:59, 11:55, 21:50; **23**: 7:46, 17:42; **24**: 3:38, 13:34, 23:29; **25**: 9:25, 19:21; **26**: 5:17, 15:13; **27**: 1:09, 11:04, 21:00; **28**: 6:56, 16:52; **29**: 2:48, 12:43, 22:39; **30**: 8:35, 18:31; **31**: 4:27, 14:22

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

These times assume that the spot will be centered at System II longitude 31° on January 1st. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 31° and 1⅔ minutes later for each degree more than 31°.

## Phenomena of Jupiter's Moons, January 2023

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

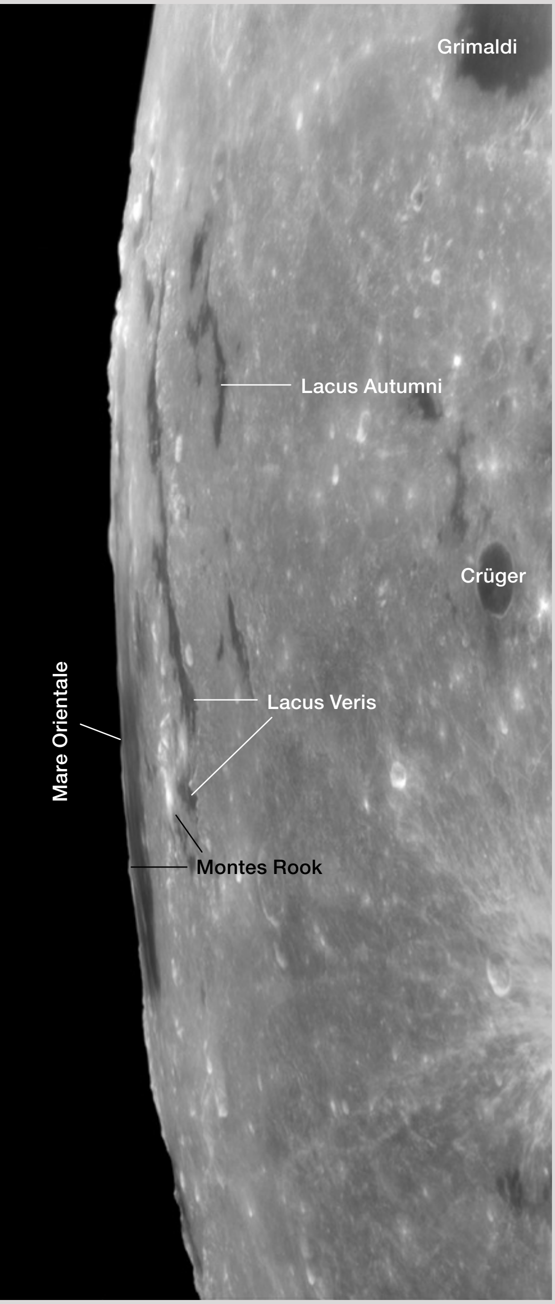
Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede,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

# Observing on the Edge

January offers a rare opportunity to glimpse one of the Moon's most challenging features.




▲This month, a favorable libration brings the southwestern limb of the Moon into view.

SEAN WALKER / S&T

The Moon spins once on its axis and completes one revolution around Earth in the same interval of time, so our satellite always presents the same familiar face. But it's never *exactly* the same face.

The shape of the Moon's orbit is slightly elliptical, causing the distance between the Moon and Earth to vary between about 28 and 32 Earth diameters every month. In accordance with Kepler's second law of motion, our satellite's orbital speed is fastest when it's at *perigee* (closest to Earth) and slowest when it's at *apogee* (farthest away). As a result, the Moon's constant speed of rotation alternately leads and lags its orbital position, making it appear as if the Moon is slowly oscillating from east to west with an amplitude of almost 8 degrees. Known as *libration in latitude*, this apparent wobble allows terrestrial observers to peer around the Moon's eastern and western limbs.

Favorable librations that occur when the southwestern limb is sunlit provide opportunities to observe one of the most imposing formations on the Moon, **Mare Orientale**, the Eastern Sea. Centered at 95° west longitude, just beyond the Moon's western limb, it marks the site of the impact of a large asteroid around 3.8 billion years ago. Despite its age, Orientale's almost pristine state of preservation makes it the most striking example of a multi-ring impact basin on the entire Moon.

The name Mare Orientale is an anachronism. In 1961 the International Astronomical Union dispensed with the astronomical convention of lunar coordinates based on telescopic views and adopted the astronautical convention that defines east as the direction of sunrise for someone standing on the Moon. Suddenly the Eastern Sea was awkwardly located on the Moon's western limb. A proposal to rename the feature Mare Pacificus was briefly entertained, but the old name was deemed too well established to be changed.

Images taken by the Lunar Orbiter 4 spacecraft in 1967 clearly revealed Orientale's bulls-eye structure for the first time. Flooded by dark basalt lavas, the central mare measures almost 330 kilometers (205 miles) in diameter and is completely encircled by a pair of concentric mountain ranges. Resembling ripples made by throwing a stone into a pond, these circular scarps are the result of shock waves in the lunar crust, which was liquefied by the colossal, basin-forming impact. The inner rim, measuring 620 km across, is marked by **Montes Rook** (the Rook Mountains). The more rugged **Montes Cordillera** defines the basin's 930-km-wide outer rim. Isolated peaks in this range tower to heights of 6 km above the central floor of the basin.

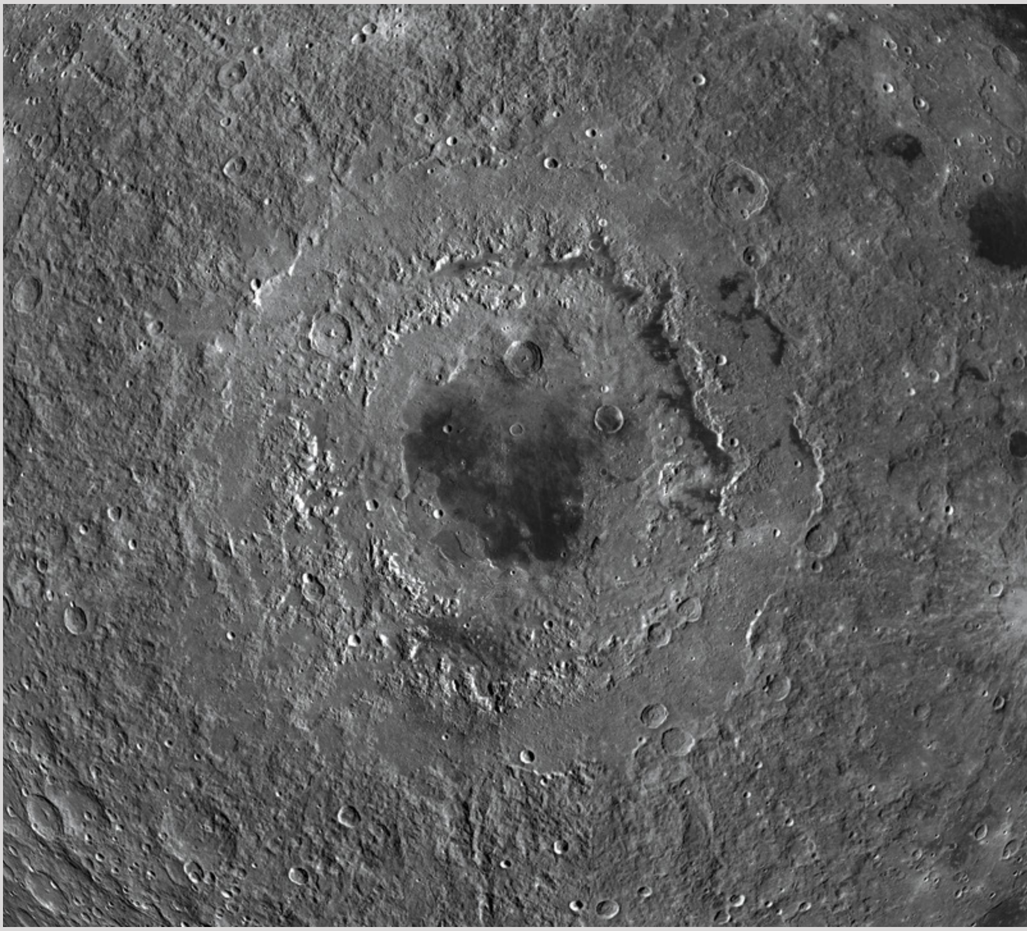
Even the best telescopic views of Mare Orientale are impaired by foreshortening. At mean libration, the surrounding mountain ranges often appear silhouetted against the background sky as irregularities on the lunar limb. German astronomer Johann Hieronymus Schröter charted them during the 1780s. However, only slivers of the central basin's dark floor can be seen. The most prominent are two dusky ribbons nestled in the lowlands between the concentric mountain rings known as **Lacus Autumni** (Lake of Autumn) and **Lacus Veris** (Lake of Spring). They were first recorded in drawings by the artist Jean Patigny that served as the basis of a large Moon map issued in 1679 by Giovanni Domenico Cassini of the Royal Observatory in Paris.

Given these fleeting and fragmentary glimpses, it should come as no surprise that Mare Orientale was discovered, forgotten, and rediscovered several times. In an obscure letter that appeared in an 1872 edition of the *Annals of the Astronomical Observatory of Harvard College*, the leading American geologist Nathaniel Shaler wrote of his suspicions that the Rook Mountains marked the ramparts of a giant crater on the lunar farside. Three decades later, Julius Heinrich Franz, director of the observatory at the University of Breslau (now Wrocław), announced the finding of "new *maria*, among them the large extended Mare Orientale, at -90° longitude, -14° to -22° latitude . . ." This was the first use of the name, but the International Astronomical Union didn't adopt it at the time, and it lapsed into obscurity.

Franz's publications in German escaped the attention of even the most avid British lunar observers like Hugh Percy Wilkins, who announced in 1937 the discovery of "a large, very foreshortened, dark plain" at the very same location. Wilkins christened this feature "The Lunar Mare X." Nine years later, his close associate Patrick Moore claimed yet another discovery of this feature and proposed that it be named Mare Orientale.

Prior to spacecraft images, the most remarkable revelation about Orientale came in 1961. At the University of Arizona's newly founded Lunar and Planetary Laboratory, a team led by Gerard Kuiper was compiling a "rectified" lunar atlas. Projecting lunar photographs onto a white, 3-foot-diameter globe made of plaster of Paris and re-photographing them from directly overhead showed features undistorted by foreshortening. One of Kuiper's most gifted graduate students, William Hartmann, recalls:

> *On its black supports in the dark photo studio, brightly illuminated by its projector down the hall, the globe seemed a realistic new planet . . . Walking around looking at it from different sides I realized there were a lot of these giant concentric ring bulls-eye features that had not been properly recognized.*



NASA / GSFC / ARIZONA STATE UNIVERSITY

▲ This mosaic recorded by NASA's Lunar Reconnaissance Orbiter clearly shows the multi-ringed "bullseye" pattern marking the Orientale basin.

Although only a fraction of Orientale could be seen from this new perspective, its distinctive form was obvious to Hartmann, who coined the term "multi-ringed basin":

> *I remember being struck by a 'eureka' experience . . . To me, a striking aspect of these discoveries was that while observers in the previous four centuries had pushed to detect ever-smaller features of the moon with ever-larger telescopes, these largest-of-all geologic structures had gone virtually unrecognized!*

This season's prime opportunities for viewing Mare Orientale occur in the early morning on January 13th through the 16th. Finding Orientale won't be difficult — look along the western limb just to the south of the dark floor of the prominent crater **Grimaldi**. Under the high Sun angle, the elongated bands of dark lavas that make up Lacus Autumni and Lacus Veris will stand out against the brighter surrounding mountains. The bright hairline of light right on the limb is sunlight reflected by the inner escarpment of the Rook Mountains on the far side of the basin. My most vivid impressions of this vast, 930-km depression are of its shallowness — with only 6 km of vertical relief, it's shallower than the saucer under a teacup.

■ Contributing Editor **TOM DOBBINS** has always been an avid observer of our closest celestial companion.

# Sword Scene

Delineating the Sword of Orion are treasures both magnificent and subtle.

Behold Orion, arguably the night sky's finest constellation. Gaze southward around 10 p.m. on a clear January night, and you can't miss the mighty celestial Hunter standing tall, near the meridian. Ruddy Betelgeuse brilliantly marks one shoulder, blue-white Rigel the opposite foot. A line of three 2nd-magnitude stars symbolizes the famous belt around Orion's waist.

A 1⅔°-long row of dim dots arranged nearly vertically beneath the Hunter's belt represent his sheathed sword. I can spot this weak streak of light from my suburban yard, even though my location's light pollution is worst toward the south. To my bare eyes, the southern tip of the sword is a clean, bright point. From there, trending northward, three more parts become progressively fainter and fuzzier — a clue that the Sword of Orion is more than a mere asterism. Any telescope (or even binoculars) will resolve the deceptively indistinct Sword into double stars, open clusters, and nebulae — including the marquee item, **M42**, the Great Orion Nebula. This is the magnet that draws me in.

◀ **COSMIC CAULDRON** Residing some 1,350 light-years from Earth, the Orion Nebula is arguably the finest deep-sky object visible from mid-northern latitudes. This gorgeous celestial nursery is one of the most studied regions in the night sky. In addition to the blazing-hot Trapezium stars at the core of M42, space-based telescopes have unveiled hundreds of stellar fledglings and protostars — unborn suns still incubating within dusty clumps of gas deep within the nebula.

NASA / ESA / M. ROBBERTO (STSCI / ESA) / THE HUBBLE SPACE TELESCOPE ORION TREASURY PROJECT TEAM

## The Star Maker

M42 is the finest emission nebula visible from mid-northern latitudes. The luminous nebulosity has been created by a family of youthful stellar siblings that are hollowing out a pocket of hydrogen gas deep inside the gigantic Orion Molecular Cloud. The gas is being energized into luminescence by powerful winds of ultraviolet radiation emanating mainly from 5th-magnitude Theta$^1$ ($\theta^1$) Orionis, the gleaming lucida of a compact quartet known as the Trapezium. Massive and white-hot, the four Trapezium stars represent the blazing heart of M42. Their radiative outflow has penetrated the side of the cloud facing Earth, allowing us to glimpse the nest of young suns within. More unborn protostars are incubating in adjacent clumps of gas and dust. M42 is literally a place where stars are born.

The famous cosmic nursery is situated just below the middle of Orion's Sword. My finderscope shows it as a greyish mist enveloping 5th-magnitude Theta$^1$ and Theta$^2$ ($\theta^2$) Orionis. The stars lie a couple of arcminutes apart, slanted northwest. My 4¼-inch (108-mm) f/6 Newtonian reflector at 38× morphs the mist into a finely textured nebula enveloping both stars. The northwestern one, Theta$^1$, is the prize.

It resolves into four stars — the **Trapezium** — whose magnitudes range from 5.1 to 7.5. The tiny quadrilateral is 19.2″ by 8.7″ in extent.

The Trapezium is surrounded by a dense, intensely luminous, greenish-grey mass. In my little reflector at 72×, this core nebulosity looks rectangular and remarkably straight on two sides. Wispy wings curling eastward and westward from the core region spread across roughly 20′ of sky. On the northern side, a wedge of blackness dubbed the Fish's Mouth intrudes almost to the Trapezium.

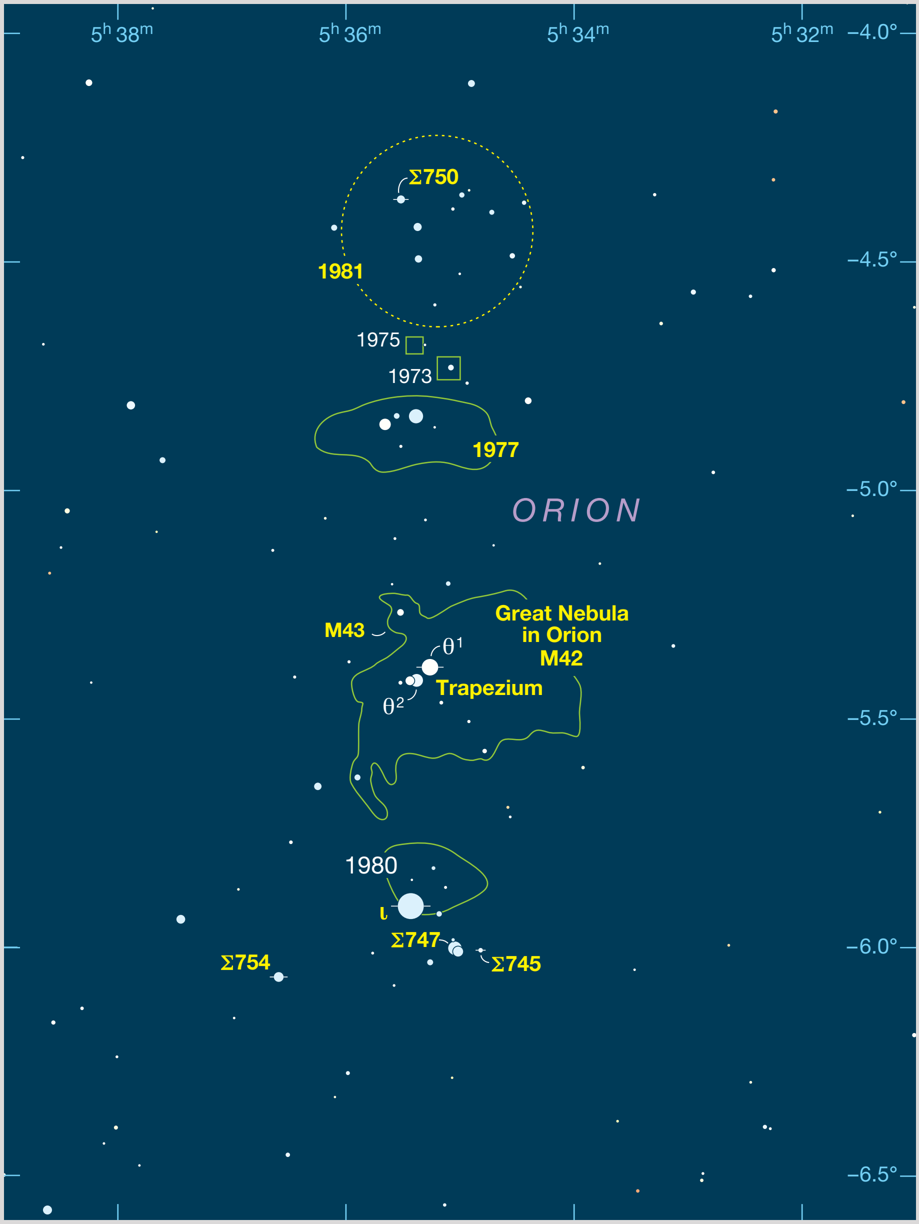
My 4.7-inch f/7.5 apochromatic refractor working at 100× clarifies all these details. If I stare patiently with my eyes cupped around the eyepiece to block out ambient light, with averted vision I can trace the delicate wings extending nearly to the edge of the ½° field. The view is enticing, yet frustrating. Oh, for a city-wide blackout!

The view in my 10-inch f/6 Dobsonian is, of course, vastly better. Admiring M42 at 169×, I discover that the intense central core is subtly mottled, and its two straight edges are tinged rusty-red. With patience (and provided the night air is calm), I sometimes note two very dim additional Trapezium stars (often designated E and F). Sublime.

North of the Fish's Mouth, seemingly separate from M42 (but in reality part of it), is **M43**, a much smaller nebula glowing weakly around 6.8-magnitude Nu (ν) Orionis. Even using averted vision, I need at least 72× on the 4¼-inch Newtonian to detect M43's tenuous oval haze. Applying an Ultra-High Contrast (UHC) filter blunts the star's glare, making the hazy halo of nebulosity around it easier to discern. (The filter also enhances M42, but at the cost of clobbering the delicate Trapezium.) M43 doesn't yield much more in the two larger scopes.

## Exploring the Sword

If you can tear yourself away from the Great Nebula, you'll discover that the rest of the Sword is well worth exploring. The portion below M42 is bursting with binaries, both easy and difficult.




▲ **GREAT LOCATION** The Sword of Orion isn't a very conspicuous asterism, yet it's easy to find thanks to its location just south of Orion's bright belt. The Sword is a few degrees below the celestial equator, so almost anyone in the world can admire its contents.

To begin, the eastern wing of M42 curls downward toward 2.8-magnitude **Iota (ι) Orionis**, which marks the Sword's southern tip. Iota is a superb binary. A 7.7-magnitude companion, 12.5″ southeast of powerful Iota, barely glimmers in my little reflector at 27× but is obvious when I double the magnification.

Scanning 8′ southwest of Iota brings us to **Struve (Σ) 747**, whose 4.7- and 5.5-magnitude components are a breezy 36.3″ apart. Only 3′ further west is another quick catch, **Σ745**, consisting of 8.3- and 9.4-magnitude stars separated by 28.7″. To my eye, this Iota group plus maybe a dozen mostly faint stars visible at 72× resemble a cluster, though no official cluster exists here. However, photographs show the bluish nebulosity NGC 1980 overlapping the group northwest of Iota.

Higher magnification unpacks a tightly spaced, uneven binary 20′ southeast of Iota. Designated **Σ754**, this tough tandem comprises 5.7- and 9.2-magnitude stars 5.3″ apart. My

**ALLURE OF THE SWORD** Few small areas of sky visible to mid-northern observers can match the asterism known as the Sword of Orion for sheer beauty. A variety of celestial attractions in the Sword show well in any telescope and even binoculars.

SEAN WALKER / MDWSKYSURVEY.ORG

plucky 4¼-inch can split Σ754 at 130× when the seeing is rock-steady. The slightly larger apo nails it perfectly at 100×, while the 10-inch Dob resolves it at 95×. In total, that's four star-pairs within ½° of one another!

About ½° north of the Trapezium, a 7th-magnitude star is flanked by 5th-magnitude 42 and 45 Orionis. These three markers, spanning 4.2′, essentially blot out **NGC 1977**, a broad yet very pale nebula. The foggy patch, together with much smaller NGC 1973 and NGC 1975, constitute the Running Man Nebula (also designated Sh2-279) — a moniker joyously conjured up by astrophotographers who can detect nebulous details invisible in city-based scopes. The "man" (running or not) eludes me on all but the clearest nights. Occasionally, the 10-inch might snag a leg or an arm when I attach a UHC filter to attenuate 42 and 45 Orionis. In any case, several faint stars scattered around the celestial jogger give this field a clustery feel.

Establishing the north end of the Sword is a loose open cluster called **NGC 1981**. Low magnification reveals a 25′-wide, east-west zigzag of eight stars ranging from 6th- to 8th-magnitude, plus at least half a dozen lesser ones. The three brightest members of NGC 1981 form a crooked north-south line. Northernmost in that line is the modest duo **Σ750**, whose 6.4- and 8.4-magnitude components are 4.2″ apart. The unbalanced binary shows well in all three scopes at around 100×.

## The Wide View

I like to complete a Sword session by returning to low magnification so I can admire the whole shebang in a single eyepiece field. Not many 2° swaths of sky are as spectacular as this one. The wide view in my 4¼-inch reflector at 22× is stunning. The refractor captures the full Sword beautifully at 30×, and the big Dob does likewise at 51×. (The same 30-mm wide-field eyepiece delivers all three magnifications.) Of course, that mighty Messier in the middle dominates the scene every time. But framing the entire glittering Sword in one go is always impressive and never disappointing. Orion's dazzling dagger is enticing in any scope!

Even after many decades as a deep-sky warrior, **KEN HEWITT-WHITE** couldn't brandish a sword if his life depended on it.

### Sword Census

| Object | Type | Mag(v) | Size/Sep | RA | Dec. |
|---|---|---|---|---|---|
| M42 | Emission nebula | 4.0 | 40′ | $05^h$ $35.3^m$ | –05° 23′ |
| Trapezium | Open cluster | ~4 | 47″ | $05^h$ $35.4^m$ | –05° 27′ |
| M43 | Emission nebula | 4.0 | 40′ | $05^h$ $35.5^m$ | –05° 16′ |
| ι Ori | Double star | 2.8, 7.7 | 12.5″ | $05^h$ $35.4^m$ | –05° 55′ |
| Σ747 | Double star | 4.7, 5.5 | 36.3″ | $05^h$ $35.0^m$ | –06° 00′ |
| Σ745 | Double star | 8.3, 9.4 | 28.7″ | $05^h$ $34.8^m$ | –06° 00′ |
| Σ754 | Double star | 5.7, 9.2 | 5.3″ | $05^h$ $36.6^m$ | –06° 04′ |
| NGC 1977 | Reflection nebula | — | 20′ | $05^h$ $35.3^m$ | –04° 49′ |
| NGC 1981 | Open cluster | 4.2 | 28′ | $05^h$ $35.2^m$ | –04° 26′ |
| Σ750 | Double star | 6.4, 8.4 | 4.2″ | $05^h$ $35.5^m$ | –04° 22′ |

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.

# Meteor Monitoring

With a simple video camera you can help study the origins of meteor showers.

**VULNERABLE CARGO** NASA astronaut Ron Garan snapped this shot of a Perseid meteor streaking through Earth's atmosphere on August 13, 2011. If a meteoroid were to strike an astronaut on a spacewalk, the consequences would be catastrophic.

NASA

Everybody enjoys a good meteor shower. But did you know that something as minuscule as a meteoroid can cause catastrophic damage if it slams into a spacecraft? That *may* be what happened to the satellite Olympus-1 in 1993 during the Perseid meteor shower, when it spun out of control. Engineers managed to stabilize the spacecraft, but the operation consumed so much propellant that they ultimately had to shepherd the satellite into the "graveyard orbit."

Imagine if that happened to a spacewalking astronaut. A millimeter-size meteoroid traveling at, say, the speed of a Perseid (around 60 km/s) would puncture a hole in our intrepid spacefarer's suit, too small to find before all the oxygen leaked out. Inevitably, the poor astronaut would suffocate.

It hasn't happened. Yet.

Statistics show there's a 1 in 5,000 chance during an eight-hour spacewalk that a meteoroid will strike an astronaut. That's during low-level activity. The risk increases during prolific showers. "That's very scary," says postdoctoral researcher Denis Vida (University of Western Ontario, Canada). In fact, NASA cancels non-critical spacewalks during times of heightened meteor activity.

But that's for *known* meteor showers. What about unforeseen events? Or sudden outbursts from the Old Faithfuls?

**Cameras and trajectories.** Vida has been fascinated by meteors ever since his astronomy club in Valpovo, Croatia (which he joined while in elementary school) obtained a video camera from a local meteor network. Video cameras are essential for calculating meteor trajectories, and the more cameras the better.

With trajectories we can better constrain meteor orbits and, through them, learn how meteor showers are created, estimate their ages, and understand their structures. For example, the origin of the Geminids is still a mystery. The parent body, the hybrid "rock-comet" 3200 Phaethon, isn't active enough to explain the current mass of the Geminids. By obtaining more precise orbits we might determine whether an impact blasted out debris. Or, does the asteroid cough out pebbles as its surface dramatically heats and cools over a day?

Systematically monitoring the near-Earth environment is a good way to start tackling these questions. But there was a fly in the ointment.

**Global Meteor Network to the rescue.** In 2015 Sony ceased manufacturing the sensors long used in meteor-monitoring cameras. Vida, high school student Dario Zubović, and (at the time) fellow PhD student Mike Mazur decided that something had to be done. Realizing that no software existed for alternative cameras, they set out to write their own. They made it open source so that it could run in *any* camera, on *any* operating system. And they proceeded to test it in a prototype camera in Ontario.

Initially pleased with the outcome, they desired wider feedback, so they advertised the camera on the popular amateur forum Cloudy Nights. Orders started flooding in — from New Mexico (a single order requested 14!), then Croatia, then Spain. Things really took off when the Winchcombe meteor sighting in February 2021 prompted requests for 200 cameras in the UK alone! Meteor networks weren't only local anymore — the Global Meteor Network had arrived.

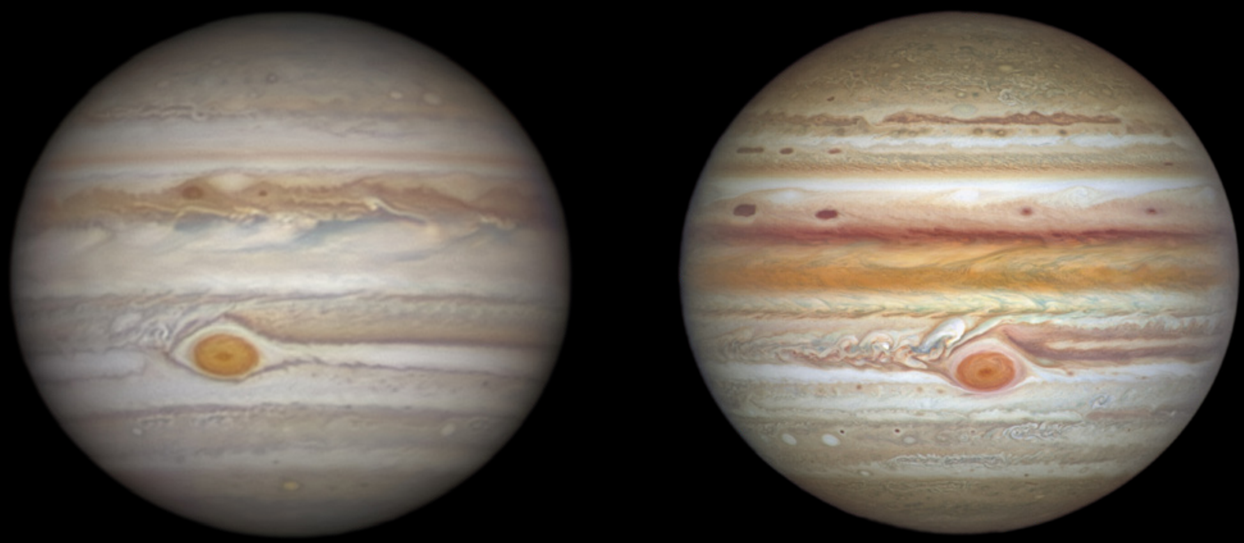
Vida and colleagues actively collect and analyze data from this network of cameras, which they release within 24 hours to meteor scientists and the general public, including amateur astronomers. The data will help scientists probe fundamental questions on the origins of meteors, as well as improve shower predictions, a vital factor in protecting spacewalking astronauts.

**Get involved.** Ready to contribute to a worldwide effort to track meteors? First, you'll need a video camera. If you enjoy tinkering with bits'n'bobs, you can assemble it yourself (a handy how-to guide is at **https://is.gd/GMNbuild**). Don't know a metal plate from a housing bracket? No fear, you can buy a ready-made camera (see options at **https://is.gd/GMNbuy**). You'll also need to set it up: **https://is.gd/GMNsetup**.

Vida says forget about installing the camera in a remote dark-sky site. Keep it nearby — if something goes wrong you can fix it promptly. The more fully functioning cameras there are, the better the trajectories can be constrained. "Our priority is to have 24-hour, continuous observation," he stresses.

Then all you need to do is sit back and enjoy. Everything is automated. You can watch the pictures come in or publish in amateur journals. Who knows, your data might one day save an astronaut.

■ Observing Editor DIANA HANNIKAINEN relishes meteor-shower watching.



# What Makes a Good Planetary Telescope?

The best optic for resolving fine detail has changed over time.

▲ **STUNNING RESOLUTION** Telescope aperture determines the smallest planetary features you can resolve, but only under the best seeing conditions. Damian Peach's image of Jupiter (left), taken with a 14-inch Schmidt-Cassegrain on May 11, 2018, captures many of the features recorded in Hubble Space Telescope images like the example at right taken on September 4, 2021.

The planets are the among the most rewarding targets for backyard telescopes, but they can also be the most challenging. Although planetary observing is all but immune to the effects of light pollution, it is particularly sensitive to atmospheric turbulence — what astronomers refer to as "seeing" — the principal enemy of telescope performance. Grappling with issues of optical design and thermal properties, aficionados strive for instruments optimized specifically for the task. In recent years, notions of what constitutes the best planetary telescope have embraced Voltaire's axiom "the perfect is the enemy of the good," often with surprising results.

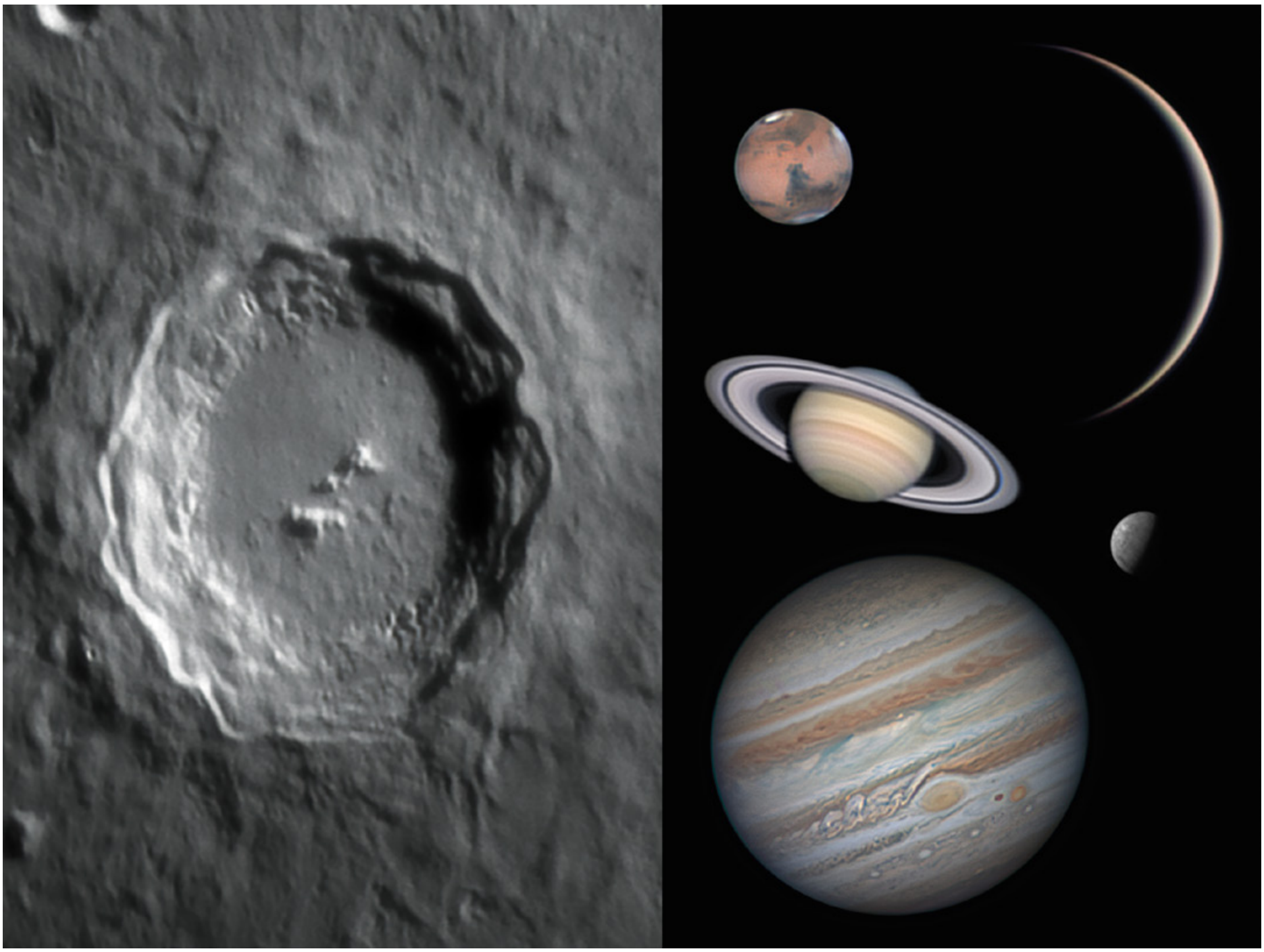
## Atmospheric Limitations

Historian and *S&T* Contributing Editor William Sheehan once compared planetary observing to "watching a motion picture in which the camera is out of focus except for an occasional sharp frame thrown in at random." We observe from the bottom of a turbulent ocean of air that's both the controlling and largely uncontrollable factor in determining the clarity of telescopic images. "The atmosphere," lamented French astronomer André Couder, "is the worst part of the instrument."

Unevenly heated from place to place, the atmosphere is filled with currents and eddies. Seeing is caused by moving cells of air at altitudes ranging from roughly 100 meters (328 feet) to more than 16 kilometers (10 miles). Because warm, rarefied air refracts light less than cool, dense air, these cells change the focal position of the image in a telescope by bending incoming rays of light differently. They have two distinct effects on a telescopic image. The image can be displaced laterally, causing it to move randomly around a mean position in the field of view. The image can also move inside and outside the telescope's focal plane, giving it an undulating appearance that's only intermittently unblurred. Both effects invariably occur in combination to some degree.

By keeping a patient vigil at the eyepiece, an observer can enjoy those magic moments that Percival Lowell called "revelation peeps." The human eye-brain combination is a remarkably powerful differentiating sensor that can reject poor images while retaining impressions of fleeting moments of clarity. That's why as recently as the late 1970s and early 1980s the eagle-eyed visual observer Stephen O'Meara was able to discover the ephemeral spokes in Saturn's B ring (*S&T:* Aug. 2022, p. 28) and determine the rotation period of Uranus (*S&T:* Sep. 2012, p. 54) using only a 9-inch refractor.

It wasn't long after the dawn of the 21st century that the unrivalled supremacy of the eye ended abruptly. Planetary observing was radically transformed in the span of only a few years by inexpensive webcams equipped with efficient sensors that took tens of frames every second, combined with free software like *Registax* that could automatically select and combine the sharpest ones. At the trifling expense of little more than $100, it suddenly became possible to capture planetary details beyond the grasp of even the most skilled visual observer using the same instrument under the same conditions. This paradigm shift gave backyard astronomers unprecedented opportunities to contribute to planetary science. Professionals soon began to increasingly rely on dedicated amateurs to monitor the planets, often in support of spacecraft missions.



PAIR OF JUPITERS: LEFT IMAGE: DAMIAN PEACH; RIGHT IMAGE: NASA / ESA, A. SIMON, M.H. WONG, OPAL TEAM; DISTANT TARGETS: SEAN WALKER / S&T

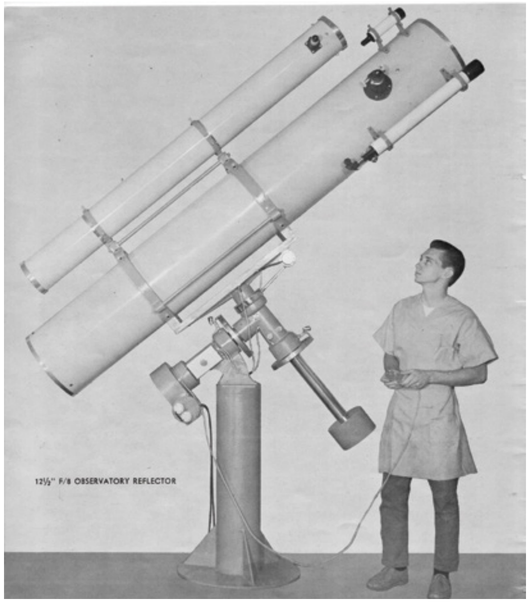
▲ **DISTANT TARGETS** The planets all appear smaller than large lunar craters. This composite shows the crater Copernicus and the major planets, all recorded at the same image scale through a 12½-inch Newtonian reflector.

## Size Matters, but How Much?

Well over a century and a half ago, planetary observers realized that a large telescope is no guarantee of better planetary performance, even if its optical quality is beyond reproach. Large apertures are disproportionately handicapped by atmospheric turbulence (*S&T:* Nov. 2018, p. 52).

Some of the world's finest locations when it comes to seeing are mountaintop observatories located where the laminar winds have crossed many miles of ocean. Even at sites like Mauna Kea in Hawaiʻi and La Palma and Tenerife in the Canary Islands, atmospheric turbulence on most nights limits resolution to 0.3 arcseconds, the theoretical resolving power of a 15-inch telescope. On rare nights, seeing can approach 0.15 arcseconds.

Instruments with apertures smaller than 8 inches are certainly capable of providing very satisfying views of the planets, but they fall short in terms of resolving power and image brightness, especially when used for imaging. A dim image requires increasing the exposure time, which blurs the resulting image more in typical seeing conditions. Under excellent conditions, a 10- to 14-inch instrument of high quality can capture at least 75% of what can typically be recorded on the brighter planets through even the largest ground-based instruments.




◀ **LONG TUBES** For generations, f/8 was the standard focal ratio for both commercial and homemade Newtonian reflectors. Their comparatively small secondary mirrors provided excellent contrast but came at a price. This 1970s-vintage Cave Optical Company advertisement for a 12½-inch f/8 Newtonian shows how massive and unwieldy these instruments became in moderately large apertures.

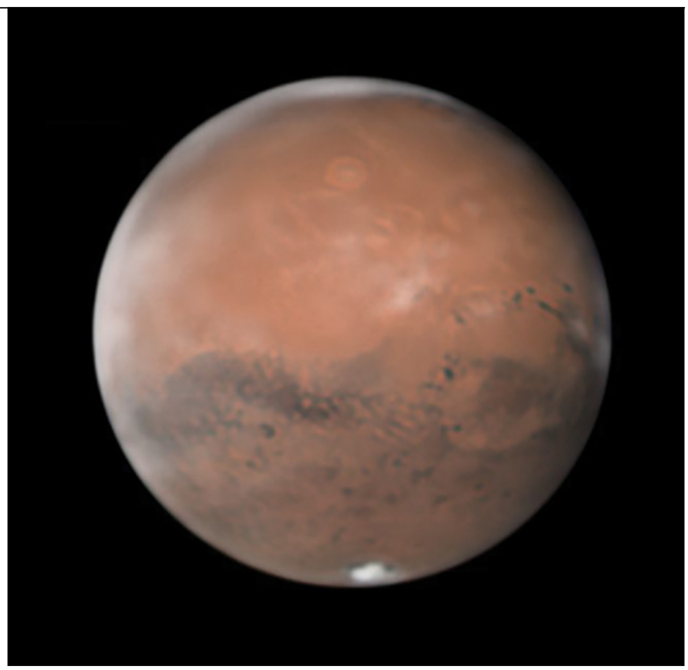
## A Question of Contrast

With the exceptions of the Cassini Division in Saturn's rings and the shadows cast by Jupiter's Galilean satellites, planetary features are subtle, low-contrast shadings colored in delicate, pastel hues. Consequently, generations of ardent visual planetary observers favored optical designs that maximize image contrast — refractors, long-focus Newtonians, and even exotic, tilted-component telescopes like the schiefspiegler.

In any telescope, the image of a point source of light like a star is a diffraction pattern consisting of the Airy disk (named after English astronomer George Biddell Airy) surrounded by a set of concentric, faintly luminous diffraction rings. In an optically perfect, unobstructed telescope (such as a refractor), the Airy disk contains 84% of the total light in the image, and the remaining 16% is distributed into the diffraction rings.

Introducing a central obstruction 20% the diameter of the aperture (the typical size of the diagonal mirror in an f/6 to f/8 Newtonian reflector) redistributes light in the diffraction pattern, reducing light in the Airy disk to 76%

▼▶ **SHORTER, FASTER** Despite its large secondary mirror, Anthony Wesley's 16-inch f/4 Newtonian reflector has captured some of the finest images of the planets ever taken from Earth. His remarkably detailed image of Mars at right was recorded on October 4, 2020.



LONG PLANETARY SCOPE: CAVE OPTICAL / PUBLIC DOMAIN; MODERN NEWTONIAN AND MARS: ANTHONY WESLEY


**CONTRAST REDUCTION** The secondary mirror in Newtonian and Cassegrain optical systems redistributes light from the Airy disk into the diffraction rings, reducing the contrast of planetary features. The above simulation created in the program *Abberator* shows the diffraction patterns of an unobstructed telescope at left compared to scopes with 20% and 33% obstructions.

while the increasing light in the diffraction rings to 24%. A 33% central obstruction (a typical size for the secondary mirror of a Cassegrain reflector and its catadioptric cousins, the Schmidt-Cassegrain and Maksutov-Cassegrain) reduces the amount of light in the Airy disk to 68% while increasing energy in the diffraction rings to 32%. The effect is similar to a wavefront error of ¼-wave, the so-called Rayleigh Criterion for diffraction-limited optical quality.

Increasing the amount of light in the diffraction rings doesn't have a dramatic effect on stellar images. But it does reduce the contrast of features in the extended image of a planet, which consists of a mosaic of minute points of light, each one the size of the Airy disk. Over these points, a thin veil composed of the combined faint light of the diffraction rings is superimposed. More light in the diffraction rings means reduced image contrast.

Volumes have been written about the evil effects of central obstruction, but there is surprisingly little agreement about their severity, even among optical experts. Laboratory experiments using greyscale test charts suggest that the decrease in image contrast produced by a 20% central obstruction is perceptible but not objectionable. Above 40% there is a universal consensus that it poses a serious handicap.

In 1993 optical engineer William Zmek published a comprehensive mathematical analysis of the effects of central obstruction on planetary images (*S&T:* July 1993, p. 91, and September 1993, p. 83). He concluded that "the performance of a centrally obstructed telescope on low-contrast detail is the same as that of an unobstructed telescope of somewhat smaller diameter."

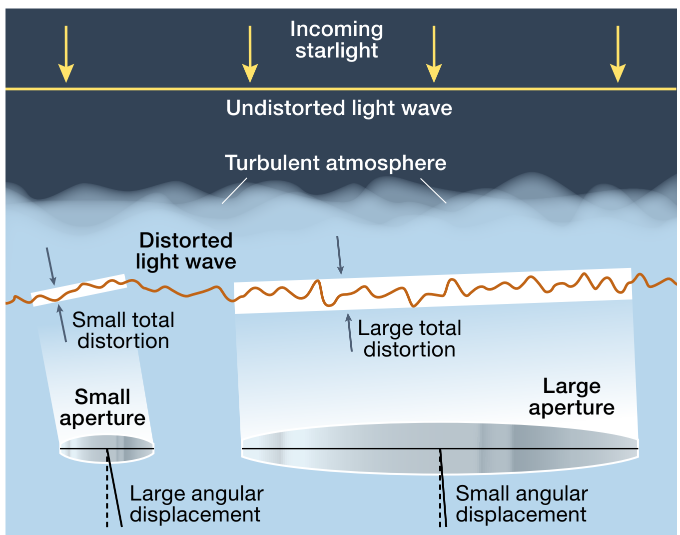
Zmek proposed that when it comes to contrast performance, the effective diameter of a planetary telescope equals its clear aperture minus the diameter of its central obstruction. According to this rule of thumb, a 10-inch telescope with a 3-inch obstruction will perform the same on the planets as a 7-inch unobstructed telescope of equal optical quality.

How does this theory hold up under real-world conditions? To many it's unduly pessimistic. Veteran observer Roger Gordon notes that, according to Zmek's rule, a 7-inch Questar Maksutov-Cassegrain with its 2.4-inch (34%) central obstruction should only be equivalent in planetary performance to an unobstructed 4.6-inch instrument. Yet in side-by-side comparisons with a fine 6-inch refractor, Gordon found delicate Martian surface features equally visible in both scopes.

The size of a telescope's central obstruction is less of a concern for imagers than for visual observers, because image-processing software makes it possible to increase contrast and color saturation with a computer keyboard. The comparatively small number of high-resolution planetary images taken through 8- to 10-inch apochromatic refractors — instruments long regarded as the ultimate planetary telescopes by many visual observers — aren't discernibly better than images taken through more affordable telescope types of the same aperture.

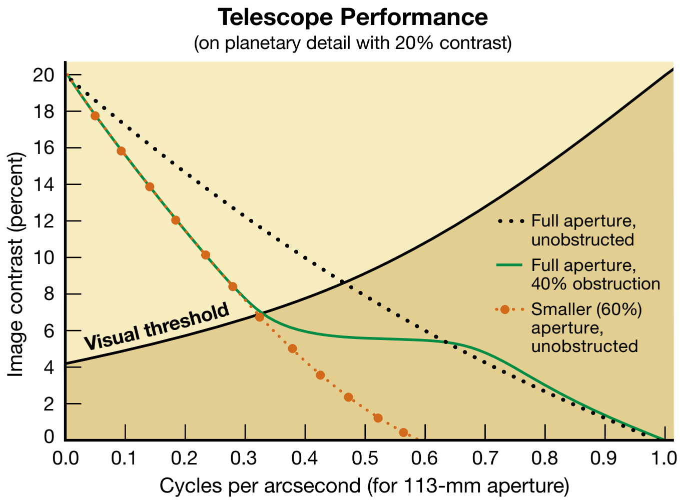
## Thermal Considerations

The performance of any telescope can also be degraded by its own thermal properties. At most locations, the temperature on a clear evening falls at a rate of 2° to 3°C (3° to 5°F) per hour. When a mirror is warmer than the surrounding air, it produces a thin, turbulent boundary layer of warm air just




▲ **SCINTILLATING SKIES** The effects of atmospheric seeing on small and large telescopes is shown here. Light arriving from the target (a planet or star) is distorted by the turbulent atmosphere. When the distorted wavefront enters a telescope, its average "tilt" determines the target's position, while the total range of distortion influences the blurriness of the view. A small-aperture telescope suffers a larger displacement but less distortion, so the target appears relatively sharp but dances around. A large telescope displays a blurry view that remains relatively stationary.

STAR SIMULATIONS: *ABBERATOR*; SEEING ILLUSTRATION: GREGG DINDERMAN / *S&T*




▲ **PLANETARY PERFORMANCE** The graph above shows the image contrast of typical planetary features as seen in a telescope with a central obstruction 40% of the diameter of the primary mirror. The red dotted line depicts the contrast in a smaller, unobstructed telescope. The visibility of low-contrast features in the smaller instrument (in the region above the visual threshold) is nearly identical to the larger obstructed one.

above its surface that can blur the image every bit as much as turbulence thousands of meters overhead. French master optician Jean Texereau determined that a thermal gradient of only 0.13°C along a one-meter light path degrades the wavefront error of a telescope by ¼-wave.

The use of a fan to sweep away the boundary layer and accelerate mirror cooling was pioneered in the 1920s by William Henry Pickering while observing with a 12-inch Newtonian. He reported that with "with poor seeing due mainly to currents in the upper air the resulting improvement is not marked, but with good seeing it is most striking."

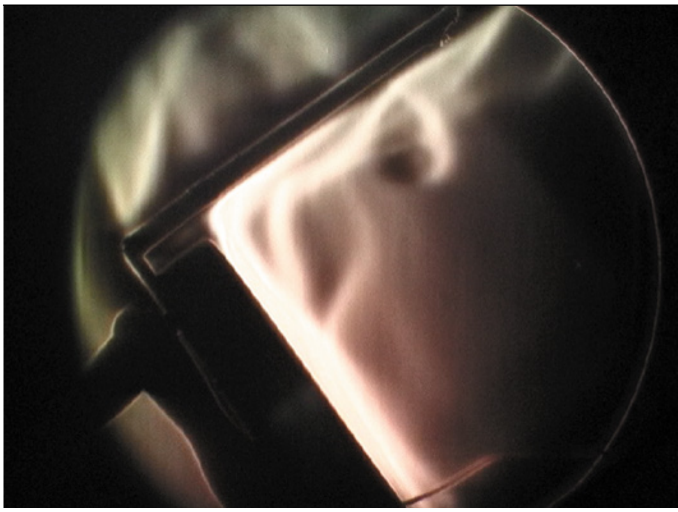
The airflow provided by a fan makes the air mass throughout the light path more thermally (and hence optically) homogeneous. Convection produced by heat exchange along the inner walls of a telescope's tube is also a source of turbulence in the light path, which a fan can eliminate. Additionally, ventilation improves the performance of closed-tube systems like SCTs and Maksutov-Cassegrains. Today, cooling fans are integral components of several commercial telescopes as well as popular aftermarket accessories.

The thickness of the primary mirror plays a large part in its ability to perform to its full potential. For well over a century, most Newtonians employed primary mirrors with a thickness-to-diameter ratio of 1:6. While these "full thickness" mirrors were relatively easy to support mechanically, their sheer mass and thermal inertia resulted in prohibitively long cool-down times with optics thicker than about 2 inches. In recent years, thinner primary mirrors with a thickness-to-diameter ratio of 1:10 to 1:15 have come into widespread use. Combined with fans, they have largely overcome the Newtonian reflector's principal shortcoming — thermal equilibration.

## Which Way Is Up?

The direction of "up" isn't usually important in astronomy — there is no "up" in space. However, for planetary observers and imagers, the altitude of a planet affects the image that any telescope produces. Earth's atmosphere acts like a weak prism when observing targets moderately low in the sky, smearing the light of the target into a tiny spectrum — a phenomenon known as *atmospheric dispersion* (*S&T:* Aug. 2003, p. 124). This effect occurs across the entire disk of the planet, effacing minute detail. Atmospheric dispersion is perceptible at altitudes of up to nearly 60° above the horizon.

Fortunately, visual observers and imagers alike can tune



▲ **THERMAL PROPERTIES** Cooling primary mirrors produce a boundary layer of warm air (seen here edge-on in a Schlieren image) that persists as long as there is a temperature difference between the glass and the surrounding air. This rising plume of warm air also flows along the tube, producing tube currents.

▲ **TECHNOLOGICAL ASSIST** Many companies offer fans and other accessories to shorten the time it takes for the optics to reach ambient temperature. Fans also inhibit dew formation because they prevent the mirror from cooling below the dewpoint temperature.

TELESCOPE PERFORMANCE: GREGG DINDERMAN / *S&T*; THERMAL IMAGE OF MIRROR: BRYAN GREER; MIRROR FAN: CELESTRON out the effects of atmospheric dispersion by using a small device called an atmospheric-dispersion corrector (ADC). An ADC fits into a telescope's focuser and incorporates a pair of wedge prisms in an adjustable housing. Changing the orientation of these prisms cancels out prismatic dispersion.

These fairly inexpensive devices can be essential to getting the best views and images from locations far from the equator where the ecliptic is low in the sky. But the key to their use is they must be oriented parallel to the horizon. This alignment is simple with catadioptric telescopes, in which the focuser is at the back of the telescope. Users of Newtonian reflectors, in which the focuser is seldom parallel to the horizon, find it more difficult to determine which way is up through their telescope to align the ADC precisely.

◀ **PLANETARY MASTER** Damian Peach of the United Kingdom is possibly the most talented planetary imager today. He images the planets primarily with a Celestron C14 Schmidt-Cassegrain. The C14's secondary mirror produces a 32% obstruction yet doesn't detract from the quality of his work, like the example seen on page 58.

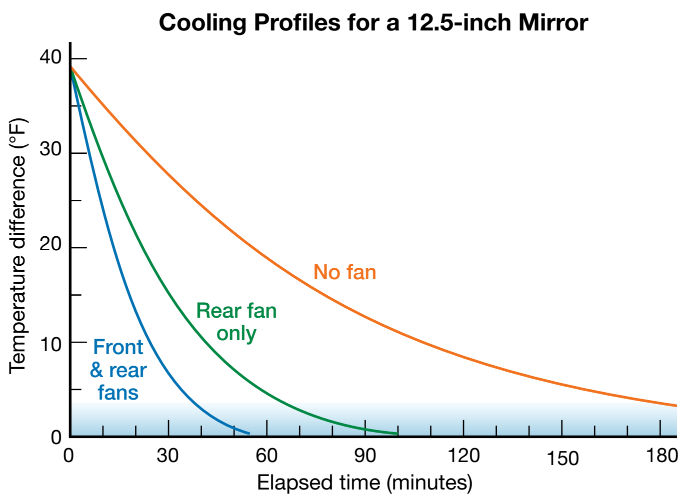
## So Which Is Best?

In a marketplace dominated by extremely compact catadioptric telescopes, fast focal ratios of about f/5 have become the norm for the current generation of large commercial Newtonian reflectors. Such steep light cones are often fitted with larger diagonal mirrors and are far more sensitive to miscollimation than the classic f/8 Newtonian and were long regarded as ill-suited to planetary work. But in the hands of skilled amateurs like Anthony Wesley and Trevor Barry, fast Newtonians regularly capture superb images of the planets.

Despite their compactness, portability, and affordability, Schmidt-Cassegrain telescopes (SCTs) were long viewed with disdain by planetary observers. Detractors were quick to point out their large, contrast-robbing central obstructions and sensitivity to even a slight loss of collimation. However, these failings paled in comparison to their variability in optical quality, particularly during the latter half of the 1980s. While some good specimens were produced, it was very much a hit-or-miss affair. During the late 1990s, both the optical quality and the consistency of SCTs improved dramatically due to better fabrication techniques, more stringent quality control, and increasingly sophisticated consumers. Today, SCTs are employed by many of the world's leading planetary imagers, notably Damian Peach and Christopher Go. Their work has dispelled any notion that SCTs are ill-suited to planetary work.

The advent of video imaging irrevocably changed planetary observing and relegated visual observers to the status of telescopic tourists in many ways. While long-focus Newtonians and refractors are destined to remain the choice of discriminating visual observers, the most successful solar system imagers today use telescopes that were widely regarded as unacceptable compromises a generation ago. By taking great pains to ensure that their instruments are precisely collimated and in thermal equilibrium with their surroundings, they routinely achieve astonishing results that were the stuff of dreams only a generation ago.

■ Contributing Editor **TOM DOBBINS** has watched the popularity of several telescope designs rise and fall over the past five decades.




▲ **FASTER COOLING** Newtonian primary mirrors benefit greatly from having fans blowing on both their rear and front faces. Using a single fan blowing on the rear of the mirror, this 12.5-inch-diameter, 2-inch-thick Pyrex mirror sheds heat twice as fast. Adding a second fan blowing across the front of the mirror cuts the time to less than 60 minutes.

▶ **DISPERSION CORRECTION** Tools like ZWO's atmospheric-dispersion corrector (ADC) allow planetary observers and imagers to enjoy color-fringe-free views of the planets low to the horizon by tuning out the prismatic dispersion introduced by Earth's atmosphere.

PEACH: DAMIAN PEACH; COOLING GRAPH: GREGG DINDERMAN / S&T; ADC: ZWO

# Sharpstar's Mark III German Equatorial Mount

*This lightweight mount with a high load capacity can serve many needs, but is it right for you?*


◀ Sharpstar's Mark III German equatorial mount and optional tripod form a highly portable system for use in the field. The mount is shown here with its 5 kg counterweight, which wasn't actually required for this telescope since it is lighter than the 22-kg limit the mount can handle without a counterweight.

ALL PHOTOS BY THE AUTHOR

## Sharpstar Mark III

U.S. Price: $2,899 mount, $499 optional tripod

Sharpstar-optics.com

### What We Like

Extraordinarily rigid mount

Often no need for a counterweight

Zero-backlash drives

### What We Don't Like

Relatively slow slewing

Unusually short cables

**IT SEEMS LIKE HARDLY** a month goes by when there isn't a new telescope mount debuting on the market. One of the newest to appear is the Color Carbon Mark III German equatorial from the Chinese manufacturer Sharpstar. From the outside, the Mark III looks like your typical German equatorial mount, but there are many aspects of it that are different — and in some cases, very different. Let's start with a big one.

The Mark III is by far the most rigid mount I have ever used in its weight class. It's almost an unnatural (but certainly welcome) feeling to reach for the focus knob of a telescope on the Mark III and not have the image shake at least a little. It almost feels as if the telescope is bolted to a granite block rather than a tracking mount. And this is for an equatorial head that weighs only 7.6 kilograms (16½ pounds) but has an impressive load capacity of 22 kg without using the supplied 5-kg counterweight, and 28 kg with the counterweight.

There was a sense of the Mark III's rigidity even as I lifted it from its shipping box. It's intuitive that a German equatorial mount has two moving axes, but there was no hint that anything about the Mark III was movable. The reason being that, rather than the worm-gear drives typically used in today's telescope mounts, the Mark III's axes are driven with strain-wave gears, often called harmonic drives. (Harmonic Drive is actually a registered brand name that's worked its way into the world of geek speak the same way that Band-Aid has become synonymous with any adhesive bandage.)

Strain-wave gears are noted for their zero backlash and extremely high torque (the force that turns a shaft) — both features that are very desirable for a telescope drive. Instead of wasting a lot of words explaining how strain-wave gears work, it's better that I point you to the internet where there are scores of videos. One I especially like is on the Harmonic Drive website (**harmonicdrive.net**). Click on the Technology pulldown menu at the top of the page and select HarmonicDrive®. There you'll find nice descriptions, diagrams, and a very cool video.

There is a price to pay, however, for the advantages of the strain-wave drives in the Mark III mount. One is the relatively slow default slewing speed of 2° per second (it can be increased to a maximum of 4° per second, but only for lightweight, compact telescopes). There are also no clutches or manual controls of any kind — the only way you can move the mount is to have it powered up and running. Lastly, there are some important considerations for imaging, but more about this later.

◀ The Mark III's hand control includes the mount's power input port (lower left) as well as the USB 2.0 input (lower right) for controlling the mount with planetarium and autoguiding software using an external computer. Because it lacks a number keypad, data entry is done with an unusual scrolling procedure described in the text.

## Initial Setup

The Mark III ships fully assembled, and if you order the optional tripod ($499) with the mount you need only set the equatorial head on it and tighten two bolts. Nevertheless, there are a few things that should be done first indoors with good lighting. One is setting the altitude adjustment bar for your latitude range. The setscrews that secure this bar (as well as its mating hex wrench) are extremely small and would be easily lost if dropped on a grassy surface. There are also very small 10-pin connectors for the hand control and a cable that goes between the right-ascension and declination housings. While both connectors are keyed and can only be inserted one way into their respective sockets, it takes a bit of gentle finessing to get them properly seated.

While on the topic of cables, the ones supplied for the hand control and various power supplies are rather short, all being well less than a meter in length. Finding extension cables for the power supplies is easy, but certainly not so for the 10-pin cable on the hand control. I should also point out that there is no guiding port on the equatorial head. All computer connections to the mount have to be made via either an ad hoc Wi-Fi connection or a USB 2.0 cable that plugs into the hand control. I tested both and had no problems operating the Mark III as an ASCOM mount with Software Bisque's *TheSkyX* planetarium program and Stark Labs's inspired *PHD2* autoguiding software, even with both running simultaneously over the single USB cable.

The optional carbon-fiber tripod weighs barely 5 kg and is notably rigid. It stands 81 cm tall, but the legs are not adjustable beyond the threaded feet, which can extend up to about 25 mm

▲ Small things matter. Several aspects of the Mark III's initial setup are best done indoors with adequate lighting. The tiny setscrews that secure the latitude adjusting bar (left) could be easily lost if dropped in the grass. The small 10-pin connector for the hand control (center) required a bit of gentle finessing to insure it was properly seated in its socket on the mount. The internal battery holder for the hand control's clock (right) has a small on/off switch, which is easily seen in this photo but which the author missed when first setting up the mount.

to aid with leveling. The tripod's height is okay for most Newtonian reflector scopes and seated observers using Cassegrains, but it's a bit short for modest-length refractors such as the one pictured on page 64, since the eyepiece is low to the ground when observing at high altitudes.

The Mark III's mounting saddle accepts both Vixen- and Losmandy-style dovetail bars, and as implied above there's no need for the 5-kg counterweight for scopes weighing less than 22 kg, thanks to the high torque of the strain-wave drives. But the counterweight does reduce vibration damping times, especially for setups that approach the weight limit.

## Hand Control

The Mark III's hand control is significantly different than ones I've used before, but if you plan on running the mount with a computer, the only time you'll have to deal with the hand control is during its required setup, which needs to be done just once since the hand control has a very good battery-powered internal clock that maintains the time, and site information (latitude and longitude) are stored in its permanent memory.

As with other hand controls that lack a numeric keypad, setting information requires scrolling. But here's where the Mark III is different. Rather than selecting each digit of a value to be entered and scrolling through the numbers 0 to 9, you scroll through the whole value. For example, setting the time on other hand controls without a number keypad typically involves selecting six digits (two for hours, two for minutes, and two for seconds) and setting each with a separate scrolling procedure. With the Mark III, however, you scroll through the whole six-digit displayed time at once. A quick click of the forward or reverse buttons changes the seconds, while a longer click starts the seconds flying by and the minutes changing. Longer still and the minutes and seconds fly as the hour value changes. The high-speed scrolling makes it easy to overshoot your mark even with the fastest hand-eye coordination, so you'll then have to start scrolling in the reverse direction. Nevertheless, once you get the hang of it, you can zero in on your target value quickly and maybe even a bit faster than if you had to scroll through each digit entry separately.

While it will be a moot point for those controlling the Mark III with planetarium software, accessing the numerous object catalogs contained in the hand control's database also involves scrolling, which can be a bit tedious for the larger catalogs. The bright-star catalog is also a bit different in that it steps through the included stars (in magnitude order) of each constellation organized in alphabetical order. Thus, to select Rigel you scroll through the constellations until you reach Orion and then scroll to Rigel. You'll need to know beforehand the three-letter abbreviation for your star's constellation as well as the star designation, which will be displayed by its Greek letter and often also common name. It's a fine way to list the stars, but it's also different from hand controls I've used before.

With my growing enthusiasm for double-star observing, I was pleased to find the Mark III's star catalogs included separate listings for selected STF doubles discovered by Friedrich Georg Wilhelm


◀ A machined tab on the back of the hand control slips into slots on the tripod leg braces to create a convenient, out-of-the-way place to store the hand control, especially when controlling the mount via an external computer.


▶ *Left:* The Mark III's hand control, AC power supply, and voltage booster all have rather short cables less than a meter in length. As such, care is needed when holding the hand control to avoid accidentally pulling the power cable out of its socket. Because the mount runs on 24-volt DC power, it comes with the booster for use in the field, where observers typically use 12-volt batteries. *Right:* The author evaluated the Mark III's performance as an astrophotography platform using this setup, with the mount attached to a pier in his backyard observatory.

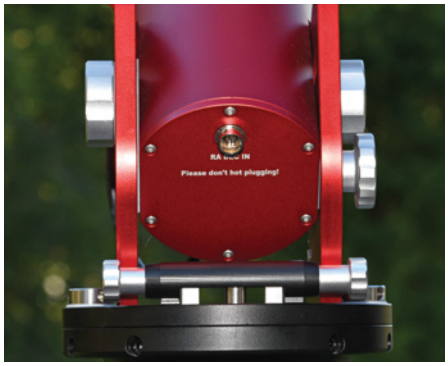
von Struve and STT doubles discovered by his son Otto Wilhelm von Struve.

## Imaging

For those looking at the Mark III as an imaging platform, there are a few things to consider. As mentioned before, the strain-wave drives have zero backlash, which is an incredible advantage for guiding the mount whether you're old-school and do it manually (I did it just for fun) or autoguide. And in the case of autoguiding, you must use a system that controls the mount through its Wi-Fi or USB computer connection, as there is no ST-4-compatible-guiding port on the mount or hand control. I had excellent success using *PHD2* mentioned earlier (downloaded for free from **openphdguiding.org**), which was all the more noteworthy because I had no prior experience using the software.

The bigger issue with using the Mark III for deep-sky imaging is its periodic error. Like traditional worm gears, strain-wave gears have inherent periodic error — a repetitive departure (fast and slow) from the constant speed that the mount's polar axis would turn if it perfectly tracked the sky. The repetitive cycle time for the Mark III's periodic error is 435 seconds, which is a comfortably slow cycle for guiding. But the total error is almost 2 arcminutes. This is a lot by today's standards for high-end mounts, but it's about the same error that my Vixen GP-DX German equatorial had, and that mount served me well as a portable imaging platform for many, many years.

Here's where a little number crunching will help you decide if the Mark III will work for your imaging needs. On multiple nights I measured the periodic error, peak to peak, as 119 arcseconds. It takes 435 seconds to smoothly go from one peak to the other and back to the start, which works out to 238 arcseconds of travel in 435 seconds, or just a touch more than 0.5 arcsecond of tracking error per second. I had no problems autoguiding the mount using 1-second exposures for the guiding camera. This kept the mount easily within the 2-arcsecond seeing that I



▲ The two silver knobs at the base of the equatorial head are used to adjust the mount's azimuth during polar alignment. The only external connection to the mount is the 10-pin socket seen here for the hand control.

typically experience on good nights. Indeed, it almost always stayed within the seeing-limited resolution of my imaging systems using autoguiding exposures of 3 and 4 seconds.

So, the bottom line for imaging is that the Mark III should serve for all but the most critical high-resolution, long-exposure applications as long as you autoguide. That said, you will also have to resort to guiding the mount for all but very brief exposures made with short-focal-length setups. For the record, I did most of my imaging tests at a focal length of 1,100 mm and autoguiding exposures of 3 seconds and shorter. Very few of my exposures lasting as long as five minutes showed elongated stars.

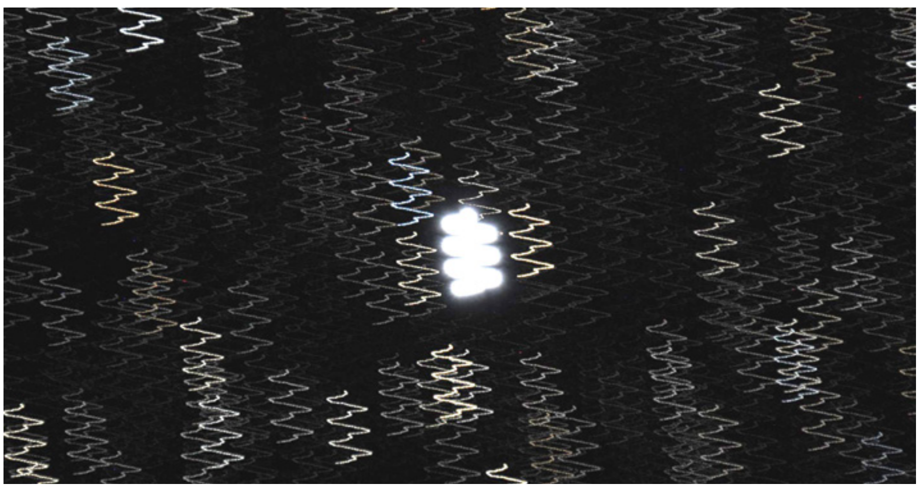
## Summing It Up

For visual observing the Mark III is really a joy to use. I was constantly taken by how much the mount's rigidity made it a pleasure to focus a scope at high magnifications when observing double stars. The relatively slow slewing wasn't an issue, since I often observe in just one part of the sky for extended periods. And once I got used to the novel aspects of the hand control, I enjoyed the freedom of using it alone rather than adding a computer to the setup. I ended up being pleasantly surprised by just how many of the things I wanted to look at were included in the mount's object databases.

For imaging, the mount's periodic error at first seemed like a handicap, but experience proved that autoguiding worked perfectly for just about any imaging setup that would be reasonably used with a mount in this weight category.

The Mark III and its tripod will serve many as a highly portable, lightweight setup for use in the field.

■ **DENNIS DI CICCO** lives under the ever-increasing light pollution of Boston's western suburbs.



▲ By offsetting the polar axis of an equatorial mount to the east of the celestial pole, stars drift southward in a camera's field of view as the mount tracks the sky. As such, a time exposure will record the drifting stars as perfectly straight lines only if the drive rate is also perfect. Any periodic error in the drive rate will cause the stars to zigzag perpendicular to the drift direction. This 24-minute exposure of the starfield around Altair shows that the Mark III's periodic error is continuous and smooth, with the exception of one small hiccup, during the drive's roughly 7-minute repeating error cycle. More details of this error and its consequences are given in the text.


### ◀ MOTOR DRIVE

Add hands-free tracking to your Orion StarBlast II EQ Reflector. The Orion TD-1 Electronic DC Tracking Drive for StarBlast 4.5 EQ ($69.95) connects to the right-ascension gear on your telescope's mount to provide sidereal tracking of targets. The drive unit includes a hand control with 2× and 4× slewing speeds plus a pause mode to aid when centering objects in the eyepiece. The TD-1 includes a clutch release to allow use of the mount's manual controls when desired. It functions in both the Northern and Southern Hemispheres and is powered by eight AA batteries (not included).

**Orion Telescopes & Binoculars**
89 Hangar Way, Watsonville, CA 95076
831-763-7000; telescope.com

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### ◀ STRAIN-WAVE MOUNT

Mount manufacturer iOptron expands its line of hybrid equatorial mounts. The HEM44 ($2,698) combines a high-torque strain-wave drive into the right-ascension axis with a worm-and-belt system on the DEC axis to achieve precision slewing and tracking throughout the sky. The mount head weighs just 6.2 kg (13.65 lb) yet boasts a load capacity of 20 kg without the need of cumbersome counterweights and shafts. The HEM44's electronic-friction-brake system and power-down memory safely stop the drives and resume tracking after an abrupt power loss — no need to realign after a restart. It comes with iOptron's powerful Go2Nova hand controller that includes more than 212,000 objects in its internal database. Its black, CNC-machined casing encloses all wiring, and telescopes are secured with a dual Losmandy/Vixen-style saddle plate. An advanced HEM44EC model with precision encoders and built-in iPolar alignment system is also available for $4,148. Each purchase includes a soft carry case and a limited two-year warranty.

**iOptron**
6F Gill Street, Woburn, MA 01801
781-569-0200; ioptron.com

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### ◀ CAMERA ADJUSTERS

ASG Astronomy introduces a modular camera-tilt adjuster for round camera bodies. The Photon Cage (starting at $649) provides precise tilt and back-focus adjustments for cylindrical camera bodies 77 mm and 90 mm in diameter. The device offers easy access to four corner-tilting screws with 120-tpi-thread pitch, allowing users to dial in pinpoint stars across the detector's field of view, particularly when paired with Celestron's 8- and 11-inch Rowe-Ackermann (RASA) astrographs. The device also adds 5 mm of fine-focus adjustment. The Photon Cage's modular design permits use of the company's filter-slider system to enable tri-color photography with monochrome cameras within the limited back focus of Celestron's RASA system.

**ASG Astronomy**
4212 SW Kirk Ave., Pendleton, OR 97801
541-310-0985; asgastronomy.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 3D-Printed Hadley Telescope

*Here's a DIY project for the 21st century.*

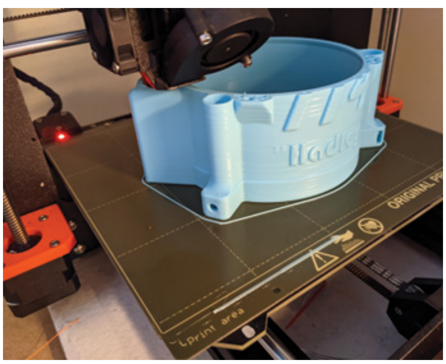
**IN OUR NOVEMBER 2021** issue I wrote about whether it was cheaper to build or buy a telescope, concluding that the break-even point was somewhere around 8 inches of aperture. Bigger than that, it was cheaper to build, but for smaller telescopes it was cheaper to buy.

I didn't reckon with the dramatic rise in telescope prices during the COVID epidemic, nor with Texas amateur Jonathan Kissner and his "Hadley" telescope. Jonathan has come up with a 4½-inch f/8 design that can be built for about $125, far cheaper than a comparable commercial scope.

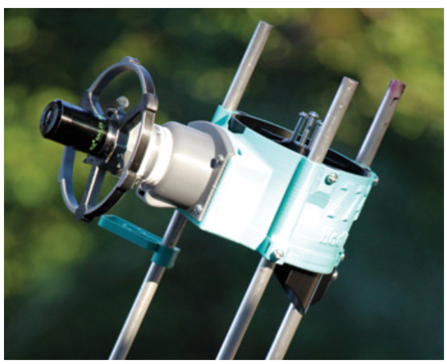
What's the secret? 3D printing. Almost everything that requires any skill to fabricate or assemble can be 3D printed with templates that Jonathan has made freely available online.

This isn't the first 3D-printed telescope to come down the pike. What's different about the Hadley (named after British astronomer John Hadley, who created the first truly useful reflecting telescope)? As Jonathan explains it, "Most free plans for 3D-printable telescopes are complicated. Tons of parts to print (one has 92!), dozens of types of screws, nuts, and springs, and big, unoptimized structures that waste time and plastic." The Hadley was designed to be painless to print, with what Jonathan calls "conscientious topology" — attention to footprint, minimizing volume and surface area, avoiding creep, managing overhangs, etc. The Hadley requires no sacrificial support material, no heat-setting inserts, no need to tap threads into the plastic, and no gluing (except for the mirrors to their supports). Jonathan says, "I think my design philosophy is reflected in the focuser, which is just a large, printed screw with a big wheel for added granularity. All it needs is a nut and a thumbscrew."

The Hadley is designed around the ubiquitous spherical, 114-mm-aperture, 900-mm-focal-length primary mirror, which can be found in countless equatorially mounted telescopes in closets or online for about $20. At f/8, a 114-mm spherical mirror is well within quarter-wave tolerance, so you don't have to pay for parabolization, the most expensive



▲ The parts are optimized for easy printing. There are no sacrificial supports, no long bridges, and no need for heat-set inserts.



▲ The helical focuser has a distinctive wide grip ring for fine motion. Also note the 3D-printed finder attached to the truss pole.

▲ Jonathan Kissner with his 3D-printed Hadley telescope.

JONATHAN KISSNER (3)

aspect of a primary mirror.

Not all the parts are printed. The OTA is a truss design, using aluminum poles bought at a hardware store. Some screws are required, but there are only three lengths to deal with and all are 10-24 machine screws, with corresponding nuts that fit into hexagonal pockets within the printed parts. You'll also need to buy some springs and some silicone glue to hold the mirrors in place.

The rocker box is made of plywood, like any conventional Dobsonian. Why not printed? Because printing the equivalent of five big slabs of plywood would be a huge waste of plastic. With a plywood rocker, the builder only needs to buy one spool of their favorite color filament, plus some black for the focuser, light baffle, and a few other minor parts that should be dark.

There's even some room for customization. Jonathan says, "One of my proudest little features is letting the user choose how the diffraction spikes appear." He provides templates for several different spiders, emulating the James Webb Space Telescope, the Hubble, or curved spiders that don't produce spikes and give you that great refractor-like view. There's an interface for tube rings if you want to mount the scope equatorially, and an optional altitude-bearing interface with embossed planets drawn by his friend Andy Cheng. Remix culture being what it is, many dozens of other tweaks have appeared, many of which were already on Jonathan's to-do

▲ The parts for a Hadley scope are simple, elegant, and easy to assemble.

JONATHAN KISSNER

list. These include different focusers, motion-control knobs, lens caps, and dovetail shoes for finderscopes.

Assembling the thing is IKEA easy. And when you're done, the scope performs beautifully. Motions are smooth in both axes, and Jonathan reports, "With a tiny Meade 4.7-mm UWA eyepiece I've seen Saturn at 192×. The Cassini Division, the shadow of the rings, and the atmospheric bands were readily apparent. It's sufficient to see the Great Red Spot on Jupiter, and the Moon is always great at any magnification."

There are already 40+ adopters of the Hadley design, and those are just the ones who have posted theirs online. This is clearly an idea whose time has come, and Jonathan has created a wonderful realization of it. If you have a 3D printer or don't mind jobbing it out to a commercial printer, you can create one, too.

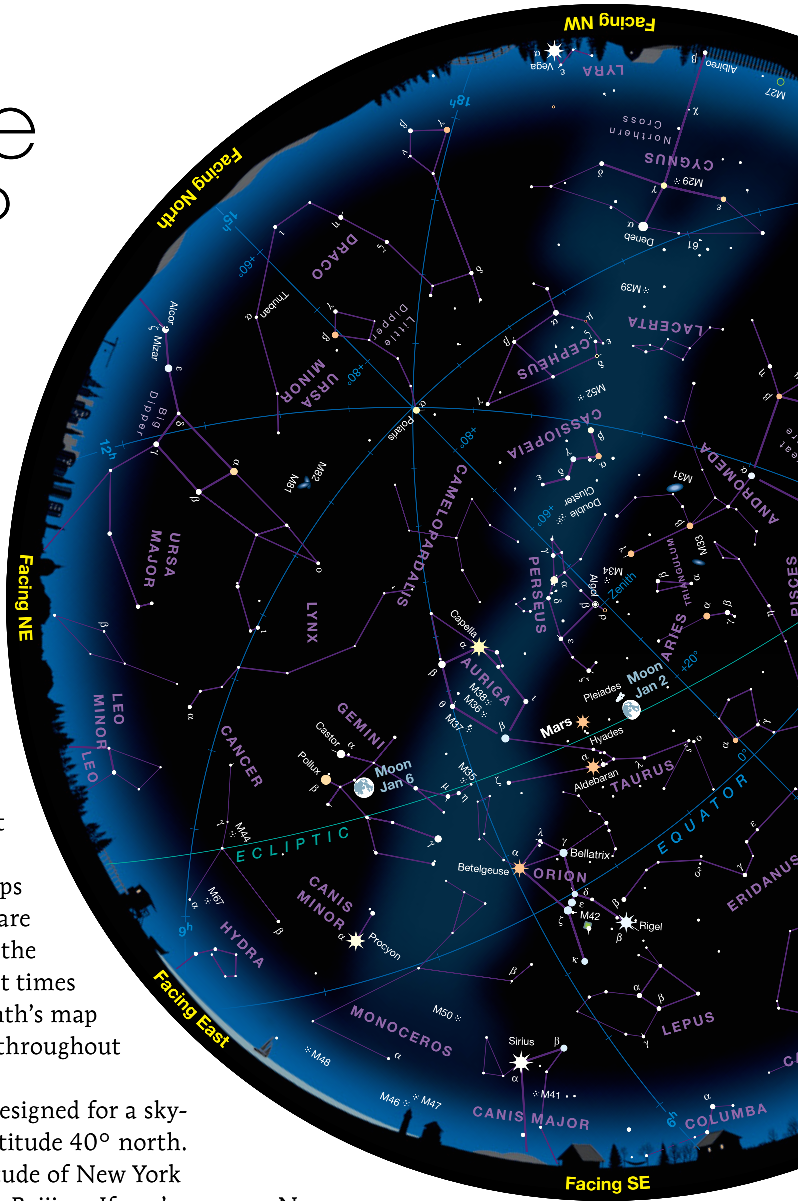
For more information, visit the Hadley site at **thingiverse.com/thing:5408737**.

■ Contributing Editor **JERRY OLTION** hasn't yet joined the 3D-printing revolution, but his resistance is weakening.

**SHARE YOUR INNOVATION**

Do you have a telescope or ATM observing accessory that *S&T* readers would enjoy knowing about? Email your projects to Jerry Oltion at **j.oltion@gmail.com**.

# How Do I Use the Center Sky Map?




**CAN YOU FIND ORION** in the night sky? How about the Big Dipper? Can you identify the North Star or the Pleiades? The first step into amateur astronomy is learning the stars in your evening sky, just using your unaided eyes. Once you do so, they'll be your companions for life. And they'll be your guideposts for finding everything fainter that you can hunt with binoculars or a telescope.

Turn to our monthly, two-page sky map on pages 42–43. Print subscribers will notice how we've printed the center map on heavier paper stock. That's so, if you want, you can carefully pull out the map for use outside while stargazing. Or just take the whole issue with you.

Before we look at how to use the map, let's familiarize ourselves with it. (For these instructions, use the center map rather than the tilted version of it at right, which we'll get to later.) Like any detailed map, it may look confusing when you first lay eyes on it. But the more you examine it, the more it makes sense. Think of it as a map of the visible sky overhead, akin to a geographic map of your area on Earth. The constellations are like states or regions, the stars like cities.

There are key differences in the two kinds of map, though. The stars and constellations appear to revolve slowly around Earth through the night as our planet rotates. And they shift about 1° westward from one night to the next as Earth orbits the Sun. So you need maps showing where they are at different hours of the night and at different times of the year. This month's map is for early evenings throughout January 2023.

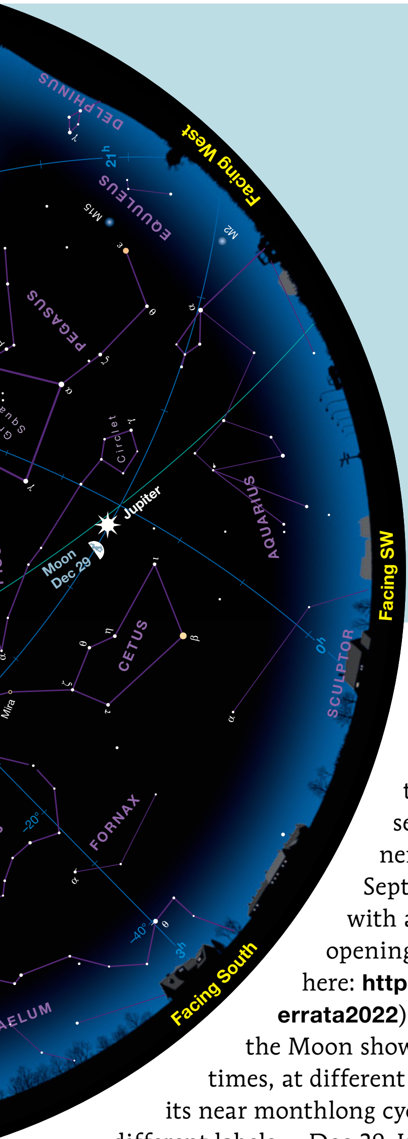
Our map is also designed for a skywatcher at or near latitude 40° north. That's about the latitude of New York or Denver, Madrid or Beijing. If you're far south of 40°N, stars in the southern part of the sky will appear higher on the map, while stars in the north will be lower. If you're far north of 40°N, the reverse will be true.

## THREE TIPS

1. Look for the bright stars and patterns first. The faint ones are often hard to see in the sky.
2. Constellations look a lot bigger overhead than on the map!
3. To see the faintest stars shown, avoid streetlights and brightly moonlit nights.

Now look more closely at the center sky map. Constellation names, like Gemini and Andromeda, are in purple type. The thin purple lines help portray each constellation, though of course you won't see them in the sky. Names of stars, planets, and deep-sky objects like galaxies and star clusters display in white. Some of the stars are labeled with Greek letters instead of a name; we'll explain why in a later Beginner's Space. Note also the cloud-like Milky Way, stretching from Monoceros in the lower left to Cygnus in the upper right.

You can also see, in green, the ecliptic, which is the path the Sun, Moon, and planets take around the sky




## THREE KEYS

The three keys surrounding our center sky map will help you get the most out of it.

**These symbols represent different deep-sky objects.**

- Galaxy
- Double star
- Variable star
- Open cluster
- Diffuse nebula
- Globular cluster
- Planetary nebula

**The brightest star on our map is magnitude -1, the faintest magnitude 4. We'll explore magnitudes in a later Beginner's Space.**

-1
0
1
2
3
4

**Our map is accurate within about an hour of these times.**

**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.

as Earth rotates. (For more on the ecliptic, see Beginner's Space, Sept. 2022, p. 74, with a corrected opening graphic here: **https://is.gd/errata2022**). Notice that the Moon shows up three times, at different phases in its near monthlong cycle and with different labels — Dec 29, Jan 2, and Jan 6. The labels indicate where you'll find the Moon on those dates. You can also spot Mars just left of center and Jupiter to the right. The planets are continually on the move, but on our center map they're always shown where they're located at mid-month. Lastly, see the blue line labeled Equator. Known as the celestial equator, that imaginary line corresponds to Earth's equator, as if it were projected out into the heavens.

### How to Use the Map

Ready to try the map outdoors? Take the map outside within an hour of the time listed below right of our center map (also in box above). Bring along a red-light flashlight to read the map by; dim red light won't spoil your night vision.

Once you're outside with a clear view of the sky, determine first which direction you're facing. If you're unsure, just remember where the Sun sets — that's roughly west. Now, look at the yellow direction labels around the map's periphery. While holding the map upright in front of you, spin it so the label for the direction you're facing is at the bottom of the map, like "Facing SE" is in the map at left. That edge is the horizon in front of you, and the stars and constellations above the label will match the stars and constellations in that part of the sky you're facing. (For now, ignore the parts of the map that correspond to other directions.)

The farther in from the map's edge toward its center a star or other object is plotted, the higher it will be in your sky. Halfway from the edge to the center of the map means about halfway from the horizon to straight up over your head. The map's center marks the zenith, or the point in the sky directly above you.

Next, try finding your way on the map. Note that in the version of the center map reproduced at left, we've turned the map slightly counterclockwise, so that "Facing SE" is at the bottom. Nearly halfway from that label to the center of the map you'll find the constellation Orion — with bright-orange Betelgeuse in one shoulder, bluish-white Rigel marking the Hunter's upraised foot, and the familiar, three-star Orion's Belt in between. Do the same outside with the map, facing southeast, and you'll see Orion approximately where the map indicates it should be.

Congratulations! You've just successfully mapped your way to a constellation. If you keep at it, finding celestial objects using our map — or any good sky map or atlas — will soon become second nature to you.

Let's try one more thing. Turn the center map around so "Facing North" is at the bottom. About halfway between that label and the zenith lies Polaris, the North Star. See the blue lines radiating from right next to it? Those help remind us that Polaris serves as the celestial north pole. It remains throughout the night in virtually the same position in the sky from your location, with all other stars, constellations, and deep-sky objects rotating around it. As you progress in backyard astronomy, you'll quickly realize just how important a role Polaris plays in our hobby, from getting our bearings in the night sky to polar-aligning a telescope. ■

Check out our interactive star map: **skyandtelescope.org/interactive-sky-chart**

**DARK DRAGONS**

Kfir Simon

NGC 6188 (center left) is sometimes called the Fighting Dragons of Ara for the dark strands of gas and dust that bisect this emission nebula. The young stars of open cluster NGC 6193 seen above the nebula illuminate the field. Bipolar emission nebulae NGC 6164 and NGC 6165 are visible at the bottom right, surrounded by a faint outer halo of material expelled from the central star long before the brighter inner lobes. North is to the right.

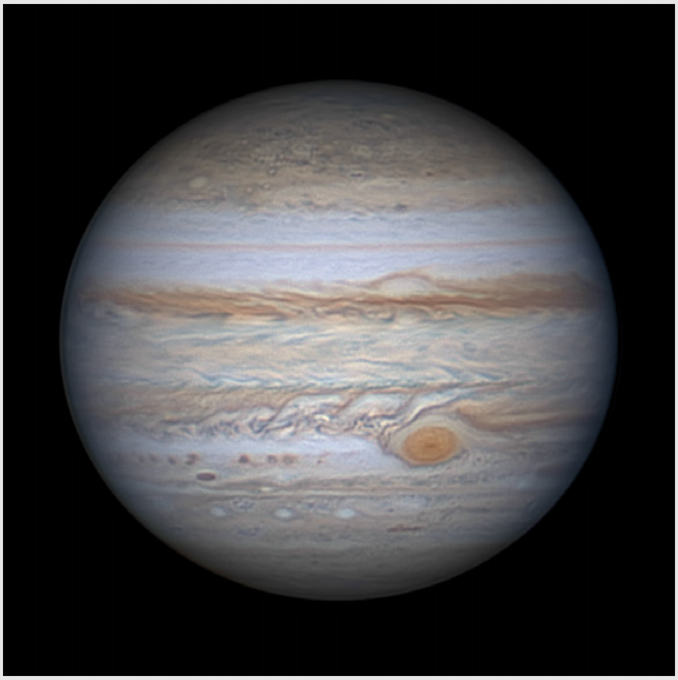
**DETAILS:** *Celestron 36-cm Rowe-Ackermann Schmidt Astrograph and QHY600 Pro camera. Total exposure: 1.5 hours through narrowband and RGB filters.*

**LADY LIBERTY AND THE HARVEST MOON**

Chirag Upreti

The descending full Moon reddens as it sets behind the Statue of Liberty in New York Harbor on the morning of September 10, 2022.

**DETAILS:** *Sony α7R III camera and 200-to-600-mm lens. Composite of 4 images, each 1/13 second at ISO 160, f/11.*



### ◁ JUPITER NEAR OPPOSITION

Jeff Phillips

Taken just three days before Jupiter reached opposition on September 23, 2022, this image reveals exquisite detail within the Great Red Spot and South Equatorial Belt.

**DETAILS:** *Celestron C14 Schmidt-Cassegrain and ZWO ASI224MC camera. Stack of many video frames recorded through IR/UV-blocking filter.*

### ▽ ALMOST HEAVEN

Sean Mathews

The Milky Way from Scorpius to Altair rises above the 2019 Almost Heaven Star Party in Spruce Knob, West Virginia. Bright Jupiter shines just below Ophiuchus at right, while dimmer Saturn sits just above the observer's shoulder.

**DETAILS:** *Nikon D800 camera and Rokinon 14-mm lens. Total exposure: 25 seconds at ISO 1600, f/2.8.*

△ A HIDDEN GEM

Vikas Chander

IC 4601 (center) is a reflection nebula in Scorpius that's illuminated by a pair of double stars embedded within a large cloud of dust. The whitish nebula vdB 101 is seen to the right.

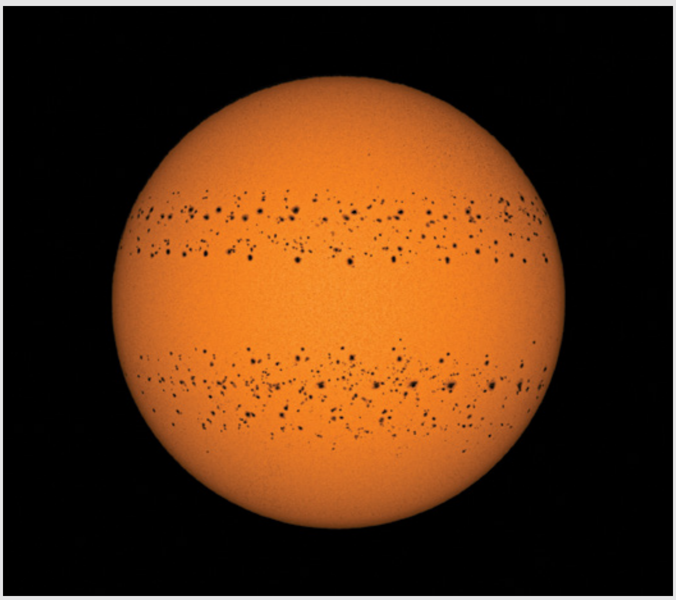
**DETAILS:** *Astro-Physics 175-mm f/8 Starfire EDF refractor with FLI ML16070 CCD camera. Total exposure: 25¼ hours through LRGB filters.*

△ DUSTY SPIRAL

Dan Crowson

Bursting with newly forming stars, NGC 488 in Pisces is a tightly wound spiral galaxy located roughly 90 million light-years from Earth. It has an unusually high rotation rate due to its massive halo.

**DETAILS:** *Astro-Tech 12-inch Ritchey-Chrétien and SBIG STF-8300M camera. Total exposure: 6 hours through LRGB filters.*

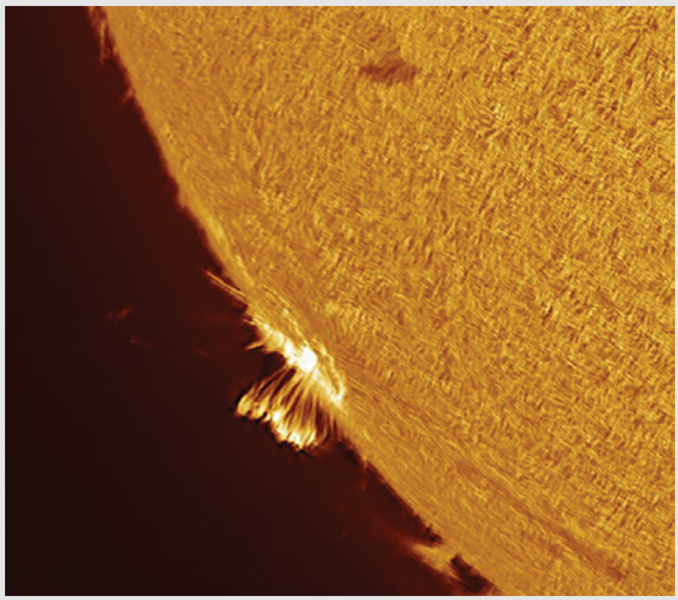


△ A YEAR ON THE SUN

Soumyadeep Mukherjee

After a long period of inactivity, solar cycle 25 began ramping up in 2021. This creative composite combines images of the Sun taken each day throughout 2021 from the photographer's home in India.

**DETAILS:** *Nikon D5600 camera and Sigma 150-to-600-mm lens. Stack of 365 exposures recorded through white-light filter.*



△ SOLAR PHOENIX

Jim Militello

A twisted portion of the Sun's magnetic field suddenly snapped back into place on August 28th, causing this picturesque coronal mass ejection to erupt from AR 3088 and launch billions of tons of plasma into space.

**DETAILS:** *Coronado SolarMax II 90-mm Hα Solar Telescope and ZWO ASI178MM camera. Stack of 300 video frames.*

**THE DARK TOWER**
Kfir Simon
Intense ultraviolet radiation from nearby hot, young stars gives this dark nebula, SFO 82, the appearance of a dark tower caught in a colorful dust storm. North is at right.
**DETAILS:** *ASA 16-inch f/8 Hypergraph and FLI ML16803 CCD camera. Total exposure: 6.5 hours through narrow-band and 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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# Event Calendar

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

*February 13–19*
**WINTER STAR PARTY**
Scout Key, FL
**facebook.com/WSPSCAS**

*April 15–16*
**NORTHEAST ASTRONOMY FORUM**
Suffern, NY
**neafexpo.com**

*April 19–22*
**MIDSOUTH STARGAZE**
French Camp, MS
**rainwaterobservatory.org/events**

*April 29*
**ASTRONOMY DAY**
Everywhere!
**https://is.gd/AstronomyDay**

*May 14–20*
**TEXAS STAR PARTY**
Fort Davis, TX
**texasstarparty.org**

*June 10–17*
**GRAND CANYON STAR PARTY**
Grand Canyon, AZ
**https://is.gd/GrandCanyonStarParty**

*June 14–18*
**ROCKY MOUNTAIN STAR STARE**
Gardner, CO
**https://is.gd/RMSS2023**

*June 15–18*
**CHERRY SPRINGS STAR PARTY**
Cherry Springs State Park, PA
**cherrysprings.org**

*July* (dates TBD)
**TABLE MOUNTAIN STAR PARTY**
Oroville, WA
**tmspa.com**

*July 16–22*
**NEBRASKA STAR PARTY**
Valentine, NE
**nebraskastarparty.org**

*August* (dates TBD)
**OREGON STAR PARTY**
Indian Trail Spring, OR
**oregonstarparty.org**

*August 11–20*
**SUMMER STAR PARTY**
Plainfield, MA
**rocklandastronomy.com/ssp.html**

*August 17–20*
**STELLAFANE CONVENTION**
Springfield, VT
**stellafane.org/convention**

*September 22*
**ASTRONOMY DAY**
Everywhere!
**https://is.gd/AstronomyDay**

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

NASA / JAY WESTCOTT

**FOCAL POINT** by Eric Geater

# A Surprise on the Beach

*A solo, wee-hour observing session suddenly turns alarming, then charming.*

**FIVE YEARS AGO** this month, my wife Suanna and I visited the Riviera Maya, a stretch of Caribbean coastline in Mexico's Yucatán Peninsula. This was our second trip to a Spanish-speaking destination. In fact, it was our 2015 vacation to Puerto Rico that inspired me *a aprender un poco de español*, or to learn a little Spanish — thank goodness, as it turns out.

I brought along binoculars and a tripod to Mexico, hoping to peek at Omega Centauri, Rigil Kentaurus (aka Alpha Centauri A), and other wonders of the southern sky that are unavailable to me in northern Alabama. To deter mosquitos and avoid airport security issues with liquid repellents, I purchased a keffiyeh, the traditional Arab headdress, to cover my head. Long-sleeved shirts and long pants completed my observing attire.

We arrived in Tulum, on the northeast Yucatán shore. After lunch at our "luxuriously rustic" beachfront resort, I asked the property manager for permission to observe from the resort's beach early the following morning. He graciously granted my request, noting my name in the logbook.

Around 3 a.m. the next morning, I greeted the night manager as I carried my equipment out onto the beach. Voluminous but widely dispersed Caribbean clouds sailed on a warm, easterly ocean breeze, and all was serene. It didn't take me long to spot the massive Omega Centauri cluster.

Suddenly I was surrounded by armed security guards barking questions in Spanish. What was I doing there? Why did I have binoculars? Was I spying on guests? I struggled to remember useful responses: "*¡Tengo permiso estar aquí!*" ("I have permission to be here!") and "*¡Yo sólo mirando a las estrellas!*" ("I'm only looking at the stars!"). My faulty Spanish wasn't helped by my keffiyeh-hidden face, but eventually I conveyed that my driver's license could be found in a pocket. My hands were up, and they weren't coming down.

One of the guards read my license over a walkie-talkie. When the reply confirmed my permission to be there, tensions instantly eased. The five guards apologized, explaining their responsibility, but I was giddy with relief. I said breathlessly that *esas estrellas* — I pointed at the stars Hadar and Rigil Kentaurus — could not be seen from where I live in Estados Unidos. "*¿Ustedes gustaría ver?*" ("Would you like to see?"), I said, offering them a look.

Several of the guards lingered and peered through my binos, their weapons no longer drawn. I pointed out targets, at least those I knew of in this unfamiliar patch of sky. One by one, the guards bade me polite farewells and returned to work at the resort. The last remaining guard seemed fascinated by the binoculars, though he struggled a bit with the eye relief. After a few minutes, he politely asked, *"¿Por qué usted mira?"* — "Why do you look?"

In all my years of observing, I actually hadn't thought of that before. I could describe light-years and orbits, or chemical connections between us and the stars, but not *why* I observe. My ham-fisted translation felt silly to say, but I replied, *"Las estrellas son en mi corazón,"* or "The stars are in my heart." Slowly the guard's smile widened into a grin, and he said, *"¡Ah! ¡Es tu alegría!"* ("Oh! It is your joy!") and returned his eyes to the binoculars.

Later I thought: "Two people limited by language somehow found a way to chat about the stars." That's what I hope to tell stargazers when I travel to Mazatlán, Mexico, for the 2024 total solar eclipse — hopefully in better Spanish.

■ **ERIC GEATER** lives in northwest Alabama, where he works in information technology. He has been an amateur astronomer for 14 years.

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Milky Way at Stellarvue Dark Sky Star Party. Image by Tony Hallas.

# Skygazer's Almanac 30°S 2023

FOR LATITUDES NEAR 30° SOUTH

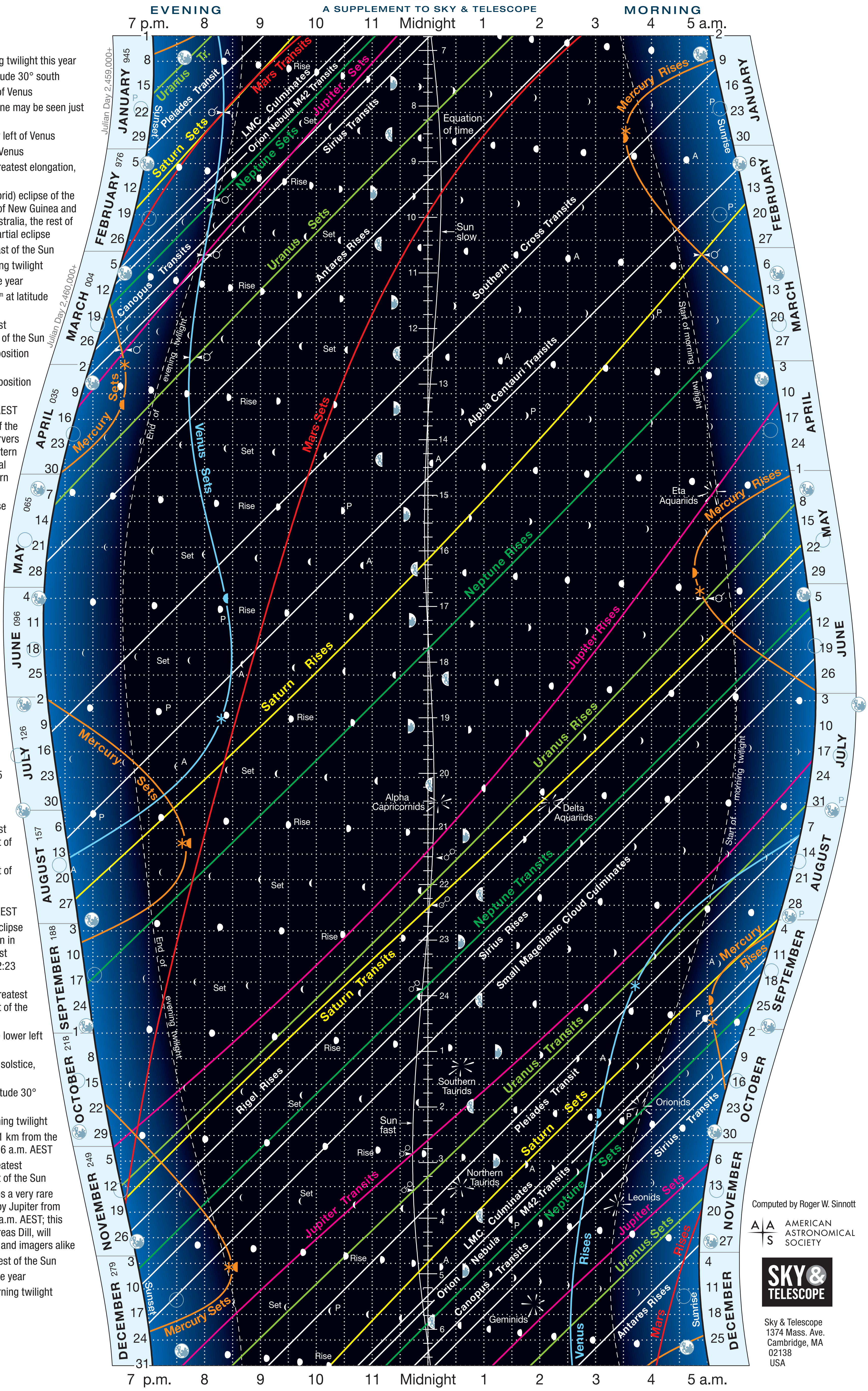
A SUPPLEMENT TO SKY & TELESCOPE

## EVENING SKY

- Jan 4 Latest end of evening twilight this year
- Jan 10 Latest sunset at latitude 30° south
- Jan 22 Saturn is 0.7° right of Venus
- Feb 15 In a telescope Neptune may be seen just 0.1° from Venus!
- Mar 2 Jupiter is 0.6° upper left of Venus
- Mar 30 Uranus is 1.3° from Venus
- Apr 12 Mercury comes to greatest elongation, 19° east of the Sun
- Apr 20 An annular-total (hybrid) eclipse of the Sun occurs for part of New Guinea and extreme western Australia, the rest of Australia seeing a partial eclipse
- Jun 4 Venus stands 45° east of the Sun
- Jun 8 Earliest end of evening twilight
- Jun 11 Earliest sunset of the year
- Jun 22 Shortest day, 10h 13m at latitude 30° south
- Aug 10 Mercury is at greatest elongation, 27° east of the Sun
- Aug 27 Saturn comes to opposition tonight
- Sep 19 Neptune reaches opposition
- Sep 23 Spring begins at the equinox, 4:50 p.m. AEST
- Oct 14 An annular eclipse of the Sun occurs for observers in a path across western United States, Central America, and northern South America
- Oct 28 A slight partial eclipse of the Moon may be seen this evening in Africa, and toward dawn (on the 29th) in Australia
- Nov 3 Jupiter comes to opposition tonight
- Nov 13 Uranus is at opposition
- Dec 4 Mercury is 21° east of the Sun
- Dec 22 Summer begins at the solstice, 1:27 p.m. AEST; longest day, 14h 05m at latitude 30° south

## MORNING SKY

- Jan 5 Earth is 147,098,925 km from the Sun (perihelion) at 2:17 a.m. AEST
- Jan 30 Mercury is at greatest elongation, 25° west of the Sun
- Mar 3 Mercury is 0.9° right of Saturn
- Mar 21 Fall begins at the equinox, 7:24 a.m. AEST
- May 6 A penumbral lunar eclipse is visible before dawn in Australia, the greatest shading being near 2:23 a.m. AEST
- May 29 Mercury stands at greatest elongation, 25° west of the Sun
- Jun 5 Uranus is 2.7° to the lower left of Mercury
- Jun 22 Winter begins at the solstice, 12:58 a.m. AEST
- Jul 2 Latest sunrise at latitude 30° south
- Jul 4 Latest onset of morning twilight
- Jul 7 Earth is 152,093,251 km from the Sun (aphelion) at 6:06 a.m. AEST
- Sep 23 Mercury reaches greatest elongation, 18° west of the Sun
- Oct 10 Ganymede undergoes a very rare grazing occultation by Jupiter from about 12:40 to 1:45 a.m. AEST; this event, found by Andreas Dill, will challenge observers and imagers alike
- Oct 24 Venus stands 46° west of the Sun
- Dec 4 Earliest sunrise of the year
- Dec 9 Earliest onset of morning twilight




Conjunction (appulse) · Greatest elongation · Greatest illuminated extent · Opposition · New Moon · First Quarter · Full Moon · Last Quarter · A Apogee · P Perigee · Waxing (moonset) · Waning (moonrise)

Computed by Roger W. Sinnott

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# Skygazer's Almanac 30°S 2023

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 2023*, 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 15, 2023.

First find "January" and "15" 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 15–16 crosses many slanting *event lines*. Each event line tells when something happens.

The dotted line for January 15–16 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 15th 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 15th, we see that at 8:10 p.m. the Pleiades star cluster transits the meridian, meaning it is due north and highest in the sky. Then the planet Venus sets at 8:20. Both of these events occur when the sky is not yet fully dark. Evening twilight doesn't truly end until 8:38, when the Sun is 18° below the horizon (note the dashed line).

Moving to the right, we see that the planet Mars transits the meridian at 8:45 and is very well placed for telescopic study. But Saturn sets a minute later, so it will be off tonight's observing list.

At about 9:45 the Large Magellanic Cloud culminates (another way of saying it transits). The two brightest nighttime stars, Canopus and Sirius, transit at 10:45 and 11:07, respectively. Transit times of such celestial landmarks help us follow the nightly march of constellations.

A small Moon symbol is centered on the dotted line at 11:53, and the legend at the bottom of the chart tells us it is at waning crescent phase, just rising.

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 15–16 this is $7^h\ 39^m$. 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 15th the Sun runs slow, transiting at 12:09 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 12:36 a.m. the dim planet Uranus sets. Then at 1:41 Antares, a star we usually associate with later seasons, climbs above the southeastern horizon. Five minutes later, similarly hued Mars sets in the west.

The first hint of dawn — the start of morning twilight — comes at 3:41. The elusive planet Mercury rises at 4:06. The Sun finally peeks above the southeastern horizon at 5:14 a.m. on Monday morning, January 16th.

### 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, Saturn reaches opposition on the night of August 27–28 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 Mercury on the morning of January 28th this year, and for Venus on the evening of July 7th.

*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 2459, as indicated just off the chart's upper left margin. To find the last three digits for days in January, add 945 to the date. For instance, on January 15th we have 945 + 15 = 960, so the Julian Day is 2,459,960.

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.

**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 |

## 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 in *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.



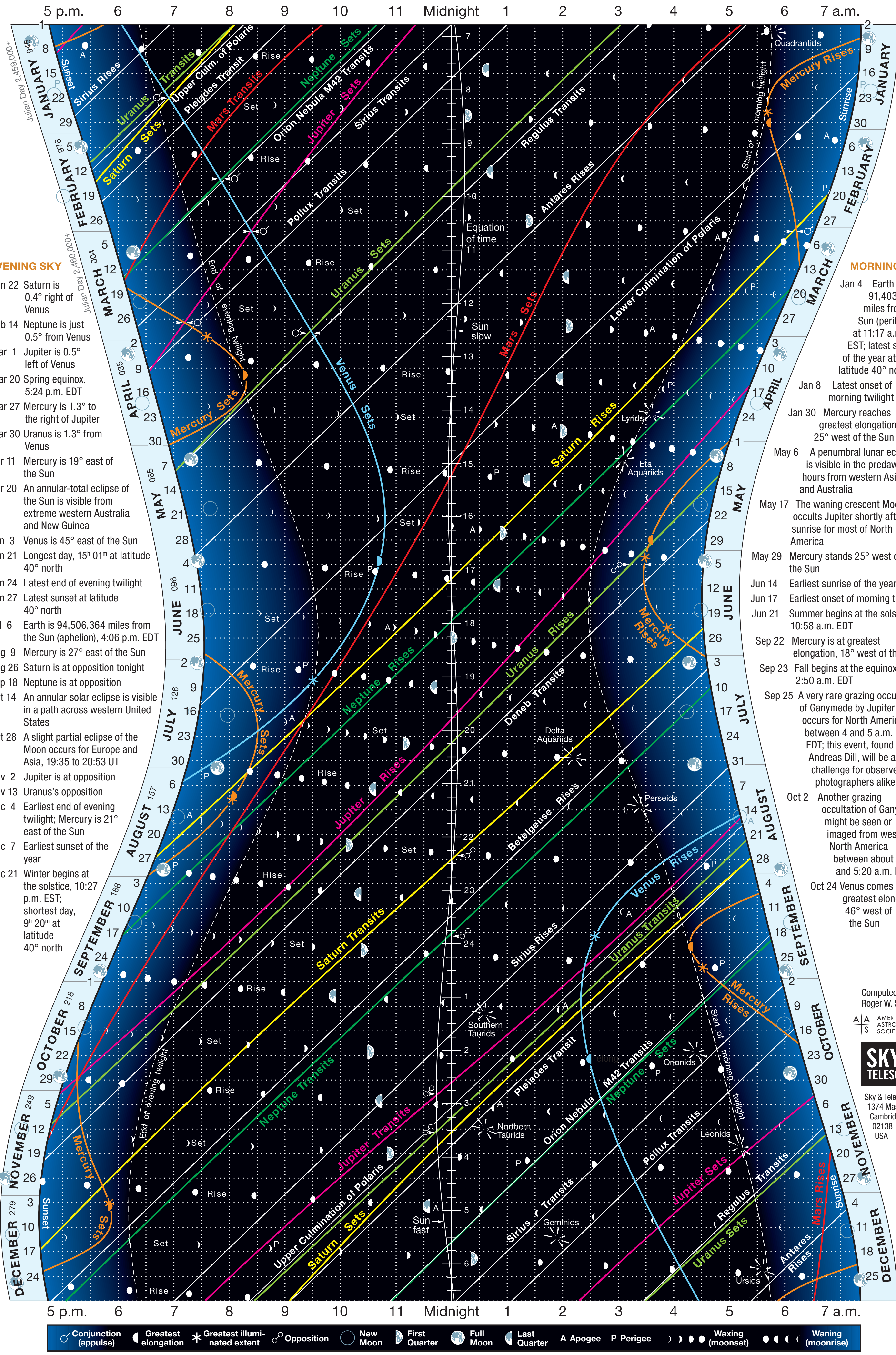
*Skygazer's Almanac 2023* is a supplement to *Sky & Telescope* Magazine, 1374 Massachusetts Avenue, Cambridge, MA 02138, USA, skyandtelescope.org.


SKY & TELESCOPE
AAS AMERICAN ASTRONOMICAL SOCIETY

# Skygazer's Almanac 40°N 2023

FOR LATITUDES NEAR 40° NORTH

A SUPPLEMENT TO SKY & TELESCOPE




## EVENING SKY

Jan 22 Saturn is 0.4° right of Venus

Feb 14 Neptune is just 0.5° from Venus

Mar 1 Jupiter is 0.5° left of Venus

Mar 20 Spring equinox, 5:24 p.m. EDT

Mar 27 Mercury is 1.3° to the right of Jupiter

Mar 30 Uranus is 1.3° from Venus

Apr 11 Mercury is 19° east of the Sun

Apr 20 An annular-total eclipse of the Sun is visible from extreme western Australia and New Guinea

Jun 3 Venus is 45° east of the Sun

Jun 21 Longest day, 15ʰ 01ᵐ at latitude 40° north

Jun 24 Latest end of evening twilight

Jun 27 Latest sunset at latitude 40° north

Jul 6 Earth is 94,506,364 miles from the Sun (aphelion), 4:06 p.m. EDT

Aug 9 Mercury is 27° east of the Sun

Aug 26 Saturn is at opposition tonight

Sep 18 Neptune is at opposition

Oct 14 An annular solar eclipse is visible in a path across western United States

Oct 28 A slight partial eclipse of the Moon occurs for Europe and Asia, 19:35 to 20:53 UT

Nov 2 Jupiter is at opposition

Nov 13 Uranus's opposition

Dec 4 Earliest end of evening twilight; Mercury is 21° east of the Sun

Dec 7 Earliest sunset of the year

Dec 21 Winter begins at the solstice, 10:27 p.m. EST; shortest day, 9ʰ 20ᵐ at latitude 40° north

## MORNING SKY

Jan 4 Earth is 91,403,034 miles from the Sun (perihelion) at 11:17 a.m. EST; latest sunrise of the year at latitude 40° north

Jan 8 Latest onset of morning twilight

Jan 30 Mercury reaches greatest elongation, 25° west of the Sun

May 6 A penumbral lunar eclipse is visible in the predawn hours from western Asia and Australia

May 17 The waning crescent Moon occults Jupiter shortly after sunrise for most of North America

May 29 Mercury stands 25° west of the Sun

Jun 14 Earliest sunrise of the year

Jun 17 Earliest onset of morning twilight

Jun 21 Summer begins at the solstice, 10:58 a.m. EDT

Sep 22 Mercury is at greatest elongation, 18° west of the Sun

Sep 23 Fall begins at the equinox, 2:50 a.m. EDT

Sep 25 A very rare grazing occultation of Ganymede by Jupiter occurs for North America between 4 and 5 a.m. EDT; this event, found by Andreas Dill, will be a challenge for observers and photographers alike

Oct 2 Another grazing occultation of Ganymede might be seen or imaged from western North America between about 4:20 and 5:20 a.m. PDT

Oct 24 Venus comes to greatest elongation, 46° west of the Sun

Computed by Roger W. Sinnott

AMERICAN ASTRONOMICAL SOCIETY

SKY & TELESCOPE

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

# Skygazer's Almanac 40°N 2023

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 2023*, 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 15, 2023.

First find "January" and "15" 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 15–16 crosses many slanting *event lines*. Each event line tells when something happens.

The dotted line for January 15–16 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 15th occurs at 4:59 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 15th rightward, we see that the bright star Sirius rises at 6:01 p.m. Then at 6:35 evening twilight technically ends. This is when the Sun is 18° below the horizon and the sky is fully dark. At 6:38 Venus sets, so we know that until this time it has been shining brightly, low in the west.

The dim planet Uranus transits the meridian at 7:10, meaning it is due south and "riding high," an excellent time to look for it in binoculars. But the ringed planet Saturn sets at 7:18, so we can cross it off tonight's observing agenda.

At 7:21 Polaris, the North Star, has its upper culmination. It then stands directly above the north celestial pole (by 38′ or 39′ this year), a good time to check the alignment of an equatorial telescope.

The famous Pleiades star cluster transits at 8:07 p.m., followed by Mars (8:43) and the Great Nebula in Orion (9:55). Not only are they best placed for viewing in a telescope, but transit times of celestial landmarks help us keep track of the march of constellations across the night sky. At 10:36 Jupiter, well placed for viewing earlier, finally sets.

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 15–16 this is $7^h\ 42^m$. 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 15th the Sun runs slow, transiting at 12:09 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 1:44 a.m. a small Moon symbol appears on the dotted line, and we can tell from the legend at the bottom of the chart that it is at waning crescent phase, rising. The wee hours continue, and not long after Mars sets at 4:15, Antares rises at 4:24. This is a star we usually associate with a much later season.

The first hint of dawn — start of morning twilight — comes at 5:44 a.m. Then the elusive planet Mercury rises at 6:01. The Sun finally peeks above the horizon at 7:20 a.m. on January 16th.

### 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 Saturn on the night of August 26–27.

*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 July 7th 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 early this year are 2459, as indicated just off the chart's upper left margin. To find the last three digits for evenings in January, add 945 to the date. For instance, on the evening of January 15th we have 945 + 15 = 960, so the Julian Day is 2,459,960. 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 in *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.



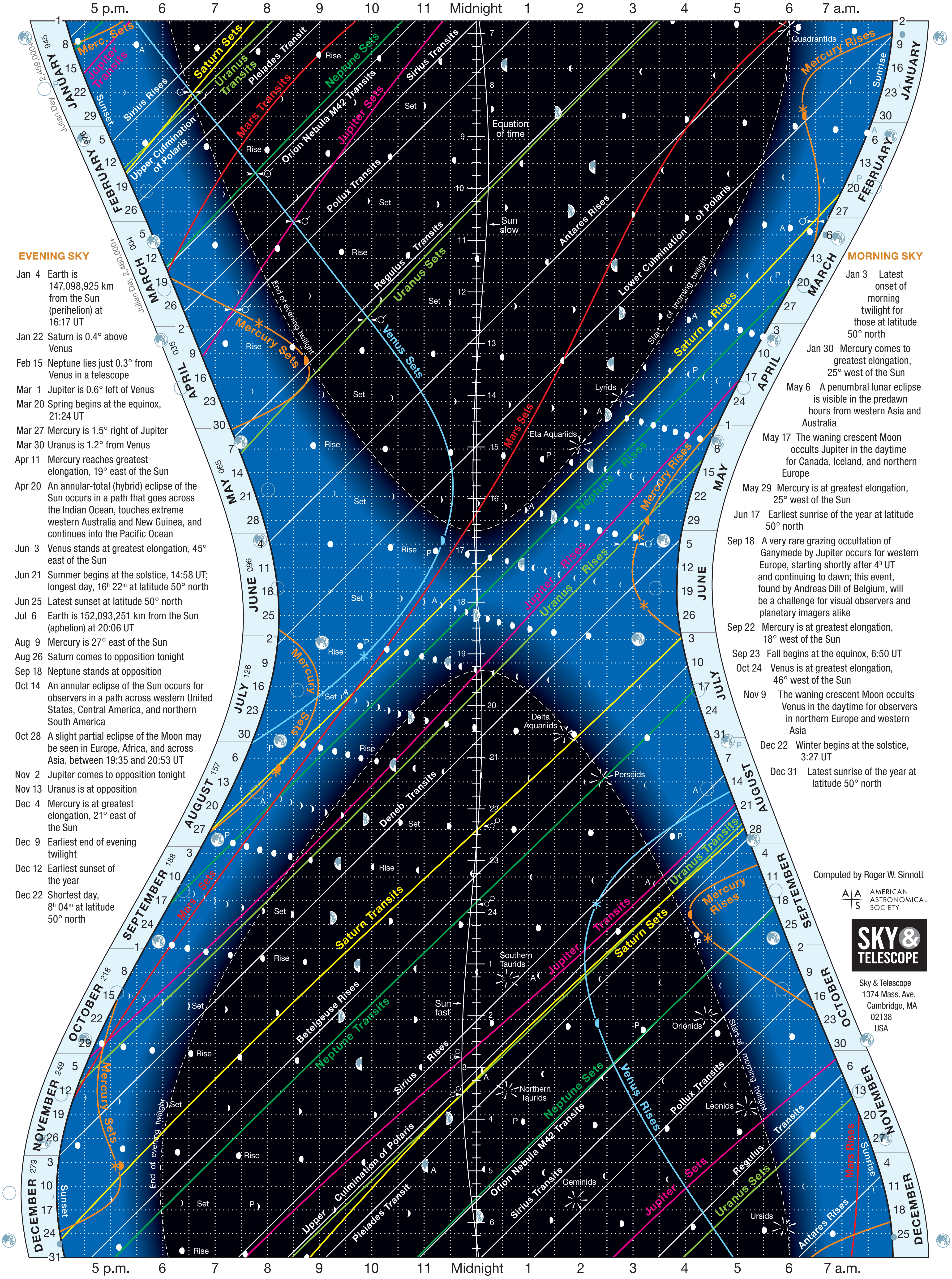
*Skygazer's Almanac 2023* is a supplement to *Sky & Telescope* Magazine, 1374 Massachusetts Avenue, Cambridge, MA 02138, USA, skyandtelescope.org.


SKY & TELESCOPE
AMERICAN ASTRONOMICAL SOCIETY

# Skygazer's Almanac 50°N 2023

FOR LATITUDES NEAR 50° NORTH

A SUPPLEMENT TO SKY & TELESCOPE




### EVENING SKY

- Jan 4 Earth is 147,098,925 km from the Sun (perihelion) at 16:17 UT
- Jan 22 Saturn is 0.4° above Venus
- Feb 15 Neptune lies just 0.3° from Venus in a telescope
- Mar 1 Jupiter is 0.6° left of Venus
- Mar 20 Spring begins at the equinox, 21:24 UT
- Mar 27 Mercury is 1.5° right of Jupiter
- Mar 30 Uranus is 1.2° from Venus
- Apr 11 Mercury reaches greatest elongation, 19° east of the Sun
- Apr 20 An annular-total (hybrid) eclipse of the Sun occurs in a path that goes across the Indian Ocean, touches extreme western Australia and New Guinea, and continues into the Pacific Ocean
- Jun 3 Venus stands at greatest elongation, 45° east of the Sun
- Jun 21 Summer begins at the solstice, 14:58 UT; longest day, $16^h 22^m$ at latitude 50° north
- Jun 25 Latest sunset at latitude 50° north
- Jul 6 Earth is 152,093,251 km from the Sun (aphelion) at 20:06 UT
- Aug 9 Mercury is 27° east of the Sun
- Aug 26 Saturn comes to opposition tonight
- Sep 18 Neptune stands at opposition
- Oct 14 An annular eclipse of the Sun occurs for observers in a path across western United States, Central America, and northern South America
- Oct 28 A slight partial eclipse of the Moon may be seen in Europe, Africa, and across Asia, between 19:35 and 20:53 UT
- Nov 2 Jupiter comes to opposition tonight
- Nov 13 Uranus is at opposition
- Dec 4 Mercury is at greatest elongation, 21° east of the Sun
- Dec 9 Earliest end of evening twilight
- Dec 12 Earliest sunset of the year
- Dec 22 Shortest day, $8^h 04^m$ at latitude 50° north

### MORNING SKY

- Jan 3 Latest onset of morning twilight for those at latitude 50° north
- Jan 30 Mercury comes to greatest elongation, 25° west of the Sun
- May 6 A penumbral lunar eclipse is visible in the predawn hours from western Asia and Australia
- May 17 The waning crescent Moon occults Jupiter in the daytime for Canada, Iceland, and northern Europe
- May 29 Mercury is at greatest elongation, 25° west of the Sun
- Jun 17 Earliest sunrise of the year at latitude 50° north
- Sep 18 A very rare grazing occultation of Ganymede by Jupiter occurs for western Europe, starting shortly after $4^h$ UT and continuing to dawn; this event, found by Andreas Dill of Belgium, will be a challenge for visual observers and planetary imagers alike
- Sep 22 Mercury is at greatest elongation, 18° west of the Sun
- Sep 23 Fall begins at the equinox, 6:50 UT
- Oct 24 Venus is at greatest elongation, 46° west of the Sun
- Nov 9 The waning crescent Moon occults Venus in the daytime for observers in northern Europe and western Asia
- Dec 22 Winter begins at the solstice, 3:27 UT
- Dec 31 Latest sunrise of the year at latitude 50° north


Computed by Roger W. Sinnott



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USA


Conjunction (appulse) · Greatest elongation · Greatest illuminated extent · Opposition · New Moon · First Quarter · Full Moon · Last Quarter · A Apogee · P Perigee · Waxing (moonset) · Waning (moonrise)

# Skygazer's Almanac 50°N 2023

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 2023*, 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 8, 2023.

First find "January" and "8" 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 8–9 crosses many slanting *event lines*. Each event line tells when something happens.

The dotted line for January 8–9 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 8th occurs at 4:17 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 8th, we see that Jupiter transits the meridian at 4:58 p.m., meaning it is then due south and highest in the sky (during twilight). At 5:30 we see a small Moon symbol, and the legend at the bottom of the chart tells us it is at waning gibbous phase and just rising. Then at 5:49 the bright planet Venus sets.

At 6:14 a dashed line marks the end of evening twilight. This is the time when the Sun is 18° below the horizon and the sky is fully dark.

At 6:54 the brightest nighttime star, Sirius, rises. At 7:21 the ringed planet Saturn sets, so we can cross it off tonight's observing agenda. But dim Uranus transits the meridian at 7:38, a good time to look for it in binoculars.

Polaris, the North Star, reaches upper culmination near 7:49. This is when Polaris stands directly above the north celestial pole (by 39′ or 38′ this year), a good opportunity to check the alignment of an equatorial telescope.

The famous Pleiades star cluster in Taurus transits the meridian at 8:36, followed by the ruddy planet Mars (9:11) and the Great Nebula in Orion (10:24) — the best times for observing them in a telescope. Transits of celestial landmarks help remind us where the constellations are during the night.

Jupiter finally sets at 11:00 p.m.

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 8–9 this is $7^h\,13^m$. 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 8th the Sun runs slow, transiting at 12:07 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.

Pollux in Gemini transits at 12:34 a.m., as does Regulus in Leo at 2:56. As the wee hours continue, Mars finally sets at 5:26, but a similarly tinted star, Antares, rises in the east at 5:38.

### 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 |
| Kiev | –2 | Warsaw | –24 |
| London | 0 | Winnipeg | +29 |
| Lyons | +41 | Zurich | +24 |

The first hint of dawn — the start of morning twilight — comes at 5:59. Elusive Mercury rises at 7:24. The Sun finally peeks above the eastern horizon at 7:57 a.m. on Monday morning, January 9th.

## 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, Saturn reaches opposition on the night of August 26–27 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, Venus does so on the evening of July 7th this year.

*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 2459, as indicated just off the chart's upper left margin. To find the last three digits for evenings in January, add 945 to the date. For instance, on the evening of January 8th we have 945 + 8 = 953, so the Julian Day is 2,459,953. For European observers this number applies all night, 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 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 SGA23E, $5.95 each) or to order a similar chart for latitude 40° north or 30° south, go to: shopatsky.com/collections/calendars-almanacs

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