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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

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PHOTO: NASA / KIM SHIFLETT

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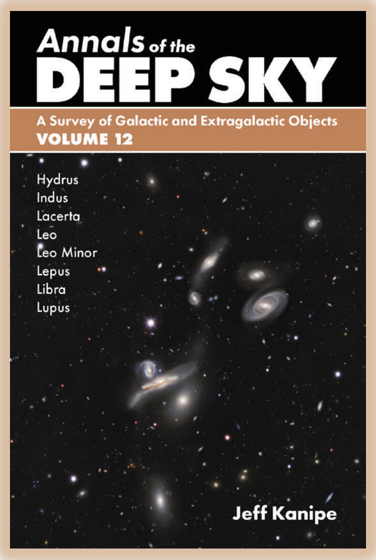

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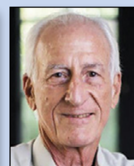

Shoot for the Moon

IF YOU'RE READING this magazine, somewhere along the line, something or someone inspired you to delve into astronomy. Inspiration takes many forms. In my chats with astronomers, both professional and hobbyist, I often hear that the space race of the 1960s was what inspired many to get into the field. With the Apollo program, the universe was no longer something distant and ineffable — it was something we could reach out and be a part of.

We potentially live in a similar moment now. As Contributing Editor Jim Bell explains on page 34, a new age of missions to the Moon is taking shape. Its novelty comes not just from the science the spacecraft will pursue but also from the entrepreneurial way planners are going about things. And let's not forget the Artemis missions, which will eventually ferry people back to the Moon. We can but hope that all this will inspire the next generation of astronomers. Who knows, today's lunar exploration might encourage tomorrow's Nobel Prize winners to embark on their life's paths.

▲ To the Moon!

NASA / KIM SHIFLETT

We at *S&T* rely on inspiration — both from our readers and the universe at large — to keep us going amid the deadlines and red ink. On page 70, you'll find a peek into what inspires us, in our own words: We're reintroducing a column we're calling Beautiful Universe. If you were a reader of the magazine two or so decades ago, you'll recognize it as a reincarnation of what was then called Images. We hope that this will give you some insight into how we see the universe and encourage you to write to us about what in turn inspires you.

In other news: It's January! And that means it's the month of the American Astronomical Society's winter meeting. This year, thousands of professional astronomers will descend on Phoenix, Arizona, for nearly a week to hobnob about science and such. But the AAS meetings aren't solely for the pros — did you know that the AAS has an amateur affiliates division and that you, too, can become a member? (See **https://is.gd/AAS_amateur_affiliates**.) Membership gives you access to many services the AAS provides, including a reduced fee to attend the meetings. If you're going to be in Phoenix, please do stop by the AAS/*S&T* booth and say hello — we love meeting our readers personally.

I often return to the refrain of inspiration in astronomy, because I personally find the concept truly powerful. In the words of this month's Focal Point author, Amy Oliver, inspiration isn't just what starts us on the path — it reminds us why we have to keep going. Let us all open our minds to "surprising sources of inspiration," as she puts it, and see where the universe will take us.

Diana

Editor in Chief

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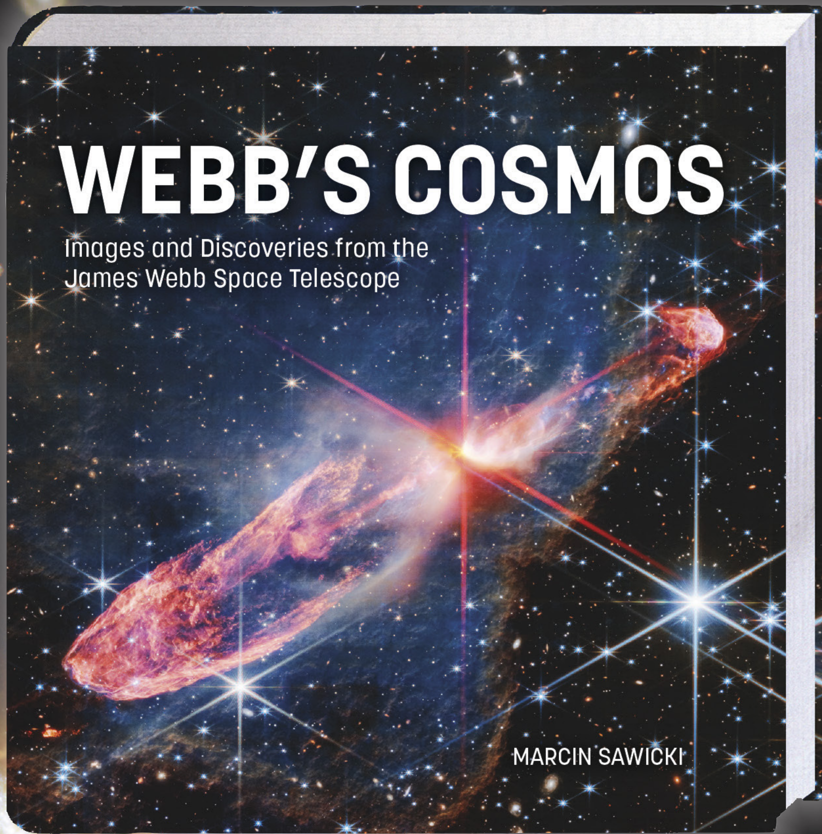
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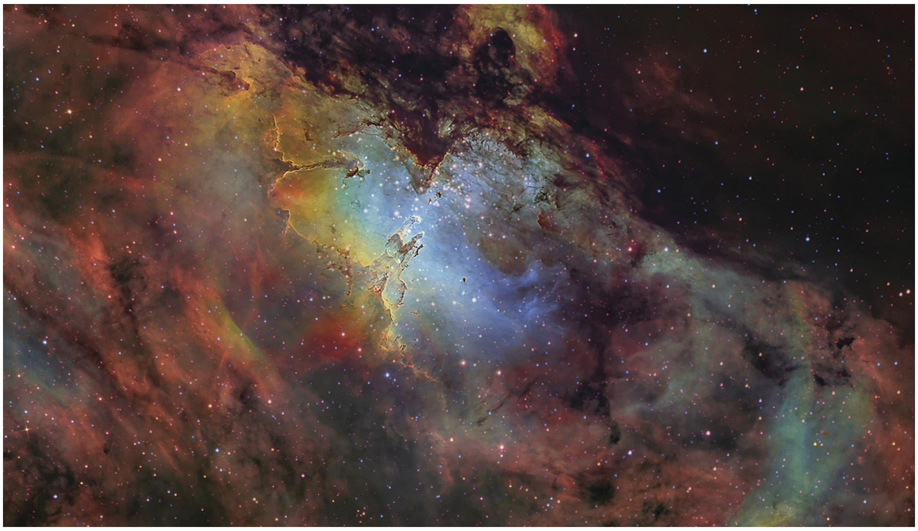


▲ The Eagle Nebula (M16) in Serpens hides the Pillars of Creation at its center, revealed here in this 12-hour exposure with a Sky-Watcher 200-mm telescope.

Night-Vision Observing

Howard Banich's article "Exploring M16 and the Pillars of Creation" (*S&T:* Aug. 2025, p. 28) was very nice. I think I was one of the early users of a night-vision device (NVD). Certainly, the Eagle Nebula (M16) with the Pillars of Creation was a spectacular improvement using an NVD with my 28-inch and 18-inch telescopes. My candidate for the most startling improvement was seeing the Cone Nebula (NGC 2264) in Monoceros. It's easy to see in a 10-inch with an NVD but invisible in a 50-inch without an NVD.

Bob Douglas
Mill Valley, California

Howard Banich replies: *I don't think I'll ever get over how incredible the Eagle and Pillars look with a night-vision device and a hydrogen-alpha filter. My experience with the Cone Nebula is the same as yours — I've yet to see it visually, but it's beautiful with an NVD and Hα.*

By Any Other Name

In William Sheehan's excellent "Who Named the Galilean Moons?" (*S&T:* Aug. 2025, p. 20), he points out that the naming notation using Jupiter-I, Jupiter-II, etc. "proved convenient and remained in general use through the 19th and into the 20th century." This prompted me to open a book I own called *Astronomy for the Use of Schools and Academies* by Joseph A. Gillet and William J. Rolfe published in 1882. There it says, "The names of these satellites . . . are *Io*, *Europa*, *Ganymede*, and *Callisto*." So, it's interesting to note that at least some astronomers were using the moons' current names by the late 19th century.

Richard Rains
Sylmar, California

Squeaky Clean

Thank you for Thomas Eversberg's very useful article "How to Clean Your Optics" (*S&T:* Aug. 2025, p. 62). He mentions using steam and CO_2, but I have one word of caution: Avoid extreme and rapid temperature gradients. I've cracked a handmade 6-inch mirror before. It really spoils your day!

Mark Goll
San Antonio, Texas

Thomas Eversberg's article follows the standard procedure. There's just one little thing I do that's different. Instead of using distilled water for the final rinse, I use acetone. Distilled water leaves tiny spots on the mirror, but acetone beads up and rolls right off.

Thomas Eversberg gave some good advice when he recommended against shining your flashlight down the telescope to the mirror. If you do that, you'll want to clean your mirror every day.

Victor Wolfe
Columbus, Ohio

Wandering Stars

I'd like some clarification concerning Ken Croswell's "A Stargazer's Guide to the Milky Way" (*S&T:* Aug. 2025, p. 34).

Page 38 states the thick disk is 6,000 light-years thick. I interpret it to mean an approximately 2,000 light-year layer exists both over and under the approximately 2,000 light-year thick thin disk.

Then later on page 38, Arcturus is given as an example of a thick-disk star. Stellarium states Arcturus is 36.7 light-years away. On page 39, Barnard's Star is offered as another thick-disk star, and the article says it's 6 light-years away. Also on page 39, Lalande 21185 is cited as another probable thick-disk star at 8.3 light-years away.

Those distances would place all three in the thin disk. What am I missing?

David Cherney
Atlanta, Georgia

Ken Croswell replies: *Yes, Arcturus, Barnard's Star, and Lalande 21185 reside near us in the thin disk, but they are not of the thin disk. Instead, they are members of the thick disk, as revealed by their motions around the Milky Way's center. Thin-disk stars have fairly circular orbits around the galactic center. But Arcturus has a highly elliptical orbit; see it for yourself on page 32 of the June 2022 issue of Sky & Telescope. Barnard's Star also has a highly elliptical orbit. Meanwhile, Lalande 21185 is plunging through the galactic disk and will someday shine thousands of light-years away from the galactic plane, in a region where thick-disk stars dominate.*

Appreciating News Notes

As I was reading the July News Notes (*S&T:* July 2025, p. 8), I was struck by the incongruity between the news and the notes. The information being conveyed is so stupendous, whereas the form in which it is being conveyed is so minimal.

I don't mean this as a criticism but rather as a commentary on the amazing age we live in. So much is being made known that there is no alternative to relating it in a short space.

For example, on page 9, among other things we are shown a tiny photograph of a total solar eclipse from the Moon by the Blue Ghost lander, so this eclipse is caused by the Earth, not the Moon, hiding the Sun. Well, the extraordinariness of the picture then hit me. What a scene! And yet here it is just a tiny image on the page.

Joel Marks
Milford, Connecticut

Monica Young replies: *As the editor of News Notes, I couldn't agree more with your note! If I could have 10 more pages, I'd take them! Luckily, these items can also be found in full on our website. Alternatively, the brevity of News Notes often forces the author to highlight only the very pith of a story, and that has its value, too.*

Soft Lights for Houston

In Houston, Texas, there is no question that by far the worst light pollution comes from private lighting, just as Jan Hattenbach wrote in "Light Pollution: What Is Brightening Our Night Skies?" (**https://is.gd/skybrightening**). But bad street lighting should not be ignored.

We believe the only way to get meaningful improvement in cities is to educate the police and have them deliver our message to the public. To that end, we have been photographing glare at fatal auto-pedestrian accident sites and alerting the police when it is present. This lighting not only impairs the vision of the driver, but it gives the pedestrians the false sense that they are well lit. We now have three resources for the police at **softlighthouston.com**.

Deborah Moran
Houston, Texas

Happy Hunting

This past year, 2025, has been a time for celebration: *S&T*'s 1,000th issue, my 90th birthday, and my logged 30,000th galaxy. Though I missed a few issues, I credit *S&T* for inspiring me.

My search for galaxies started in 1982. It wasn't planned, but after 10,000 it became a lifelong endeavor. One of my latest "discoveries" is NGC 4187. This one is fairly bright at magnitude 13.2 and right on the Canes Venatici-Ursa Major border near the beautiful edge-on galaxy NGC 4157.

Though I'm 90, I have no retirement plans. I recently did four all-night, galaxy-hunting sessions 150 miles from home in 10 days. That means being up for 25 or so hours during each session.

Happy birthday to *S&T* and me.

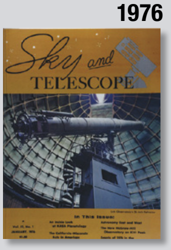
Dennis Horvath
Via email

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

75, 50 & 25 YEARS AGO by Sabrina Garvin

1951

1976



2001

January 1951

Milky Way Mapping "Jacobus [C.] Kapteyn was born at Barneveld in the Netherlands. He was one of the leading astronomers during the first quarter of this century . . .

"The central problem at which he worked was that of the structure of the galactic system. . . . Kapteyn's principal problem was: How to construct [a] miniature universe?

"In the first of two attempts [he supposed] that the motions of the stars show no preference for any special direction. . . . On working out the observational data [his] supposition was not fulfilled . . . But the failure was really a success, for the proof that the motions of the stars are not at random led Kapteyn to [discover] star streams."

January 1976

Uniting Astronomers "[A] highly successful three-week expedition [occurred] last summer to England and the Soviet Union, sponsored by the Amateur Astronomers Association of New York City. The purpose of the trip was to promote cooperation with European astronomers, both amateur and professional. . . .

"[Our] party first visited the Royal Greenwich Observatory . . . Our host, C. A. Murray, showed us many of the instruments . . .

"We [also] flew to Moscow and were enthusiastically welcomed at the Sternberg State Astronomical Institute, which adjoins Moscow University. . . .

"Our highly successful expedition was a breakthrough in the annals of amateur astronomy, for it was the first time that amateurs from the West had the privilege of entering these Soviet astronomical institutions. We hope that it was the beginning of many exchanges in years to come."

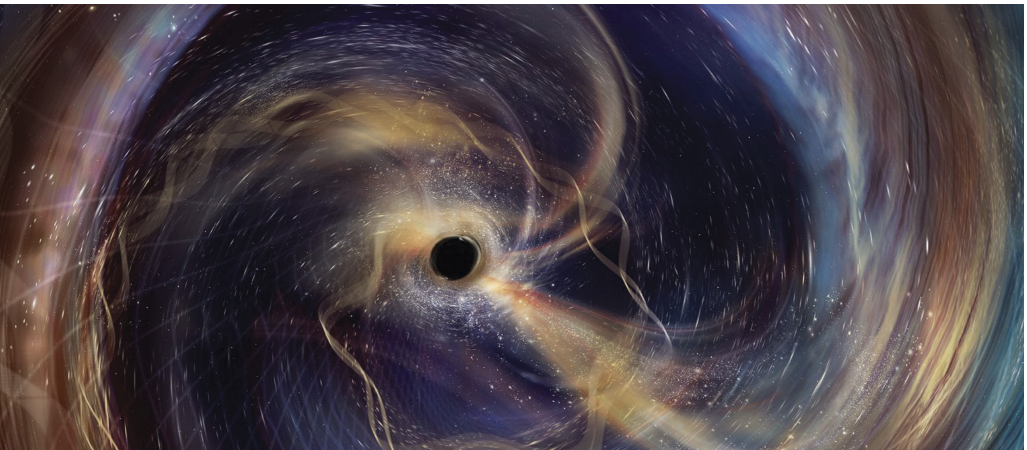
January 2001

Online Learning "Ten years ago, almost no one had heard of the Internet, let alone used it. With the creation of simple-to-use software to browse the World Wide Web, we have moved into a new world. . . .

"Upon the introduction of a powerful technology — such as the Web — people scramble to find uses for it. Sooner or later, teachers start mulling over how to incorporate it into their classes. . . . I believe that the Internet can be an effective way for some students to learn astronomy. However, as in so many other aspects of life, the devil is in the details. . . .

"Of course, in some distant future all these problems will be solved. Internet courses will have streaming video and highly interactive exercises to illustrate every concept. . . . Interactive virtual planetariums will have personalized lessons that guide you through the cosmos."

It's fascinating to look at the ways the internet and how we discuss it have evolved in just 25 years. Many of the online educational tools that John Wallin foresaw are currently in use and have been for some time.



This artwork imagines the view of GW250114, a collision of two black holes.

GRAVITATIONAL WAVES

Ten Years of Gravitational-Wave Astronomy

THE LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY (LIGO) has detected the clearest signal yet from colliding black holes, confirming key predictions of general relativity. Released to coincide with the 10th anniversary of the first LIGO signal, the measurement is part of the observatory's latest data release.

Gravitational waves are ripples in spacetime predicted by Einstein in 1916. Since the first discovery of gravitational waves from two colliding black holes a century later, the floodgates have opened — LIGO now observes a black hole merger roughly every three days.

The increase in detections comes thanks to a fourfold improvement in sensitivity, which has now for the first time enabled researchers to precisely measure the *ringdown* of a merger-made black hole settling down after the crash. By analyzing the final vibrations of the event known as GW250114, the collaboration found that the mass and spin of the new black hole are consistent with the solutions to Einstein's equations that physicist Roy Kerr found more than 60 years ago. The size of the black holes' event horizons before and after the merger likewise match predictions that Stephen Hawking made 55 years ago. The results appear in the September *Physical Review Letters*.

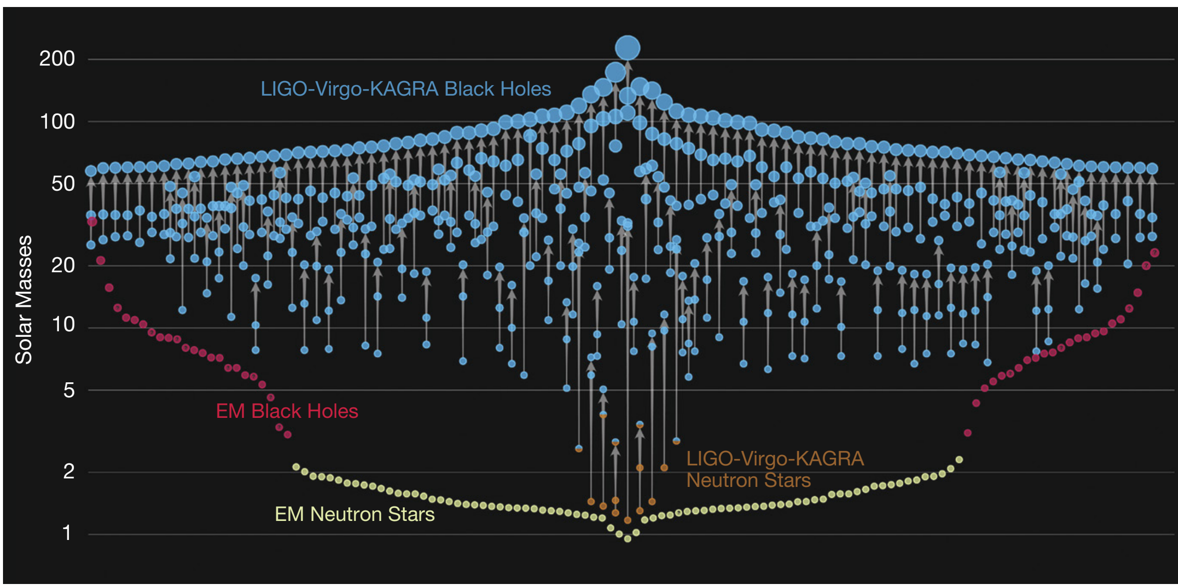
That event and others in the first part of LIGO's fourth observing run were released on August 25th as part of the updated catalog put together by the LIGO-Virgo-KAGRA Collaboration. The latest round of detections now reaches out to when the universe was 8 billion years old, just over half its current age.

The new results include 128 confidently detected mergers, all but two of which were smashups of binary black holes. These events bring the tally of events over all observing runs so far to 218, more than doubling the previous count. The mergers have implications across a range of topics, from cosmology to gravity itself, discussed in a slew of companion papers. The researchers are in the process of submitting these to the *Astrophysical Journal Letters* for an upcoming special issue.

Two of the 128 mergers appear to have involved a black hole and a neutron star, based on the objects' masses. (None of the mergers in this run involved two neutron stars.) But while astronomers expect that black holes could shred neutron stars before swallowing them, researchers detected no sign of shredding for these two mergers.

The other 126 events were mergers of two black holes, spanning a wide range of masses from 4 solar masses to more than 100. For an overview of the findings, visit **skyandtelescope.org/O4a**.

■ **COLIN STUART & CAMILLE M. CARLISLE**



Arrows connect merging black holes (blue) and neutron stars (orange) to the objects created by the merger. Electromagnetic (EM) detections of black holes and neutron stars are shown in magenta and yellow, respectively. (The butterfly layout of the data points is for aesthetic reasons.)

BLACK HOLE ART: AURORE SIMONNET (SSU / EDEON) / LVK / URI; MERGER CATALOG VISUALIZATION: LIGO-VIRGO-KAGRA / AARON GELLER / NORTHWESTERN UNIV.

BLACK HOLES

Early Black Hole Has the Mass of 50 Million Suns

ASTRONOMERS USING the James Webb Space Telescope have confirmed that, just 800 million years after the Big Bang, there is a galaxy with a supermassive black hole — and not much else. The black hole has more than 10 times the mass of the one in our own galaxy.

The distant galaxy, known as QSO1, is *gravitationally lensed* by the foreground cluster Abell 2744, whose gravity distorts and magnifies QSO1's light into three identical images. Combining nature's optics with those of Webb, Ignas Juodžbalis (University of Cambridge, UK) and colleagues zoomed in on the galaxy's center, picking apart the motions of gas swirling within mere light-years of the black hole.

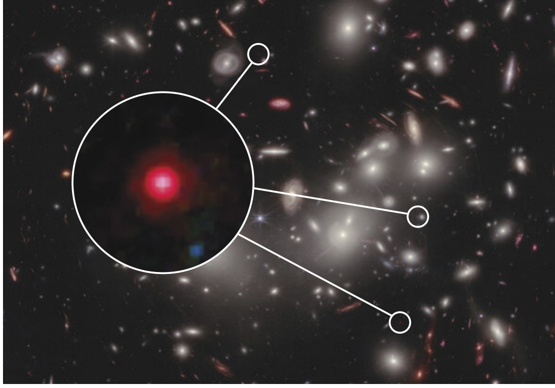
Even with nature's help, Webb struggles to resolve the galaxy's inner regions, so the team used a technique called *spectroastrometry*. Starting with spectra measured across the distant galaxy, the team created images of the gas moving at different velocities, precisely mapping those motions in the process.

The result is the first direct mass measured for such a distant black hole: 50 million Suns. It's not a record-breaker by modern-day standards, but it's hard to explain how the black hole accumulated so much mass so early on — especially because the black hole appears to be nearly dormant.

Even stranger, almost all the galaxy's mass is in the black hole, with little in its stars. The team calls QSO1 "the most 'naked' black hole ever found."

So where did it come from? In one scenario, pristine gas clouds collapse directly into black holes, skipping the intermediary star formation. In another, black holes are primordial, forming just after the Big Bang.

But both scenarios have their drawbacks. The galaxy's mass is so low com-



▲ The distant galaxy QSO1, shown here amidst the foreground Pandora Cluster, contains a 50-million-solar-mass black hole.

pared to the black hole that it wouldn't support direct collapse. Yet the primordial scenario doesn't make the black hole massive enough on its own.

"I think the issue is that it's difficult to find the 'smoking gun' of either scenario," says Kevin Hainline (University of Arizona). But this measurement is just the first for the many early black holes that Webb is finding, he adds. The population as a whole will provide astronomers with better insight into black hole formation.

■ MONICA YOUNG

SOLAR SYSTEM

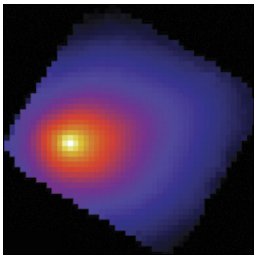
The Unexpected Composition of Comet 3I/ATLAS

OBSERVATIONS WITH the James Webb Space Telescope have shown that the new interstellar comet, 3I/ATLAS, is surprisingly rich in carbon dioxide.

Using the Near-Infrared Spectrograph's integral field unit, astronomers found that the comet's coma contains almost eight times more carbon dioxide (CO_2) than water vapor. That's in contrast to the gaseous halos around solar system comets, almost all of which contain more water vapor than CO_2.

"I have never seen such a strong CO_2 peak in a comet spectrum," says Martin Cordiner (NASA Goddard), who led the study that will appear in *Astrophysical Journal Letters*.

Cordiner's team received 18 minutes on August 6th to collect a near-infrared spectrum of the comet — enough time and wavelength coverage to measure the abundance of both molecules.



▶ Infrared image of Comet 3I/ATLAS on August 6th

"The detection of such a high level of CO_2 is quite exciting," says Bryce Bolin (Eureka Scientific, Inc.), who wasn't part of the study. He adds that Comet 3I/ATLAS's brightness had already suggested that something besides water must be driving its activity.

Carey Lisse (Johns Hopkins University) and others used NASA's SPHEREX telescope to confirm abundant CO_2 in 3I/ATLAS. That result appeared in the September *Research Notes of the American Astronomical Society*.

The unexpected finding emphasizes the importance of observing the comet as it zips toward perihelion on October 30th. As increasing solar heat vaporizes ices, analysis of the coma's content will give insight as to the comet's composition and origins.

■ JEFF HECHT

PANDORA CLUSTER: NASA / ESA / CSA / I. LABBE (SWINBURNE UNIVERSITY OF TECHNOLOGY) / R. BEZANSON (UNIVERSITY OF PITTSBURGH) / A. PAGAN (STSCI), QSO1 INSET: LUKAS ET AL. / *ASTROPHYSICAL JOURNAL* 2023; 3I/ATLAS: NASA / JWST

IN BRIEF

Zambuto Mirrors Shutting Down

After 28 years, Zambuto Optical Company is closing up shop. Zambuto mirrors have long been known for their superb craftsmanship and are considered by some to be among the best mirrors available to amateur astronomers. (Some professional telescopes have used them, too.) But in Carl Zambuto's words, "Nothing can possibly last forever." In a statement posted to the company's website in August, Zambuto explained the rationale for the decision: He and his colleague, Chuck Smith, are well past retirement age, and they wanted to close down the business while they were still capable of maintaining their superb product standards, instead of holding on past the point when quality started to sag. Sales are also waning. Although the company is no longer accepting orders for new mirrors, Zambuto and Smith will complete all standing orders, keeping them busy into 2026. They will also continue providing inspection and coating services to existing Zambuto mirrors when able. Zambuto estimates that they have some 3,500 mirrors in telescopes around the world.

■ CAMILLE M. CARLISLE

SOLAR SYSTEM

Mars Has a Solid Inner Core, Marsquakes Show

FOR FOUR YEARS, NASA's Mars lander, the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (INSIGHT) mission, captured marsquakes with its seismometer in Elysium Planitia. Now, it turns out, the data still have the potential to reveal the unexpected.

Marsquake analysis in 2021 showed the Martian core was large, light, and therefore — since lighter elements don't easily solidify — mostly liquid. "Nobody on the INSIGHT team took the search for a solid inner core seriously," says Amir Khan (ETH Zurich, Switzerland), who led one of the 2021 studies but is not involved in the current work. The team expected that, if there were a solid inner core, it would be tiny.

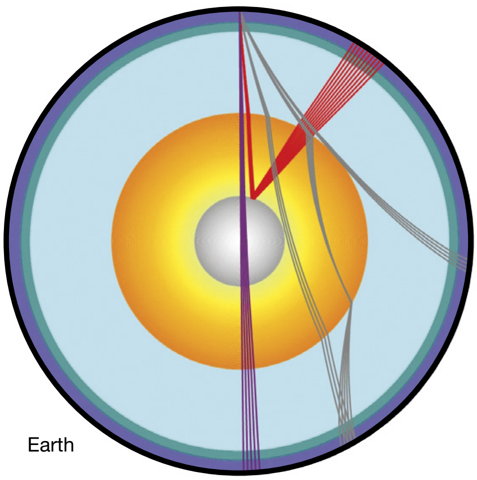
But when Huixing Bi, Daoyuan Sun (both at University of Science and Technology of China), and colleagues zeroed in on wiggles that occurred long after certain quakes started, they found evidence for a solid inner core within the larger liquid region.

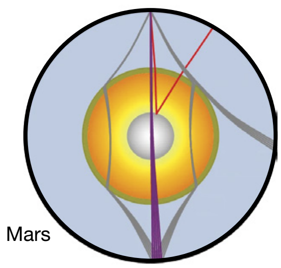
The team identified two types of shaking in the data. One came from waves that traversed the interior. The other came from waves reflected by a sudden change in density, delineating a solid inner core 600 km (400 mi) in radius. At that size, the core takes up the same amount of room in Mars, percentage-wise, as Earth's inner core does. The results appear in the September 4th *Nature*.

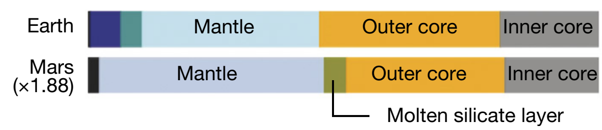
To explain how the inner core could be light, large, and solid, the researchers explored the possibility that it's made not of iron and nickel, as in Earth, but rather of iron oxide. The lighter composition would also explain why the density change from the inner core to the outer core is small compared to the density jump within Earth.

Khan, while calling himself a "healthy skeptic" of the results, acknowledges the team is making the most of a rather noisy data set measured a world away. "You've only got this one data set, right, and therefore it's a unique resource," he says. "You have to mine it as much as you can."

■ MONICA YOUNG







◀ The solid, inner core measured for Mars is the same size, percentage-wise, as the one measured for Earth. The purple and gray lines show the variety of paths seismic waves can take.

IN BRIEF

No Atmosphere on TRAPPIST-1d

New James Webb Space Telescope observations of the third world in the seven-planet TRAPPIST-1 system show that it's most likely airless. In Webb's spectra of starlight passing through TRAPPISt-1d's atmosphere — published in the August 20th *Astrophysical Journal* by a team led by Caroline Piaulet-Ghorayeb (University of Montreal) — there were no chemical fingerprints of water, methane, carbon dioxide, or any other molecules that the team searched for. There aren't even signs of a Titan-like haze. While TRAPPIST-1d is most likely bare, it's still possible that the planet hosts a very thin, carbon dioxide–dominated atmosphere (think Mars) or maybe even thick, high-altitude clouds that block our view (like on Venus). Definitive studies of the outer TRAPPIST-1 planets (that is: e, f, and g) are forthcoming.

■ MONICA YOUNG

SOLAR SYSTEM

Meet 2025 PN_7, Earth's New Quasi-moon

OUR HOME PLANET just obtained a new companion — or at least, a new-found one.

Earth only has one true Moon, but in recent years astronomers have found seven other asteroids — so-called *quasi-moons* — that appear to circle us. In reality, they're orbiting the Sun alongside our planet (*S&T:* Feb. 2025, p. 34).

Now, there's a new quasi-moon in town. Discovered on August 29th by the Pan-STARRS telescope on Haleakalā, Hawai'i, asteroid 2025 PN_7 was quickly confirmed by other observatories. Earlier images of the object extend back to 2014. It appears to have been on a quasi-moon orbit for about 60 years, and it will remain so for about 60 more.

Alan Harris (Space Science Institute), in a posting on the Minor Planets Mailing List, writes that its velocity relative to Earth is 3.4 km/s (7,600 mph), higher than would be expected for lunar ejecta. He adds that it's "likely just an asteroid that has trickled into a near-Earth orbit from the inner main belt."

Based on this object's brightness, it's likely between 10 and 30 meters (30 to 100 feet) across. From the changes in its brightness over time, amateur astronomer Sam Deen adds that it "seems to be an angular, quite elongated solid rock."

In its orbit around the Sun over the next decades, 2025 PN_7 will never come closer to our planet than 0.024 astronomical unit, about 10 times the Moon's distance. Even as it's accompanying Earth, 2025 PN_7 won't be a threat, Harris notes. "Any such object does not come unexpectedly, out of the blue, to impact Earth."

■ DAVID L. CHANDLER

BRIGHT SATELLITES

A New Kind of Satellite Could Damage Your Eyes

MANY COMMUNICATION satellites in low-Earth orbit are unintentionally bright; however, soon a new type of satellite could purposefully beam sunlight to Earth's surface at night.

Reflect Orbital has raised $20 million in funding for their planned constellation and intends to launch a demonstration spacecraft next year to advertise their services to potential customers. That satellite will rival the full Moon in brightness, reflecting sunlight using a specially shaped expanse of Mylar film that will stretch over 324 square meters (3,490 square feet).

To create more light, the company plans to launch even larger satellites over the next several years. Those bigger spacecraft would each cover about three-fourths of an acre and far exceed the full Moon's brightness, illuminating spots on the ground 5 kilometers (3 miles) across.

Once those satellites are in orbit, nearly all of the stars would disappear for observers within illuminated areas on the ground. Residents of municipalities and other entities that purchase illumination would be deprived of darkness at night, not to mention the beauty of the starlit sky.

Reflect Orbital states that its main motivation is selling reflected sunlight to solar energy farms (though research funding has also come from other sources, such as the Air Force). Speaking at the International Conference on Energy from Space in 2024, CEO Ben Nowack said, "It would be really great if we could get some solar energy before the Sun rises and after sunset, because then you could actually charge higher prices and make a lot more money."

Besides a likely increase in diffuse brightness across the night sky, these satellites pose safety and environmental hazards as well. John Barentine (Dark Sky Consulting) pointed out that research on eye safety — conducted by James Laframboise (a physicist and amateur astronomer) and Ralph Chou (a professor of optometry) — warns that sunlight reflecting off of satellites this large might damage human eyes. The effects of reflected sunlight on wildlife has raised additional concerns (*S&T:* Jan. 2024, p. 34).

However, resistance is building. The U.S. Federal Communications Commission (FCC) must license the company before it launches any satellites. As of press time, organizations were preparing to submit comments on Reflect Orbital's proposal to the FCC.

■ ANTHONY MALLAMA

▲ Reflect Orbital employees pose with a large mirror surface.

Royal Observatory Greenwich / ZWO Astronomy Photographer of the Year

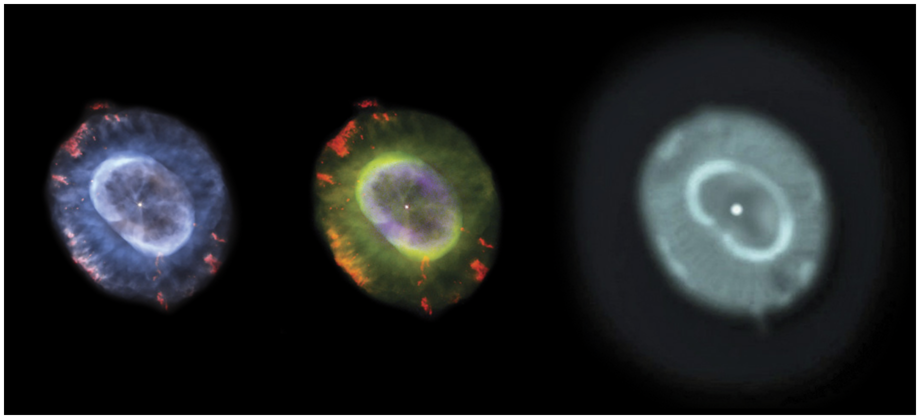
On September 11th, the Royal Observatory Greenwich, partnering for the first time with ZWO, announced the winners of the 17th annual Astronomy Photographer of the Year contest. A Chinese team, consisting of Weitang Liang, Qi Yang, and Chuhong Yu, took the top prize for "The Andromeda Core," their deep, high-resolution image of the Andromeda Galaxy (M31). "The Andromeda Galaxy has been photographed in so many different ways and so many times with telescopes that it is hard to imagine a new photo would ever add to what we've already seen," said judge and astrophotographer László Francsics. "But this does just that, an unusual dynamic composition with unprecedented detail that doesn't obscure the overall scene." The team used a 20-inch PlaneWave Corrected Dall-Kirkham astrograph to reveal hundreds of H II regions in the galaxy's spiral arms leading toward the center of its nuclear bulge. They took advantage of the excellent seeing conditions at Nerpio, Spain, to focus on the intricate structure of the galaxy's central region and its surrounding stellar population. See the photos from winners of the other categories at **skyandtelescope.org/APY2025**.

■ SEAN WALKER

REFLECT ORBITAL MIRROR: REFLECT ORBITAL; ANDROMEDA: WEITANG LIANG, QI YANG & CHUHONG YU

A Tricky "Blue" Snowball

What color do you see in this Andromeda planetary nebula?



▲ **COLOR PERCEPTION** *Left and middle:* Two Hubble Space Telescope views of the 8.3-magnitude planetary nebula NGC 7662. These images demonstrate why one should be leery of color in published images, as it depends on the filters used in processing. *Right:* A drawing of the nebula by French amateur astronomer Bertrand Laville, as described in the text. North is up in all images.

THIS MONTH, after taking in the beauty of M31, the Andromeda Galaxy, look about 14° west for the 5.7-magnitude star 13 Andromedae. Approximately 26′ to the star's south-southwest lies the exotic, 8.3-magnitude planetary nebula NGC 7662, popularly known as the Blue Snowball.

The object's low-power view is tricky, as it appears starlike. You'll need a magnification of at least 70× to discern its disk. In a 1908 *Monthly Notices of the Royal Astronomical Society*, American astronomer Edward Emerson Barnard noted that, "In the 4-inch finder of the 40-inch [refractor] it is only distinguishable from an ordinary [8th-magnitude] star . . . by a slight fuzziness of the image." Higher powers will reveal the nebula's more intricate details, but before we delve into that realm, let's consider its color.

As recorded in his 1864 *General Catalogue of Nebulae and Clusters of Stars*, John Herschel was first to describe the object (listed as GC 4964) as "blue." But is it really blue? Lying some 5,700 light-years away, NGC 7662's visible-light spectrum is dominated by two emission lines from doubly ionized oxygen (O III) at 493.1 and 500.6 nanometers. These correspond to cyan (greenish blue) and green, respectively. How much blue you see may depend on several factors, including the color sensitivity of your eyes, your telescope size, magnification, atmospheric conditions, and the object's altitude. We can even add a psychological effect — perhaps you see blue because the color is suggested by the object's name.

English astronomer William Huggins was the first to record the nebula's true color. In *The Scientific Papers of Sir William Huggins* in 1899, he logged the following view of NGC 7662, as seen through his 8-inch Alvan Clark refractor: "With a power of 600 this nebula appears distinctly annular. The colour of its light is greenish blue." He also detected visually the color of the nebula's brightest emission lines through an attached spectroscope — no doubt confirming or inspiring his observation.

In fairness, *Sky & Telescope* columnist Leland S. Copeland, who was the source of the nickname for this planetary, did not call it the Blue Snowball. "Looking like a light blue snowball" was how he described it in *S&T*'s February 1960 issue.

Structurally, NGC 7662 is a triple-shell planetary with a bright, 18″ × 12″ inner shell only 2.5″ thick, enveloped by a 31″ × 27″ outer shell, and an extremely dim spherical halo 134″ in diameter. Observers have detected these structures through 16-inch and larger telescopes.

In the Hubble Space Telescope images above, red knots of dense gas known as Fast Low-Ionization Emission Regions, or FLIERS, are visible lining the nebula's outer shell. French amateur astronomer Bertrand Laville made marvelous observations of these features in 2015 through his 25-inch telescope at the Observatoire des Baronnies Provençales in Moydans. His composite drawing above, sketched at 150× to 890×, shows enhancements in the outer ring that coincide with the positions of the Hubble FLIERS. Laville notes that, on a scale of 1 to 10 — with 1 being the dimmest light observed through the 25-inch and 10 the brightest — he estimated the outer annulus to be 5, and "almost all of [the FLIERS] being 6." He also detected 3′ of the spherical halo and noted the 13.2-magnitude central star.

Indeed, that central star is the most challenging feature of NGC 7662. I believe one reason why so few observers using large telescopes have seen it is because of lack of magnification. Powers in the range of 800× to 1,200× are most likely required to enlarge the planetary's inner annulus enough to penetrate and dissolve its luminous interior. Don't be afraid to use even higher magnifications if your seeing allows it.

Another reason for the lack of observations may be the star's possible variability. In his 1908 report, Barnard also wrote: "I have . . . established conclusively the fact that the nucleus of 7662 is actually variable to an extent of upwards of three magnitudes." He estimated its period to be approximately 28 days.

Now, it's up to you to discover how much detail *you* can visually squeeze out of this wily little planetary nebula. You just might surprise yourself as to what you can see!

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

BLUE HST IMAGE: NASA / ESA / A. HAJIAN (UNIVERSITY OF WATERLOO); GREEN AND RED HST IMAGE: BRUCE BALICK AND JASON ALEXANDER (UNIVERSITY OF WASHINGTON) / ARSEN HAJIAN (US NAVAL OBSERVATORY) / YERVANT TERZIAN (CORNELL UNIVERSITY) / MARIO PERINOTTO (UNIVERSITY OF FLORENCE) / PATRIZIO PATRIARCHI (ARCETRI OBSERVATORY) / NASA / ESA


B28
B27
B26
SU Aurigae
vdB 31
AB Aurigae

Exploring Sidney van den Bergh's Reflection Nebulae

Discover a catalog that offers a plethora of visual and photographic targets.

Scattered between the stars in the Milky Way are vast clouds of *dust* — a catchall term astronomers use to describe any interstellar matter larger than molecules. Dense dust clouds with no source of illumination and whose outlines are only made visible by the background stars they obscure are called *dark nebulae*. But those that shine because of the light from a nearby star, or stars, scattering off the dust (thought to consist of tiny carbon particles coated with ice) are called *reflection nebulae*.

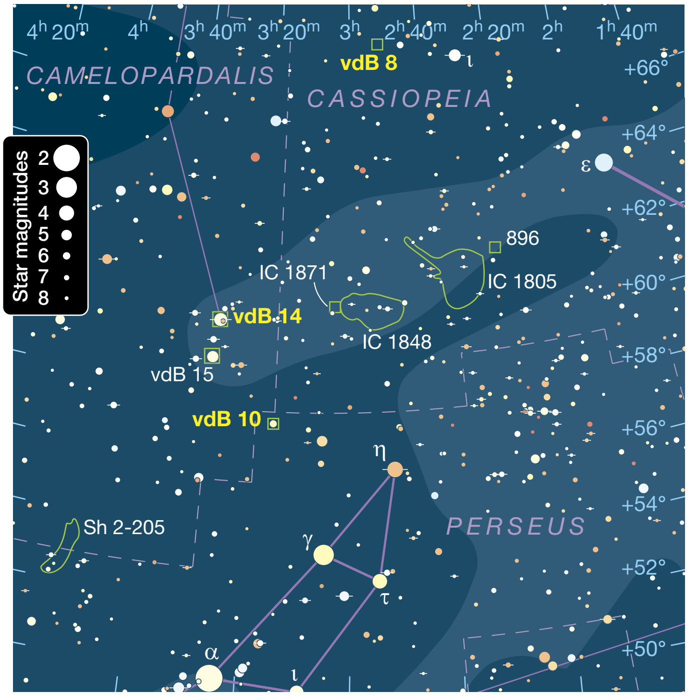
Dutch-Canadian astronomer Sidney van den Bergh created one of the first catalogs of reflection nebulae 60 years ago while working at the University of Toronto's David Dunlap Observatory in Ontario. He compiled 158 of them by looking for stars brighter than 10th magnitude that were surrounded by nebulosity on both blue and red scanned prints of the Palomar Sky Survey above declination −33°. Interestingly, it's now understood that he's the original discoverer for only about a third of those objects. Van den Bergh published his catalog as an article entitled "A Study of Reflection Nebulae" in *The Astronomical Journal* of December 1966.

Over the past decade, I've spent many nights observing nebulae from van den Bergh's catalog and viewed more than a third of them with my vintage 10-inch Schmidt-Cassegrain telescope (SCT). For this escapade, we'll tackle a dozen of his objects with a variety of scopes, with the only caveat being that each was discovered after 1950. This helps keep us from bumping into the more common ones!

Before we begin, I suggest you refer to Contributing Editor Brian Ventrudo's article "Winter's Best Reflection Nebulae" (*S&T:* Feb. 2025, p. 20). You may want to revisit it for his excellent tips on snagging those targets — that'll prepare the ground for the ones I outline here, which are more challenging.

◀ **BRIGHT AND DARK COSMIC CLOUDS** This view shows 7th-magnitude variable star AB Aurigae enveloped in a bluish reflection nebula designated van den Bergh 31. It appears blue because the nebula's fine interstellar dust is more effective in scattering starlight at shorter (bluer) wavelengths. Superimposed are dark, obscuring clouds of dust cataloged as Barnard 26, 27, and 28 that are an additional challenge to detect at the eyepiece. North is up in all images.

ROBERTO MARINONI



Northern Reflections

Let's start in the far north with van den Bergh 8 (**vdB 8**) since, as you'll see for yourself, it's a great object to hone your skills on. To locate it, first find the 3rd-magnitude stars Delta (δ) and Epsilon (ε) Cassiopeiae, which make up the eastern stroke of Cassiopeia's famous W asterism. Follow the line from Delta to Epsilon and continue northeastward for 7.2°. Doing this with your telescope and a low-power eyepiece should place vdB 8's illuminating star, the 9th-magnitude blue giant HD 17443, within the field of view.

In my 6-inch reflector at 25×, I don't see anything special about the star. But increasing to 112× reveals a distinct glow off to its southwestern side that appears elongated for brief moments using averted vision. Switching to my 10-inch SCT, it's apparent the nebula gets brighter the closer it is to HD 17443. Before van den Bergh reclassified vdB 8, astronomers had listed it as a galaxy.

Van den Bergh assigned objects in his catalog to one of two types. He defined Type I nebulae as those in which the

◀ **HIDDEN IN PLAIN SIGHT** Use this and the other accompanying finder charts to track down the vdB reflection nebulae highlighted in this article. You can also refer to the text for detailed star-hopping instructions.

JAUME ZAPATA

▲ **BLUE COCOON** The young, hot, 5.8-magnitude *A*-type supergiant star HD 20041 in Perseus appears shrouded in the blue mist of vdB 10. The image is reminiscent of reflection nebulosities found in M45, the Pleiades, in Taurus.

illuminating star is embedded in nebulosity, while Type II have the illuminating star located outside of the reflected nebulosity. Under this scheme, vdB 8 is classified as a Type I reflection nebula.

In the case of our second target, **vdB 14**, it's a Type II since it lies 18′ southeast of the 4th-magnitude variable blue supergiant star CS Camelopardalis. With just my 5.1-inch reflector at 27×, I believe I can detect the nebula as a soft glow spanning some 6′ × 12′. But it's at 59× that all doubt leaves. With my 6-inch yielding a 1.5° field at 56×, my view of vdB 14 is so good that it isn't trumped by anything my 10-inch has to offer!

I find it easiest to detect the nebula by panning a field or so east of it, concentrate on memorizing the darkness of the sky between the field stars, then slowly swing back west and look for the nebula as I pass over it and keep going. This technique also helps me discern that its middle region is brighter and in which direction it's elongated.

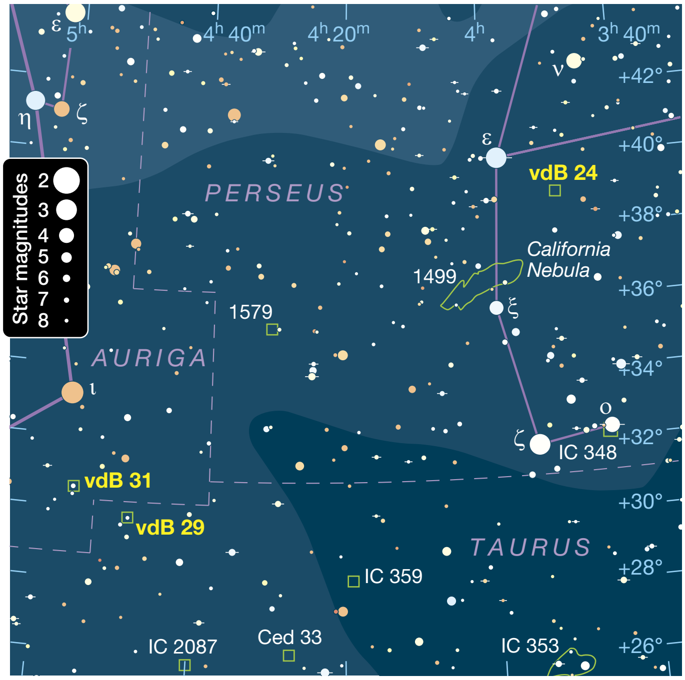
A short 3.2° hop to the southwest of CS Camelopardalis will bring us to the 5.8-magnitude star HD 20041, just over the border into Perseus. At 3,070 light-years distant, it's the illuminating source for the tragically overlooked nebula **vdB 10** that surrounds it. Why tragically? Because with just my 5.1-inch at 27×, the glow around the spectral type *A* supergiant is disproportionally larger and brighter than any found around nearby stars of similar brightness. This is even more apparent at 59×, and with similar magnification in my 6-inch the object spans about 10′. Yet you've probably never seen this Type I nebula plotted on popular star atlases!

Where Light and Dark Meet

Staying in Perseus, let's drop down about 19° south-southeast into the neighborhood of 3rd-magnitude Epsilon Persei. We're seeking **vdB 24**, which lies another 1.9° to the southwest with its associated variable star XY Persei, also designated HD 275877. Using my 6-inch and an eyepiece yielding 37× with a 100° field, the illuminating star slides into view just before Epsilon leaves. Increasing to 112×, I can see a small, fan-shaped glow on the southwestern side of XY Persei that isn't visible around other stars of similar brightness.

Long-exposure photos of the area reveal a complex dark nebula, LDN 1442, that's only partially illuminated by XY Persei. Your challenge here is to see if you can detect the presence of any section of that surrounding dark nebula. I've yet to succeed using my 10-inch but I suspect my 16-inch Dobsonian could do it.

The constellation Auriga, the Charioteer, harbors five van den Bergh reflection nebulae — American astronomer George Herbig discovered **vdB 31** six years prior to the publication of van den Bergh's catalog. The nebula caught Herbig's eye while studying its illumination source, AB Aurigae, which he noted to be an early-type, pre-main-sequence star. It varies in brightness from magnitude 6.9 to 8.4 over a period of 6.6 days. Since then, excitement has only grown as we've learned this 4-million-year-old star is surrounded by a protoplanetary disk that hints at ongoing planet formation.



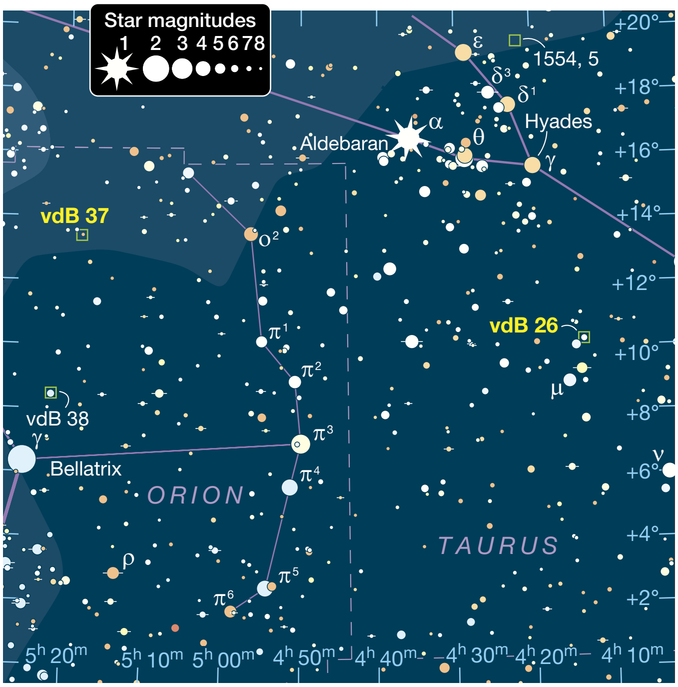
To find vdB 31, search 2.7° south of 3rd-magnitude Iota (ι) Aurigae, near the border with Taurus, for the variable star AB Aurigae at its heart. I can see a small glow around the star using my 5.1-inch at 93×, but the glow is distinctly brighter just off its east-southeastern side. With the extra light-gathering capability of my 10-inch and 200× magnification, the entire glow around AB Aurigae spans about 2′, while a mere 3′ east-northeast of the star lies the orange irregular variable SU Aurigae. Herbig noticed a compact nebula attached to that star that "has a small but much brighter curved nebulous tail." I was excited when I first glimpsed this little nebula in my 16-inch at 300×, while at 440× I noted that it protrudes west of SU Aurigae with a noticeable spike.

As for the Barnard dark nebulae B26, B27, and B28 so prominent in the image on pages 14–15, even with my 16-inch at 100× I wasn't able to see them as "pits" in the sky. Instead, my 6-inch at 37× gave the best view when it showed the area northwest of vdB 31 being void of nearly all stars.

Sliding 1.8° southwest of vdB 31, across the border into Taurus, we find faint **vdB 29**. The object is illuminated by the 7.4-magnitude star HD 30378, which sits at the northernmost point of a wide triangle formed with two other 7th-magnitude stars. Images reveal that HD 30378 weakly illuminates the northwestern region of the larger cloud LBN 792.

I observed vdB 29 one night with my 5.1-inch when my Sky Quality Meter gave a reading of 21.5 magnitudes per square arcsecond, which indicated dark, rural sky. At 59× and 93×, I could detect a large, lopsided glow around the star that was brighter on the western half. This was even more evident in my 6-inch at 112×.

For fans of deep-sky objects, western Taurus can seem like a desert. But if you're willing to wander 5.6° south-southwest from the Bull's nose star, Gamma (γ) Tauri, you can take a



crack at **vdB 26**. It's a faint, circular Type I nebula with the 6.2-magnitude *B*-type star HD 26676 at its heart. Just 19′ southeast lies 5.2-magnitude HD 26793.

Several years ago, I made my first attempt at vdB 26 and was able to confidently identify it in my 10-inch. I was excited about the challenge because the nebula closely mimics the light you see scattered around bright stars in telescopes. At 94×, its dull glow is most discernible as extra brightening to the north and east of HD 26676. Increasing to 150× makes it a little easier, but don't give up if you can't detect it at first try since it can take a lot of patience and practice.

A Trio in Orion

Since stars come in various colors, you'd expect that so, too, would starlight reflecting off a nebula. However, the majority of reflection nebulae appear blue in photographs because the size of the dust grains they're composed of is comparable to the wavelength of blue light. The result is that blue light is scattered more efficiently than longer, redder wavelengths. One notable exception to this is **vdB 37**, a rare yellow Type I nebula set aglow by the 8th-magnitude semiregular variable star V1057 Orionis, an *M*-type red giant.

To find it, seek out 1.6-magnitude Bellatrix, Gamma Orionis, in the Hunter's left shoulder before panning your telescope 7.3° north-northwest. V1057 Orionis sits just below a crooked line of 7th- and 8th-magnitude stars running for 0.7° from east to west. In my 10-inch at 135×, I see vdB 37 as a milky, soft haze around an orange star that isn't apparent around any of the four bright stars north of it. The nebula is distinctly visible on the west-northwestern side of the variable at 200×, while in a large area northeast of it, the number of stars visible drops precipitously. Images reveal the lack of stars is caused by the nebula extending and obscuring starlight in that direction.

Everyone is familiar with Orion's most prominent emission nebula, M42, but what about **vdB 42**, a Type II reflection nebula associated with it? It's an outer wisp of the expansive Orion Nebula complex illuminated by the young, 10th-magnitude *A*-type eclipsing variable EY Orionis (see the image on pages 20–21). Sadly, even though it lies just 1° west-southwest of the Trapezium, you won't find it on popular printed atlases like *Uranometria 2000.0* or the *interstellarum Deep Sky Atlas*. In fact, if it wasn't for the recent sleuthing of Dutch amateur astronomer Victor van Wulfen, I wouldn't have known that vdB 42 was first cataloged by a pair of German astronomers, Johann Dorschner and Joachim Gürtler, in 1963, some three

Cosmic Reflections in the Winter Sky

Object	Type	Constellation	Distance	Illuminating Star (Mag)	Size	RA	Dec.
vdB 8	I	Cassiopeia	930	HD 17443 (8.7)	4′ × 1′	02h 51.5m	+67° 49′
vdB 14	II	Camelopardalis	3,100	CS Camelopardalis (4.2)	23′ × 23′	03h 30.8m	+59° 45′
vdB 10	I	Perseus	3,070	HD 20041 (5.8)	15′ × 10′	03h 15.8m	+57° 08′
vdB 24	II	Perseus	1,390	XY Persei (9.8–11.0)	7′ × 4′	03h 49.6m	+38° 58′
vdB 31	I	Auriga	510	AB Aurigae (6.9–8.4)	8′ × 5′	04h 55.8m	+30° 34′
vdB 29	II	Taurus	510	HD 30378 (7.4)	14′ × 6′	04h 48.2m	+29° 46′
vdB 26	I	Taurus	470	HD 26676 (6.2)	11′ × 8′	04h 13.6m	+10° 13′
vdB 37	I	Orion	1,180	V1057 Orionis (7.7–8.1)	4′ × 3′	05h 18.0m	+13° 25′
vdB 42	II	Orion	1,340	EY Orionis (9.4–10.1)	5′ × 3′	05h 31.3m	–05° 42′
vdB 54	I	Orion	1,090	BD –6° 1287 (10.7)	2′ × 2′	05h 41.9m	–06° 15′
vdB 64	I	Lepus	2,080	UCAC4 380-010611 (12.0)	3′ × 2′	05h 57.8m	–14° 05′
vdB 83	I	Canis Major	3,150	TYC 6516-2583-1 (10.0)	6′ × 6′	06h 39.7m	–27° 15′

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

▲ **GOLDEN VEIL** While the majority of reflection nebulae appear blue in photos, vdB 37 in Orion exhibits a rare yellowish hue due to the 8th-magnitude variable star V1057 Orionis that's illuminating it is an *M*-type red giant.

GARY IMM

years prior to the publication of van den Bergh's list.

To be frank, the object is one of the most challenging reflection nebulae for me to detect in my 10-inch. At 135×, I can just suspect a large, very subtle glow on the northwestern quadrant of EY Orionis; only with 200× can I definitely confirm its presence. In my 16-inch on those truly dark, transparent nights, it's quite obvious at 150× and seems to extend about 2′ from the star.

Let's head back to M42 then swing 2° east-southeast to **vdB 54**. Long-exposure images show the area east of the Orion Nebula is awash in faint nebulosity, with vdB 54's solitary illuminating star, 10.7-magnitude BD –6° 1287, lighting up a very small section (page 20). This nebula, like vdB 8 and vdB 37, was first included in the *Morphological Catalogue of Galaxies* before van den Bergh correctly reclassified it. More recently, the European Space Agency's Gaia satellite was able to pierce the nebula and found BD –6° 1287 to be a tight double star.

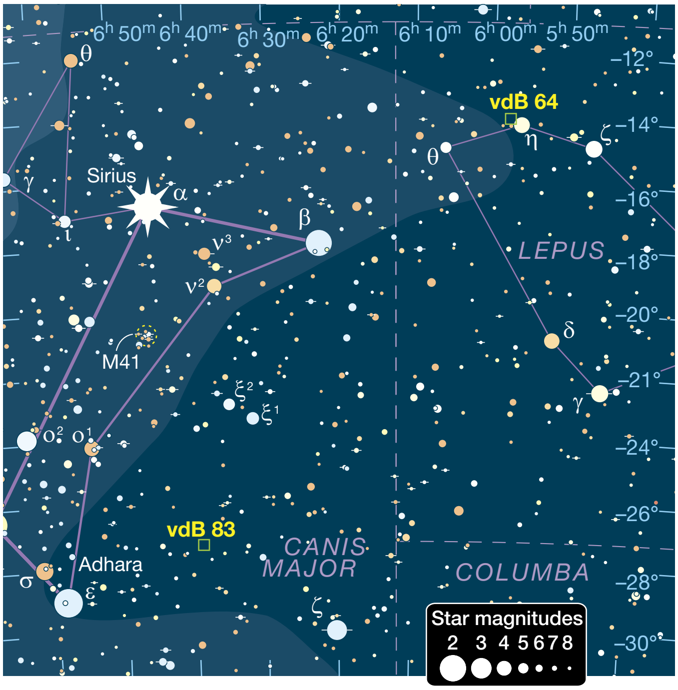
In my 5.1-inch at 59×, the star is, oddly enough, just one of many stars of similar brightness in the field. However, it's the only one with a relatively bright halo spanning 1.5′ across. In my 10-inch at 117×, vdB 54 is an extremely small but distinct glow around the star once you know what to look for. It's so bright that for fun, I tried (but failed) to detect the nebula in my image-stabilized 15×50 binoculars.

Southern Pearls

Except for the vdB reflection nebulae in the Pleiades, location-wise they don't get much easier to find than **vdB 64** in northeastern Lepus, the Hare. That's because it surrounds a small, sparse open cluster of stars 21′ east-northeast of 3.7-magnitude Eta (η) Leporis. Last winter I was surprised to detect its brightest part in my 6-inch at just 71× as a peculiar softness around the 12.0-magnitude star UCAC4 380-010611. The best way I can describe its appearance is that, unlike nearby stars of similar brightness, the sky just isn't black right up against the star.

Switching to my 10-inch, I like to get a tight focus on lemon-hued Eta at 200× before pushing over to the "nebulous star." Once there, my eye is immediately met with a glow on the northeastern side of the star. With patience and a magnification increase to 260×, a 15th- and a 16th-magnitude star are revealed inside the nebula. This is opposite to what I was expecting since most images make the two faint stars seem brighter than the nebula itself.

The final reflection nebula we'll visit lies more than 3,000 light-years away in southwestern Canis Major. It transits the



meridian this month around local midnight, so try to stay awake! Known as **vdB 83**, it lies 4.5° west-northwest of Adhara, Epsilon Canis Majoris, though *interstellarum Deep Sky Atlas* has it plotted 13′ too far northwest. The object was first found by Russian astronomer Boris Vorontsov-Velyaminov, who mistakenly cataloged it as interacting galaxy group VV 134.

In my 10-inch at 91×, I see an equilateral triangle that measures 3.5′ on a side, with vdB 83's illuminating star, 10th-magnitude TYC 6516-2583-1, being the brightest and southernmost of the triangle. That star is in focus with direct vision but goes out of focus when I switch to averted vision. Increasing to 135× reveals the culprit — a close companion star just 13″ northwest. But now I can detect a glow that's noticeably more subtle than vdB 64 and consistently more obvious north of the stellar pair. It spans less than 1′ even though images reveal the entire triangle is engulfed in a fine mist, with an even more elusive vdB 84 just 10′ south-southeast.

I've found out that most observers haven't seen many reflection nebulae even though they are some of the brighter deep-sky objects. One reason for this is because the objects rarely, if ever, have a listed visual magnitude. Another is that they're one of the first to fall victim to light pollution — don't be afraid to try a broadband filter (so-called "galaxy filter") if you live in a more suburban location. So, use this article under the darkest skies you can find, and I hope you have as much fun looking for van den Bergh's nebulae as I have!

■ Is it possible that Contributing Editor **SCOTT HARRINGTON** is a bigger fan of nebulae than of galaxies? You can reach him at **sn4ark@gmail.com**.

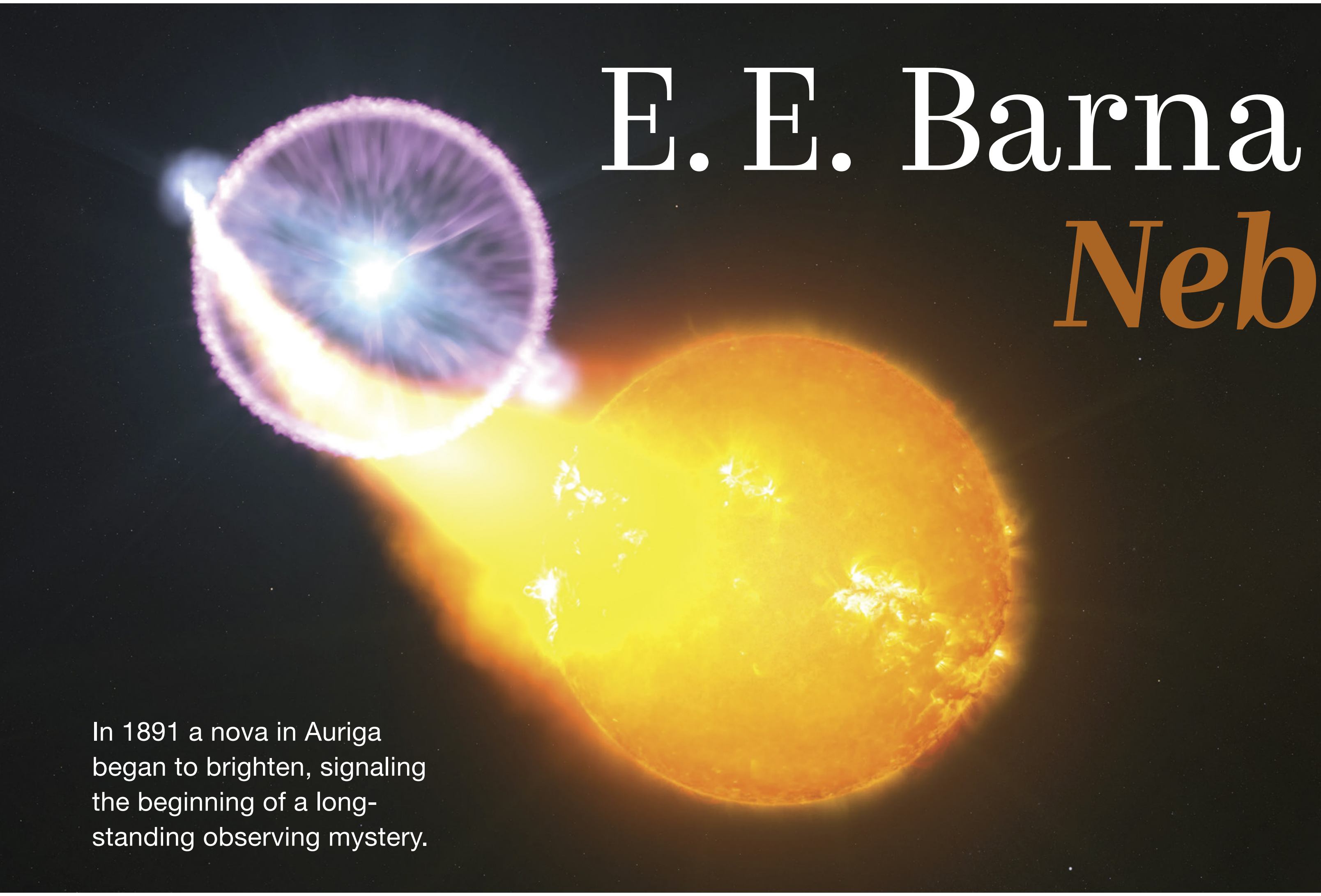
FURTHER READING For images of the entire catalog, check out Gary Imm's book *The Complete vdB Catalog* on **amazon.com**.

OVERSHADOWED IN ORION
The small, bluish patch at right is vdB 42, illuminated by the young, 10th-magnitude variable star EY Orionis. At left is smaller but brighter vdB 54. Outshining both reflection nebulae is the immense, colorful emission nebula complex of M42, the Orion Nebula.

SEAN WALKER


M42
vdB 42

E. E. Barna
Neb



In 1891 a nova in Auriga began to brighten, signaling the beginning of a long-standing observing mystery.

Edward Emerson Barnard needs no introduction to *Sky & Telescope* readers. His name is attached to the many comets he discovered, a nearby star, a large nebulous loop in Orion, and to numerous Milky Way dark nebulae cataloged as Barnard objects (*S&T:* Aug. 2023, p. 28). He is also remembered for his discovery of Jupiter's fifth satellite, Amalthea — the first such find since Galileo and Simon Marius discovered the planet's four largest moons 282 years earlier (*S&T:* Aug. 2025, p. 20).

Born on December 16, 1857, Barnard grew up in crushing poverty in Nashville, Tennessee. He might have been lost to obscurity but for the chance of being hired by a photography gallery at age nine. There he learned darkroom techniques and became intrigued by the night sky. His interest in astronomy truly began a decade later when he chanced upon a book on the subject, *The Complete Works of the Reverend Thomas Dick, Volume 2*. Within a few years he'd saved enough of his meager earnings to acquire an excellent, 5-inch refractor telescope. An enthusiastic observer, Barnard initially specialized in the discovery of comets, finding his first in 1881. Several more followed and led to his appointment to the original staff of the Lick Observatory, in California. The director, Edward Singleton Holden, knew that comet discoveries were excellent public relations for the fledgling institution. But soon after Barnard arrived at Lick, he began to prioritize other investigations, including wide-angle Milky Way and comet photography with an old and inexpensive

▲ **BINARY BLOWUP** The 1891 Auriga nova that Edward Emerson Barnard observed is categorized as a *classical nova* — a stellar duo consisting of a white dwarf interacting with a main-sequence, subgiant or red giant star. This illustration depicts another classical nova, V407 Cygni. That system differs from T Aurigae in that the white dwarf is paired with a red giant instead of a main-sequence star.

▶ **INSIDE THE DOME** The James Lick Telescope at the University of California's Lick Observatory is depicted in this engraving (c. 1890) which appeared in an 1895 American history book. The 36-inch refractor was the largest such telescope in the world until 1897, when it was superseded by the 40-inch refractor at Yerkes Observatory in Wisconsin.

NASA GODDARD SPACE FLIGHT CENTER / S. WIESSINGER rd and the

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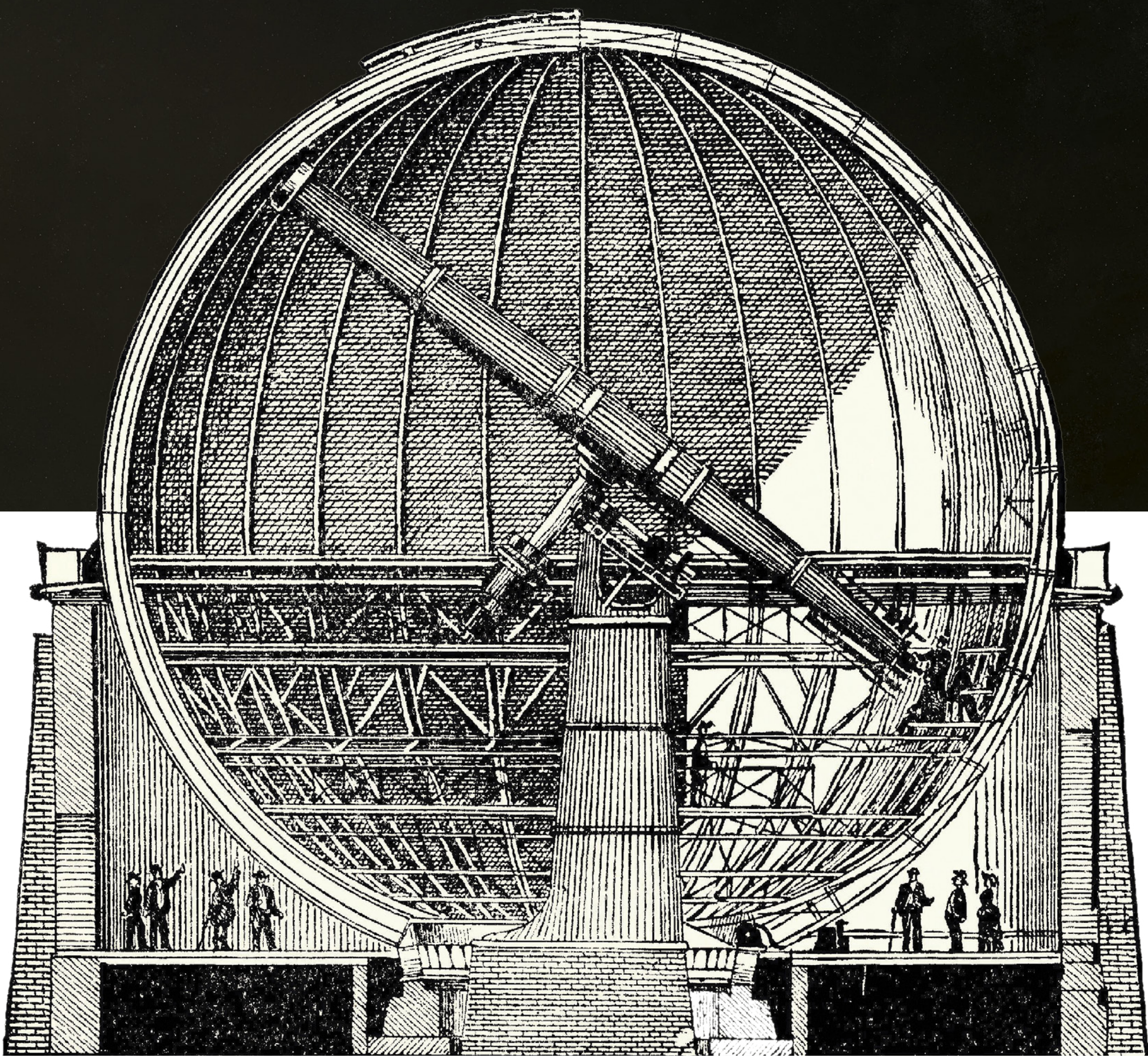
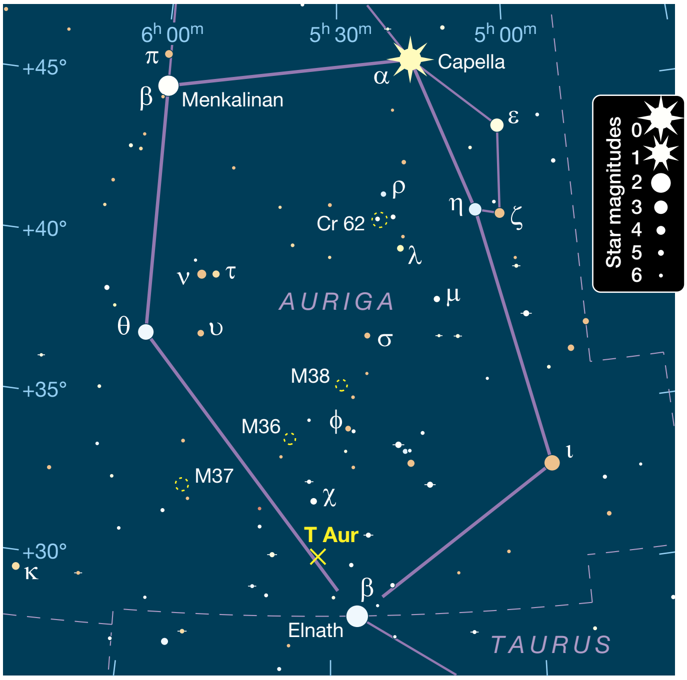


M&N / ALAMY STOCK



▲ **"X" MARKS THE SPOT** This chart shows the location of T Aurigae, which erupted in 1892 and peaked at magnitude 4.5. Presently the star slumbers dimly at around magnitude 15, though it could brighten once again in the distant future.

portrait lens Holden had acquired principally to capture the total solar eclipse of January 1, 1889 — the centerline of which swept across California some 220 km (140 miles) north of the observatory.

Early Struggles

As the most junior member of the Lick staff, Barnard was assigned to the observatory's 12-inch refractor instead of the observatory's crowning glory, the great 36-inch Clark refractor. At the time it was the largest refractor in the world and was ultimately surpassed in 1897 by only one other, the 40-inch at Yerkes Observatory, in Wisconsin. A compulsive observer who hated wasting even a scrap of clear night, Barnard chafed at having to work with the smaller instrument while Holden — who reserved two nights per week on the 36-inch to himself — often "voted it cloudy" by 10 o'clock and went home. Barnard grew increasingly unhappy and embittered. So, in a bid to gain access to the 36-inch, he went over Holden's head and appealed directly to the Board of Regents of the University of California, the institution that controlled the observatory. Before the regents could come to a decision, Barnard's colleague and friend Sherburne Wesley Burnham resigned after becoming increasingly frustrated with Holden's autocratic manner. As a result, beginning on July 1, 1892, Barnard inherited Burnham's Friday-night slot on the great telescope.

Barnard's vision was of legendary acuity. On one occasion, Burnham was observing the Trapezium in Orion with the 36-inch and was measuring a faint star that optician Alvan G. Clark had discovered during tests of the instrument. As Barnard wandered into the dome, Burnham invited him to take a look. In an item appearing in *Monthly Notices of the Royal Astronomical Society*, Burnham wrote that Barnard ". . . detected another new star just preceding the Trapezium, which had been missed by all who had examined it with this telescope. . . . He also saw that this exceedingly faint star was itself double." Before the night was through, Barnard discovered a still fainter Trapezium star, but this one Burnham had to take on faith — no one else at Lick was able to see it.

As soon as Barnard regularly started having access to the great telescope, he was eager to make the most of the opportunity. Matching his keen eye with the powerful lens, he set out to examine the surface of Mars, which was attracting feverish interest at the time due to the controversy over its purported canals. He also hoped to discover "new objects," like the two small Martian moons (Phobos and Deimos) that Asaph Hall had found in 1877 with the 26-inch Clark at the U.S. Naval Observatory in Washington, D.C.

On Saturday morning, August 13, 1892, Barnard was searching for possible satellites orbiting Venus, then a brilliant crescent in the morning sky. He noted no faint objects in the field but did set down the position of a star he estimated to be 7th magnitude. When he attempted to identify it later, he found nothing that bright listed in Friedrich Argelander's great catalog *Bonner Durchmusterung*. What Barnard actually observed is a mystery that has long exercised historians of astronomy ever since. Unfortunately, the great observer never returned to the field himself. Little wonder — he was soon preoccupied with an exciting new discovery.

A "New Star" in Auriga

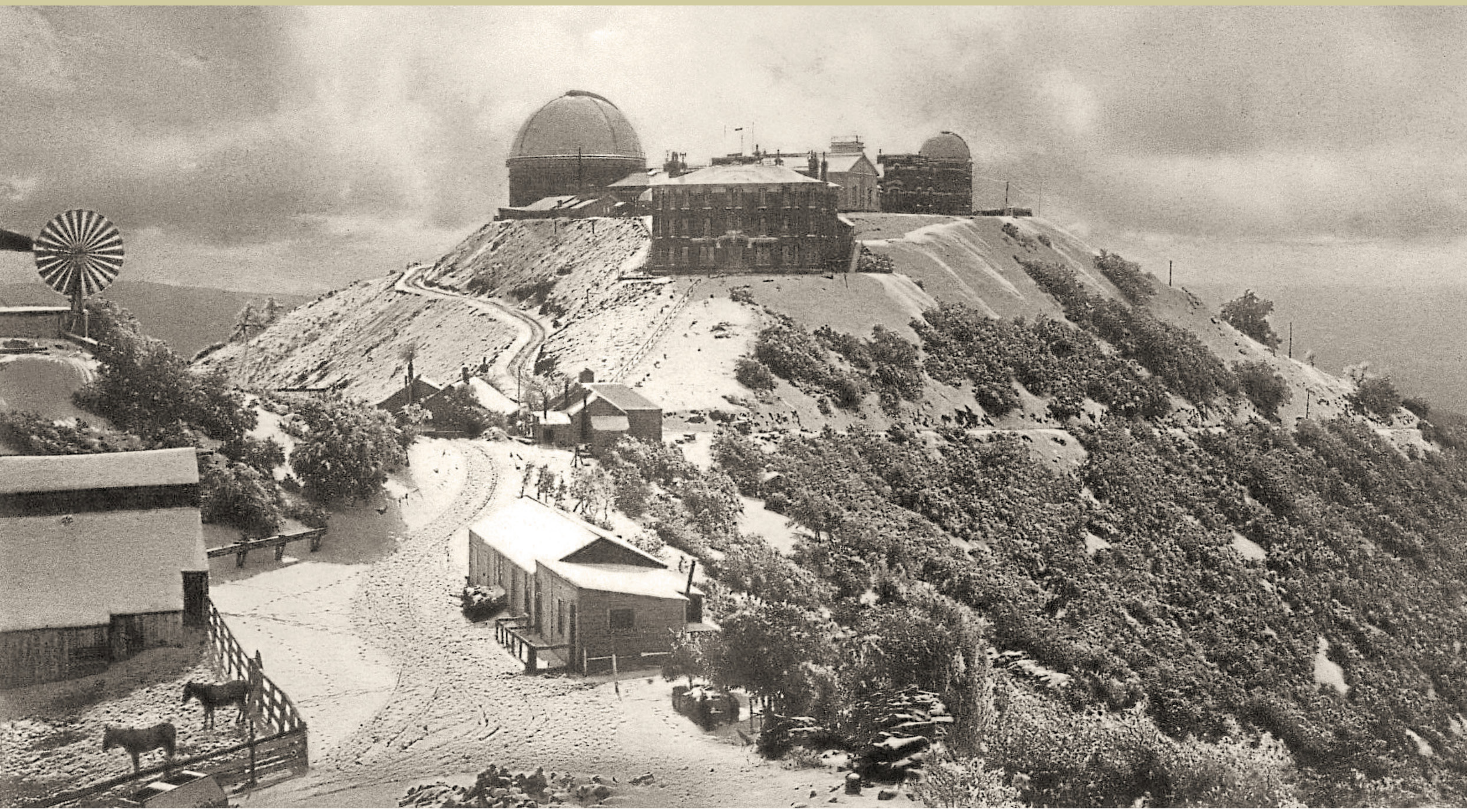
Barnard's attention was captured by Nova Aurigae (now known as T Aurigae, or T Aur), a 5th-magnitude interloper. Edinburgh, Scotland, amateur astronomer Thomas David Anderson announced its discovery on January 31, 1892 — he had first seen it on January 24th. Later, it was found that a Harvard College Observatory patrol photograph had serendipitously recorded it on December 12, 1891, though it was absent on a plate taken three days earlier. The nova peaked at magnitude 4.5 and remained near 5th magnitude for three months, after which it began to rapidly fade. By April 1892, Burnham noted it at 16th magnitude in the 36-inch refractor.

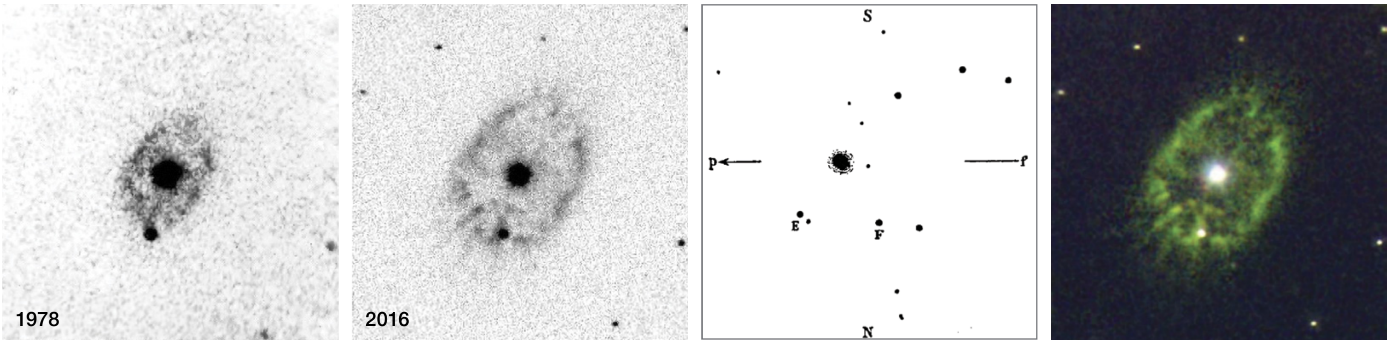
T Aurigae was the first nova that astronomers observed undergoing a deep, months-long dimming. We now know the star's fading was caused by ejecta enveloping the star in a dense dust cloud. As the dusty shroud expanded and thinned, the still-bright star within reappeared. In the early morning hours of August 19, 1892, Lick astronomer William Wallace Campbell was surprised to see T Aurigae brighten a second time. He estimated it had risen to magnitude 10.5, though a recent analysis by American astronomer Bradley Schaefer and colleagues published in the *Astronomical Journal* shows the actual magnitude was in fact 11.4. Campbell immedi-

◀ **EAGLE EYE** In this September 1892 self-portrait, legendary observer Edward Emerson Barnard stands by the 36-inch Clark refractor at Lick Observatory after using the telescope to discover Jupiter's fifth satellite, Amalthea. One month earlier, he made a mysterious observation of nebulosity surrounding the newly discovered nova in Auriga.

▼ **HILLTOP HAVEN** Lick Observatory is situated on the summit of Mount Hamilton, in the Diablo Range just east of San Jose, California. It would have appeared much as it is shown in this photo captured during Barnard's time at the facility. The 36-inch refractor is housed in the large dome, and Barnard, until 1895, lived in a small house hidden behind the small hillock with the windmill. At the time, transportation down the mountain was exclusively by stagecoach (note the corral at lower left).

BARNARD AT LICK: AUTHOR'S PRIVATE COLLECTION: LICK OBSERVATORY
EXTERIOR: D. APPLETON & COMPANY / WIKIMEDIA COMMONS / PUBLIC DOMAIN





▲ **MULTIPLE VIEWS** Hydrogen-alpha photographs of the nebulous shell around Nova Aurigae, showing expansion between 1978 *(left)* and 2016 *(second from left)*. Barnard's August 19, 1892, sketch (*third from left*) shows nebulosity surrounding Nova Aurigae, as published in the journal *Astronomische Nachrichten* (*Astronomical News*). He described the object as "pretty bright and dense" and used a micrometer to measure its diameter to be 3 arcseconds. A 2020 false-color image *(far right)* of the shell of T Aurigae made by combining three narrowband images.

ately summoned Holden and another Lick astronomer, John Martin Schaeberle, to the dome. They confirmed the star's resurgence, and the next day Holden telegraphed the exciting news to the Harvard College Observatory.

The story was even covered in newspapers, which is how Barnard first learned of it, despite being on staff. Naturally, he was eager to have a look. As luck would have it, the night of August 19th was a Friday, and so he had the 36-inch at his disposal. When he located the star in the giant refractor, he saw "a small bright nebula with a star-like nucleus of the 10th mag." He noted that the nebula appeared blue-white and, "found by the micrometer, to be 3″ in diameter."

Unbeknownst to Barnard, Campbell was also observing the star that night with a spectroscope attached to the observatory's 12-inch refractor. The spectrum revealed the bright

▼ **GOLDEN YEARS** Although still in use for public programs, the 36-inch refractor long ago retired from active duty as an instrument for frontline astronomical research. Nevertheless, classic instruments like this remain a source of awe and are still capable of vividly conjuring the memory of great observers like E. E. Barnard.

emission lines characteristic of a planetary nebula and that the gas in the nebula was rushing earthward at a staggering speed of 300 km/s (670,000 mph). It appeared that Barnard and Campbell had independently discovered that the object "seemed to have become transformed into a small nebula or nebulous star," as Barnard recounted in an 1895 article in the magazine *Popular Astronomy*.

Not So Fast

Barnard's visual detection of the nebula seemed to be yet another example of his amazing visual acuity. The story of this sighting has gone largely unquestioned, passed down from one author to the next. Thus, Edwin B. Frost, director of Yerkes Observatory when Barnard was on staff there later in his career, wrote in his obituary of the great astronomer, "He, in fact, discovered visually, in the summer of 1892, the nebulous ring about Nova Aurigae." Robert Burnham, Jr., in his popular, three-volume *Celestial Handbook*, seems to agree. "Using the 36-inch Lick refractor, E. Barnard found that the image of the nova appeared as a diffuse nebulous disc, measuring about 3″ in diameter." It's an account I repeated myself 30 years ago, when I wrote Barnard's biography, *The Immortal Fire Within*. And yet, it turns out, he could not have seen the star's nebular shell.

German-born astronomer Walter Baade first photographed the feature in 1943 using one of the large reflectors at Mount Wilson Observatory, in California. Baade's image shows an elliptical nebula, 12 arcseconds in diameter. Since then, researchers have kept the object under close surveillance and found it to have a linear expansion rate of 0.10 arcsecond per year, corresponding to a velocity of about 350 km/s. By 2016, the nebula had grown into an ellipse measuring some 25 by 19 arcseconds. Working back to the start of the eruption, the nova's shell would have been tiny when Barnard observed it — only 0.07 arcsecond across. In short, it wouldn't have been possible for Barnard to make out the nebula. And yet, he apparently saw *something*. But what?

The solution to this mystery turns out to be an all-too-familiar optical error called *chromatic aberration* — a defect

EXPANDING NEBULA PAIR AND COLOR IMAGE OF NEBULA: EDGAR SANTAMARIA / WIKIMEDIA COMMONS / CC BY-SA 4.0 (3); BARNARD SKETCH OF NEBULA: INTERNET ARCHIVE / PUBLIC DOMAIN; LICK OBSERVATORY MODERN INTERIOR PHOTO: PHILLIP BOND / ALAMY STOCK inherent in achromatic refractor telescopes, like the 36-inch f/19 at Lick. As most readers know, in a reflector all colors are brought to a common focus, but in a refractor, they are not — red and blue light have slightly different focal points; the larger the lens, the worse the effect. When Barnard observed the nova, he compared it to an unrelated yellowish star. When that star was in focus, there was no halo around T Aurigae. However, as he refocused on the nova, a nebulous, woolly patch appeared. Tellingly, observers equipped with reflectors at the time failed to see anything there but a perfectly sharp star.

Spectra of novae are notorious for having an excess of blue light. When Barnard made his observation, the nova was radiating largely in the blue end of the visual spectrum, with the brightest emission line appearing at 501 nanometers. By focusing on the dominant wavelength, light from other colors was thrown into an out-of-focus, nebulous halo. The fact that Barnard was able to make the nebula come and go simply by changing focus at the eyepiece shows conclusively that the apparent nebulosity was merely a telescopic effect. Even Barnard suspected as much and admitted that its appearance might simply be "an effect of some peculiarity of its spectrum," though afterwards he wavered and over the years seemed to allow for the possibility that the nebula he saw was genuine.

Regardless, the Auriga nova is historically important because Anderson's discovery kickstarted a worldwide program of amateur nova hunters. Along with T Coronae Borealis in 1866 and Nova Cygni 1876, T Aurigae was among the first novae studied spectroscopically. In 1958 it became just the third shown to be an eclipsing binary, having a period of 4.9 hours and an eclipse depth of 0.18 magnitude. It is the prototype (along with its sister variable DQ Herculis) of recurrent novae categorized as *D-class*, typified by "dust dips" in the star's light curve.

We now know that all novae are close binary systems in which a white dwarf accretes matter from a companion (either a main-sequence, subgiant, or red giant star). The white dwarf in the T Aurigae system has about 0.8 solar mass, though estimates range from 0.68 to 0.93. Eruptions like that of 1891 involve the transfer of hydrogen from the companion onto the surface of the white dwarf. When enough material has accumulated, surface thermonuclear reactions are triggered, and the dormant white dwarf enjoys a brief revivification. White dwarfs in D-class novae are distinctly low-mass, and as such, the recurrence time scale for an eruptive episode is greater than 100,000 years. Someday T Aurigae will undergo another dramatic brightening. Here's hoping someone will be around to see it!

■ Contributing Editor **WILLIAM SHEEHAN** is the author of the Barnard biography, *The Immortal Fire Within.* He also independently discovered Nova Cygni in 1975 (along with thousands of others) after arriving home late from his job as a parking ramp attendant.

A Book That Changed a Life

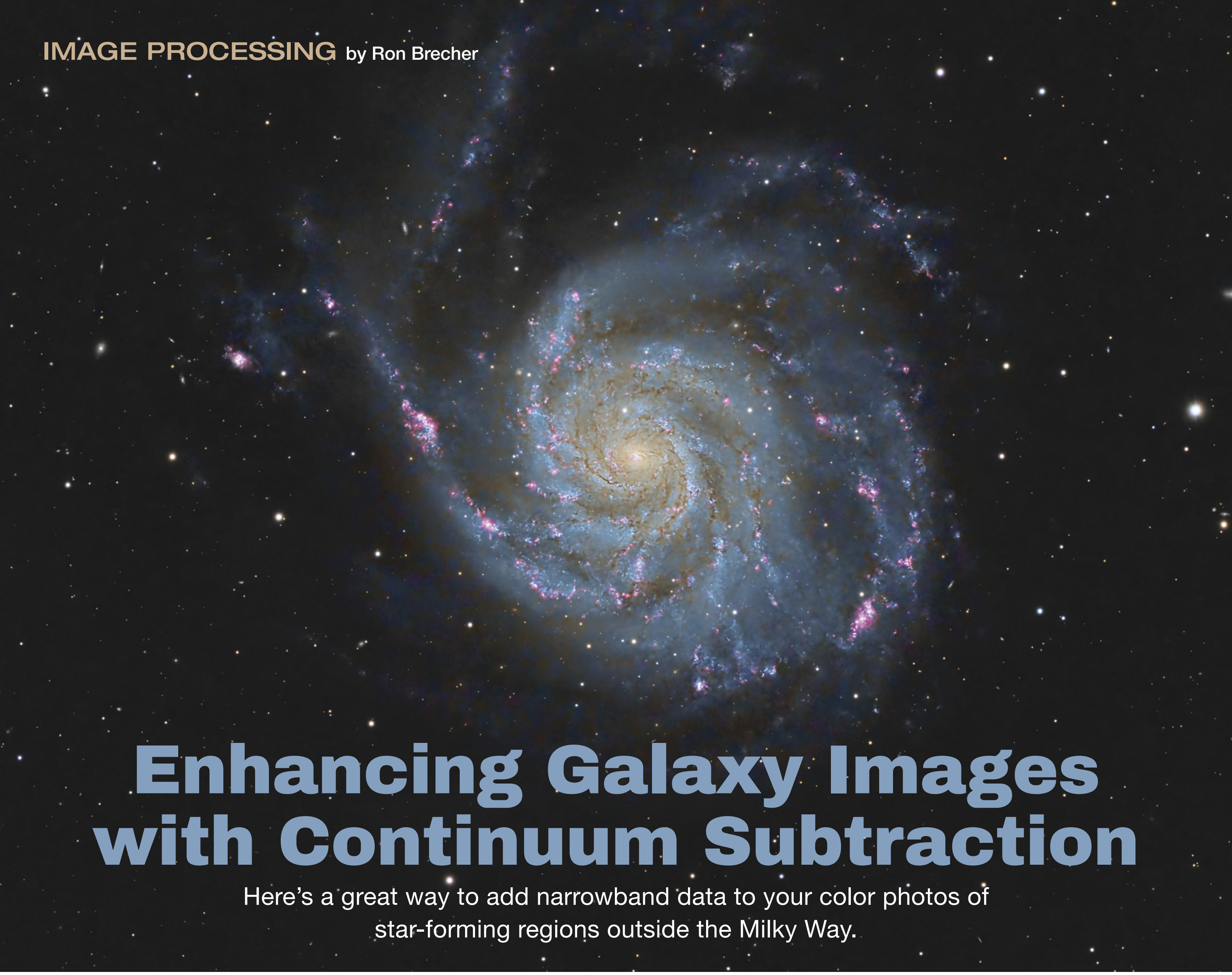
Born in 1857 and growing up in Nashville, Tennessee, during and after the Civil War, Edward Emerson Barnard had only two months of formal education before being sent to work at age nine to support his impoverished family. At a time when there were no child labor laws, he was fortunate to be employed at a photographic gallery where he received mentoring and on-the-job training through which he developed the photographic techniques he later applied so effectively.

Despite his later renown as an astronomer, Barnard came to the subject late. When he was 19, he was living alone in the top story of a downtown hotel and, though he was curious about the world around him, he hadn't acquired even rudimentary knowledge of the heavens, such as the names of bright stars and planets. One night an acquaintance arrived unannounced. The visitor was, as Barnard said, "a born thief." On this night the visitor came around hoping to borrow money. It was not the first time, and Barnard's earlier loans had not been repaid. But this time the "thief" had a book in his possession, which he gave as a loan surety, though Barnard was certain the book had been stolen. He never saw the boy again, but the book changed his life.

The work in question was the second volume of *The Complete Works of Reverend Thomas Dick*, which included a small section of star charts. Immediately Barnard set out to use them to explore a patch of sky visible from the open window of his room. As he recalled long afterward:

> *In less than an hour I had learned the names of a number of my old friends; for there was Vega and the stars in the Cross of Cygnus and Altair and others that I had known from childhood. This was my first intelligent glimpse into astronomy. It is to be hoped that my sins may be forgiven me for never having sought out the rightful owner of that book in all these long years.*

Barnard's close friend and Lick Observatory colleague, Sherburne Wesley Burnham, later noted that the young astronomer studied the book "with great avidity, and it awakened a thirst for astronomical knowledge. . . . He had never seen either a telescope or an observatory. All he knew of the literature of the subject was found in this old book."



Enhancing Galaxy Images with Continuum Subtraction

Here's a great way to add narrowband data to your color photos of star-forming regions outside the Milky Way.

Most astrophotographers remember their first time capturing M42, the Orion Nebula, or perhaps other bright nebulae like Eta Carinae and the Lagoon Nebula. But did you know that you can image similar nebulae in other galaxies outside the Milky Way? These vast, diffuse clouds of ionized hydrogen atoms, known as H II regions, appear as little bubblegum-hued knots and globules in most nearby galaxies like the Magellanic Clouds, NGC 6822, and even more distant ones like M31 and M33. Typically, these nebulae are faint and tough to bring out, especially when imaging through typical color filters.

The secret to producing eye-catching images of these galaxies is by enhancing natural-color, broadband images with additional data recorded through narrowband filters. The results are indeed stunning, but the challenge is how to fold that narrowband information into the final image without imparting a color bias to parts of the galaxy that ought to appear neutral, bluish, or yellowish. The best way to do this is to employ a technique known as *continuum subtraction*. Let me show you what it is and how to do it.

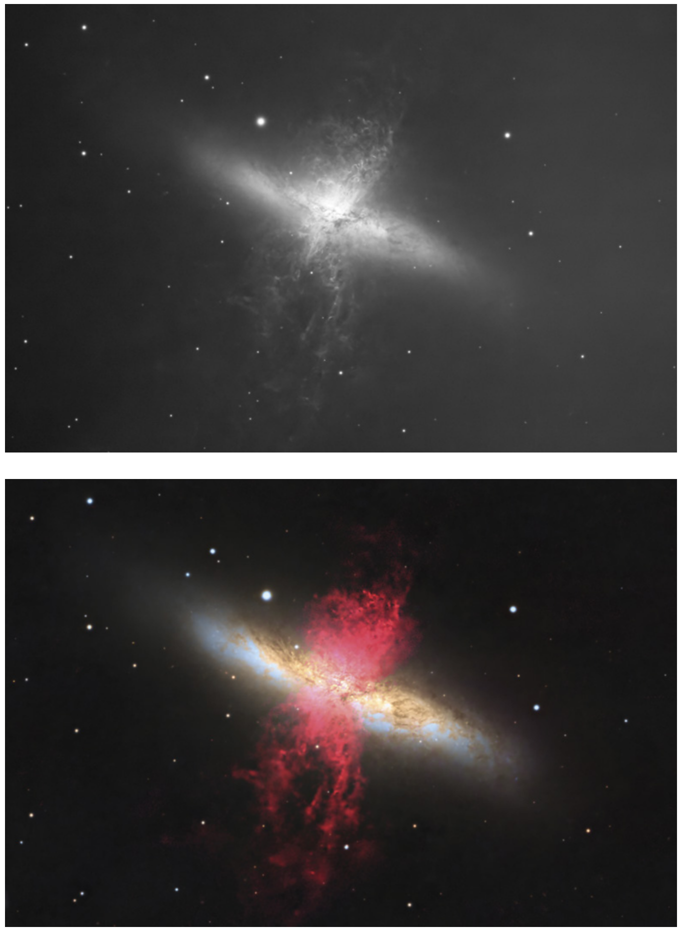
What Is Continuum Light?

Stars emit light across the entire range of visible wavelengths, from about 400 nanometers at the violet end of the spectrum to 700 nm at the red end. In other words, they emit light over a continuum of wavelengths that includes all the colors of the rainbow. This continuous range also includes the wavelengths emitted by emission nebulae and supernova remnants, mainly hydrogen alpha ($H\alpha$), doubly ionized oxygen (O III), and ionized sulfur (S II) at 656.3 nm, 495.9 and 500.7 nm, and 672.4 nm, respectively.

▲ **NEBULOSITY EVERYWHERE** Local galaxy M101 in Ursa Major sport numerous pink nebulae, all of which are star-forming regions like our own M42. These regions stand out better when narrowband signal is used to enhance the color image with the continuum-subtraction technique described by author Ron Brecher.

CREDIT: ALL IMAGES ARE COURTESY OF THE AUTHOR

▲ **DECONTAMINATION RESULT** These portraits of M33, the Triangulum Galaxy, show the spiral with hydrogen-alpha (Hα) enhancement applied two different ways. The version at bottom adds the continuum-subtracted Hα exposure and displays natural-looking colors — especially the blues and yellows — compared to the image at top where the Hα was applied without subtracting the continuum signal.



▲ **SELECTIVE APPLICATION** The Hα result of M82 *(top)* contains relatively strong continuum emissions in the disk of the galaxy that could have overwhelmed its blue and gold tones. Continuum subtraction ensured that addition of the narrowband data enhanced only the massive Hα structures bursting forth from this starburst galaxy *(bottom)* in Ursa Major.

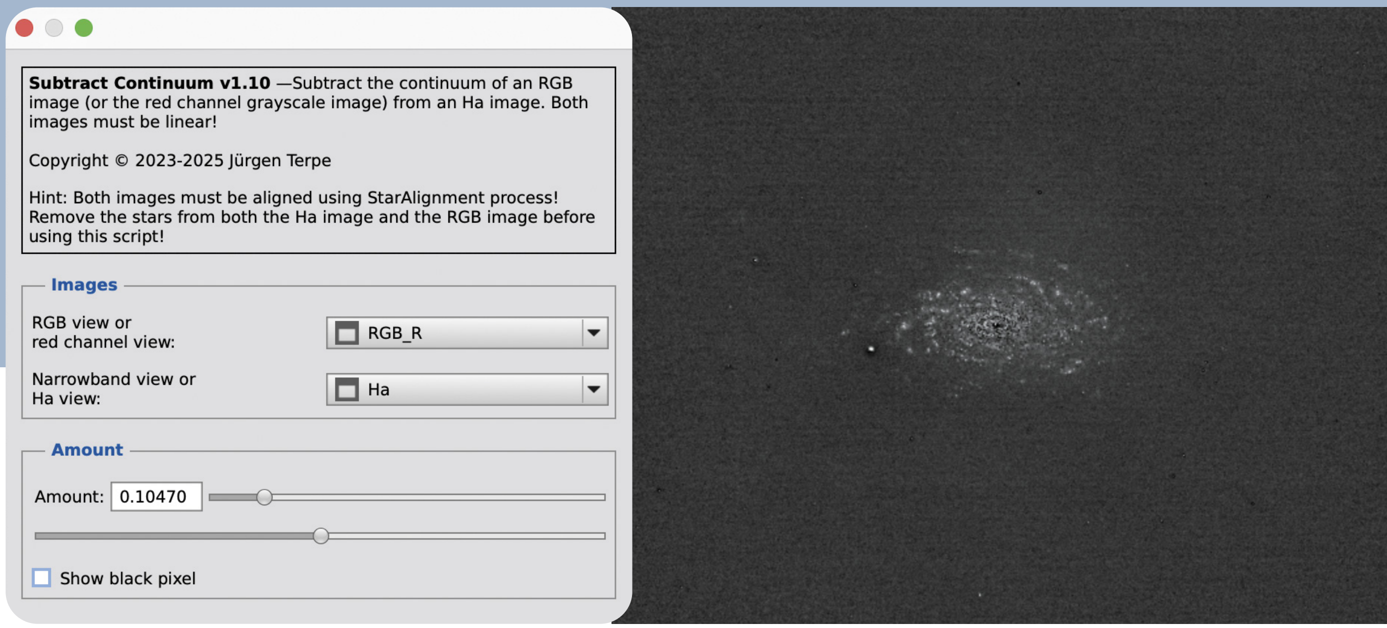
Continuum light in a narrowband image refers to the fraction of starlight, both direct and reflected, that happens to be at the same wavelength that's transmitted through your narrowband filter. This unwanted continuum signal doesn't come from non-stellar emission objects, so it's considered to be contaminating the narrowband image. It shows up most prominently in the spiral arms of galaxies. Continuum emissions can also affect narrowband images of nebulae and supernova remnants within the Milky Way, in regions where there are integrated flux nebulae, which represent the dim glow of dust-reflected starlight from billions of Milky Way stars. It should be noted that light from H II regions primarily consists of Hα, but it also contains O III and other trace emissions.

Simply adding an Hα image into your broadband data often imparts an overall reddish cast to the resulting picture. Similarly, adding O III exposures can impart a greenish-blue color cast to your color picture. You can achieve a more natural galaxy appearance while adding narrowband exposures by first reducing the continuum signal in the Hα image, so that only the galaxy's H II regions are enhanced. This leaves its typically yellowish core, brownish dust lanes, and bluish spiral arms virtually unchanged.

Note that continuum subtraction isn't required for narrowband images of nebulae and supernova remnants in the Milky Way. Unlike distant galaxies, such local objects aren't considered to be broadband light sources. You can remove Milky Way stars, which are discrete broadband light sources, from narrowband images using tools such as *StarNet* (**starnetastro.com**) or *StarXterminator* (**rc-astro.com**). Nevertheless, it's worth experimenting and comparing results with and without continuum subtraction to see which works best for your data.

Tools and Scripts

Let's focus on continuum subtraction from Hα exposures of spiral galaxies, since amateurs commonly add this wavelength to enhance the visibility of emission nebulae along



▲ **ISOLATED WAVELENGTH** Jürgen Terpe's ***ContinuumSubtraction*** script included in his Toolbox repository is easy to use with properly prepared data. It also includes a real-time preview so you can try different settings before applying it to your data.

the spiral arms. The same technique can be used for any narrowband filter.

To use the continuum subtraction technique, you'll of course need an Hα image that contains the arm structures you're after, along with regular red, green, and blue exposures to create the natural-color image that you're going to enhance. The unwanted continuum emissions from the target galaxy's billions of stars are also present in those RGB shots, and we'll be using them in two different ways.

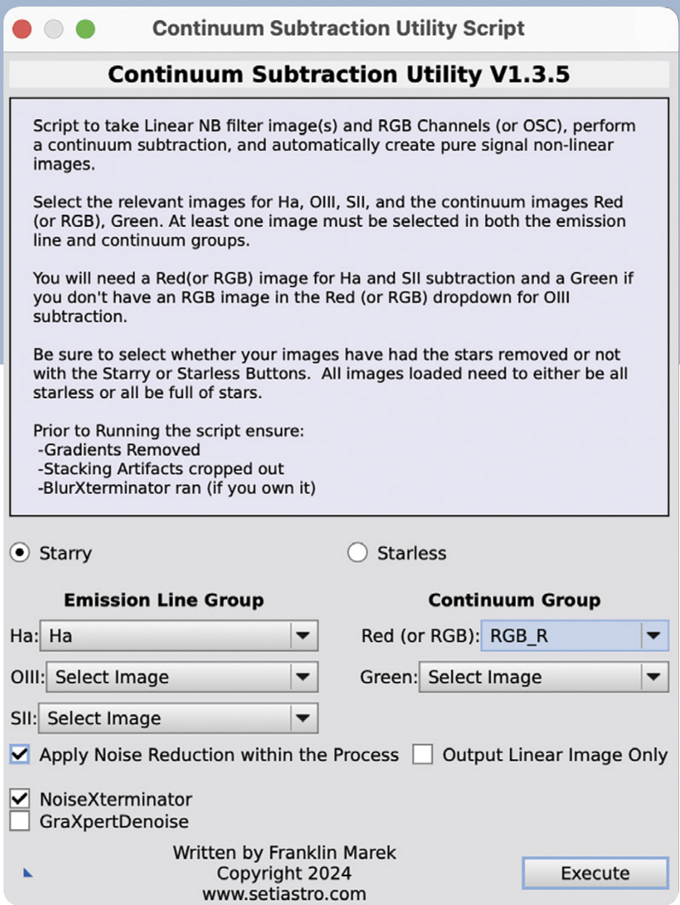
If you photograph with a monochrome camera, start by preparing your master Hα image — that is, performing all the usual image-reduction steps like calibration, alignment, and stacking. For one-shot color (OSC) cameras, acquire your narrowband images using either an Hα filter or a dual-bandpass filter that transmits both Hα and O III. Reduce this OSC narrowband information with the additional step of *debayering* to convert the raw OSC data into a full-color RGB composite image. Next, you'll need to extract the red channel of the master image and use it as your Hα image. You can accomplish this in *PixInsight* (**pixinsight.com**), using the ChannelExtraction process from the pulldown menu: ***PROCESS > ChannelManagement > ChannelExtraction***.

Next, use this red continuum image to clean up the Hα image. Astrophotographers with monochrome cameras can apply their red-filtered data for this process. Some additional cleanup should be done on both the Hα and red exposures. External factors like moonlight, light pollution, or imperfect flat-field correction may produce gradients that must be removed from both images. *PixInsight* includes four processes that can assist with this task: ***AutomaticBackgroundExtractor***, ***DynamicBackgroundExtraction***, ***GradientCorrection***, and ***MultiscaleGradientCorrection*** (*S&T:* June 2023, p. 60). These are all found in the PROCESS menu. After correcting any uneven field illumination, you can also apply deconvolution and noise reduction, if desired. Be sure to keep all your images in a linear state; stretching the data before subtracting the red from the narrowband image produces inaccurate results.

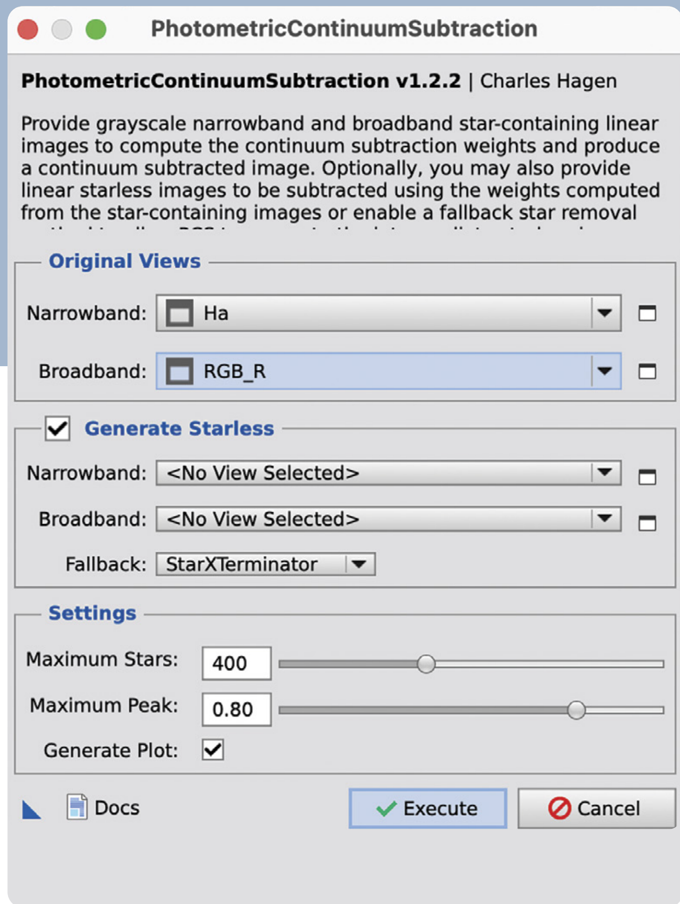
We're now ready to perform the continuum subtraction. There are several ways to approach this in *PixInsight*. One requires removing the stars from your data with the earlier mentioned plug-ins. Additionally, the tools I prefer for the process are third-party scripts that you'll need to install by adding update repositories to *PixInsight*. My favorite ones are located in the following repositories — note that, except for the last one, the following links don't take you to a web page in your browser and will return an "Invalid request" error message:

- Charles Hagen's *NightPhotons*: https://raw.githubusercontent.com/charleshagen/pixinsight/main/updates/
- Franklin Marik's *Seti-Astro*, which is useful for both regular and star-subtracted images: https://raw.githubusercontent.com/setiastro/pixinsight-updates/main/
- Jürgen Terpe's *Toolbox*, which requires starless images: https://www.ideviceapps.de/PixInsight/Utilities/

To install any of these collections of scripts, select the pull-down menu ***RESOURCES > Updates > Manage Repositories***, then click ***Add*** and type in each the URLs of the repository locations listed above. Click ***OK*** to save, and exit back to the main screen. Now select ***RESOURCES > Updates > Check for Updates***. Click ***Select All*** and then ***Apply***. Any available updates to each script will then be downloaded and queued



▲ **STARS OPTIONAL** Seti-Astro's ***ContinuumSubtractionUtility*** script allows you to work on images with or without stars while working on multiple narrowband-filtered exposures.



▲ **MEASURED APPROACH** The ***PhotometricContinuumSubtraction*** script uses information about the stars in the Hα and continuum (red) image to estimate and subtract the continuum emission.

up for installation. When you quit the program, you'll see a dialog box confirming the installation.

In my experience, no single script performs best for every data set, so try each of them to find the optimum fit for your images. Each script dialog box provides easy-to-follow instructions. All require you to select your linear, cleaned-up Hα and continuum images — either with stars or without stars, as required by the particular script. All the other settings in these scripts are very straightforward to understand and use, and experimenting will help you home in on your desired result. Each script produces a new continuum-subtracted image rather than overwriting the originals, so it's easy to analyze and compare the effect of changing various settings.

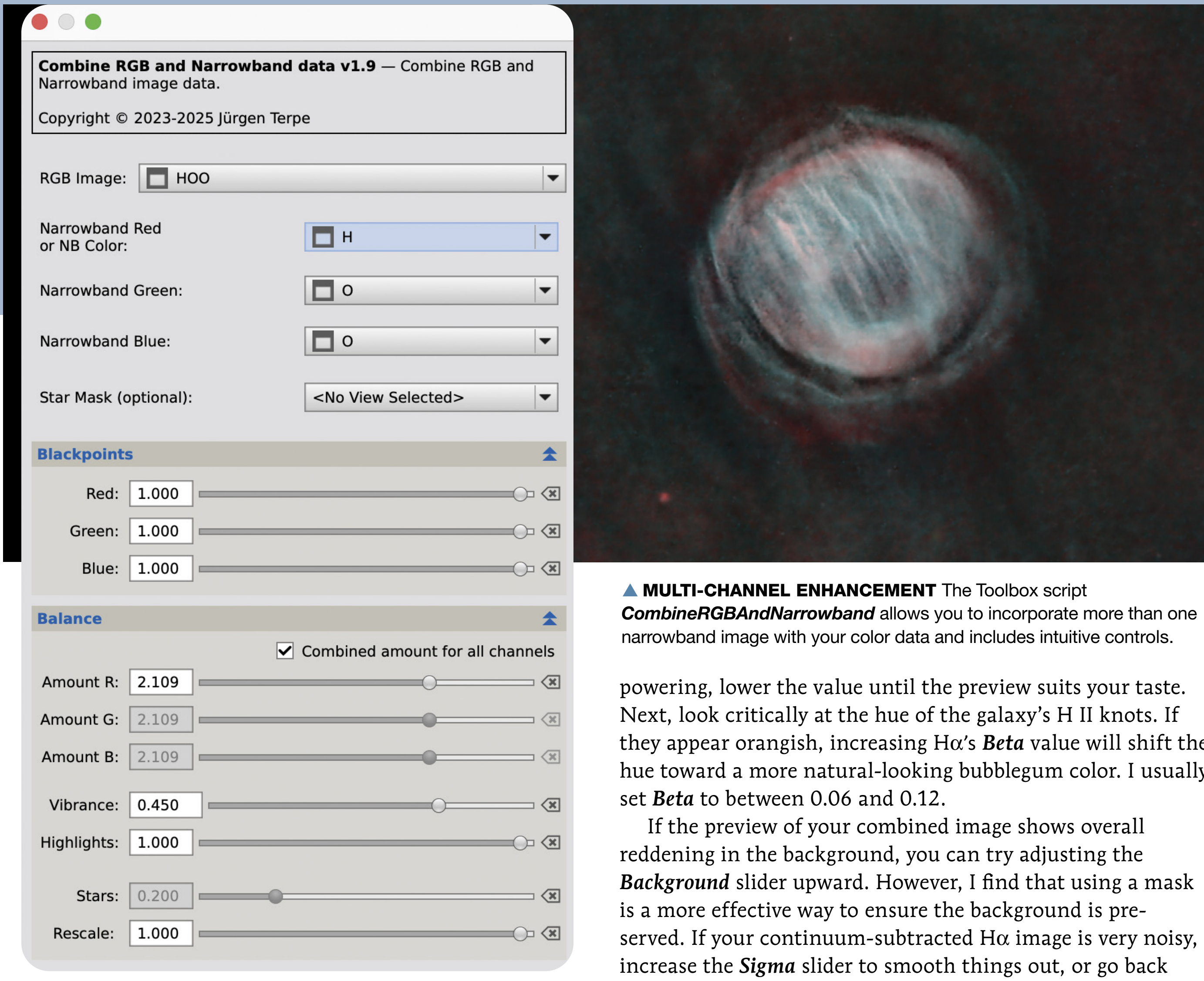
Combining the Result

Once you've reduced the continuum emission in the Hα image, it's time to add the result into the broadband color image. This can be done either before or after stretching, and with or without stars in the image. My preference is to add Hα (and O III) into the natural-color picture after stretching and then removing the stars from both the color and narrowband images.

Some preparatory steps are needed prior to performing the combination. It's beneficial to increase the galaxy's saturation in the color data. This prevents Hα's contribution from overwhelming the other colors in the galaxy and helps retain a good range of hues. Applying ***PROCESS*** > ***IntensityTransformations*** > ***CurvesTransformation*** saturation adjustment (found at the bottom right of the window) works well using a mask that selects only the galaxy. This mask will preserve the background, so it doesn't become too colorful. Masks are nonlinear (stretched) grayscale images that are placed on top of your working image so you can change selected parts of the picture without affecting the other areas.

A quick method for creating a mask for your color picture is to first stretch the image, then use ***PROCESS*** > ***ChannelManagement*** > ***ChannelExtraction***. In the window that opens, select the ***CIE L*a*b**** color space and uncheck the boxes to the left of the a and b channels. Click apply, and in a moment the L, or lightness, channel is extracted, appearing as a grayscale version of your color picture.

Once you've created the mask, apply it by right-clicking your working image and then click ***Mask*** > ***Select Mask***. This menu also allows you to remove a mask, invert it, enable or disable it, or toggle the visibility of the mask.



▲ **MULTI-CHANNEL ENHANCEMENT** The Toolbox script ***CombineRGBAndNarrowband*** allows you to incorporate more than one narrowband image with your color data and includes intuitive controls.

If your color and continuum-subtracted Hα images still contain stars, it's a good idea to remove them before combining. Personally, I discard the Hα star data since my goal is to enhance only the nebulae in the picture.

Bringing It All Together

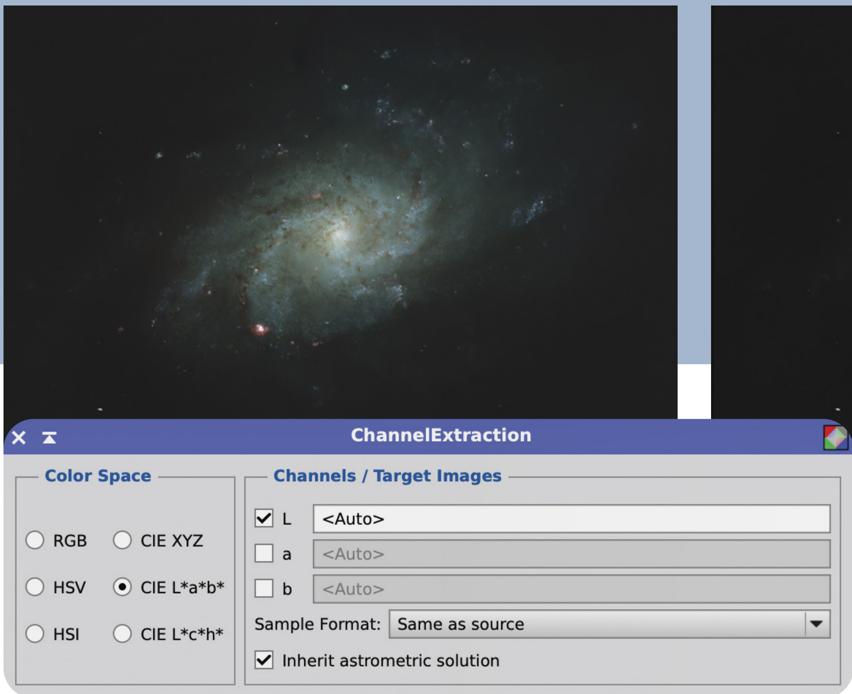
As is typical in most astrophotography, there's more than one way to combine a continuum-subtracted Hα image with your color photo. You can try ***SCRIPT* > *Utilities* > *NBRGBCombination*** that comes with *PixInsight*. However, I prefer the ***CombineHaWithRGB*** script by Jürgen Terpe that comes with the *Toolbox* repository mentioned above. You can find it within the suite of installed scripts under ***SCRIPT* > *Toolbox***.

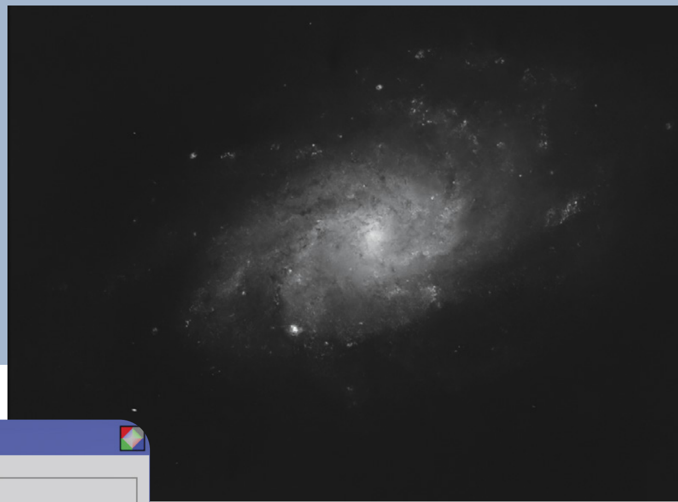
Once the script window is open, select the color and Hα images to be combined. When activated, the script generates a preview using default settings for all parameters. These settings are adjustable and will display any changes immediately. The first parameter to tweak is ***Amount***. If the Hα is too overpowering, lower the value until the preview suits your taste. Next, look critically at the hue of the galaxy's H II knots. If they appear orangish, increasing Hα's ***Beta*** value will shift the hue toward a more natural-looking bubblegum color. I usually set ***Beta*** to between 0.06 and 0.12.

If the preview of your combined image shows overall reddening in the background, you can try adjusting the ***Background*** slider upward. However, I find that using a mask is a more effective way to ensure the background is preserved. If your continuum-subtracted Hα image is very noisy, increase the ***Sigma*** slider to smooth things out, or go back to the Hα image and clean up the noise before combining it with your color exposure.

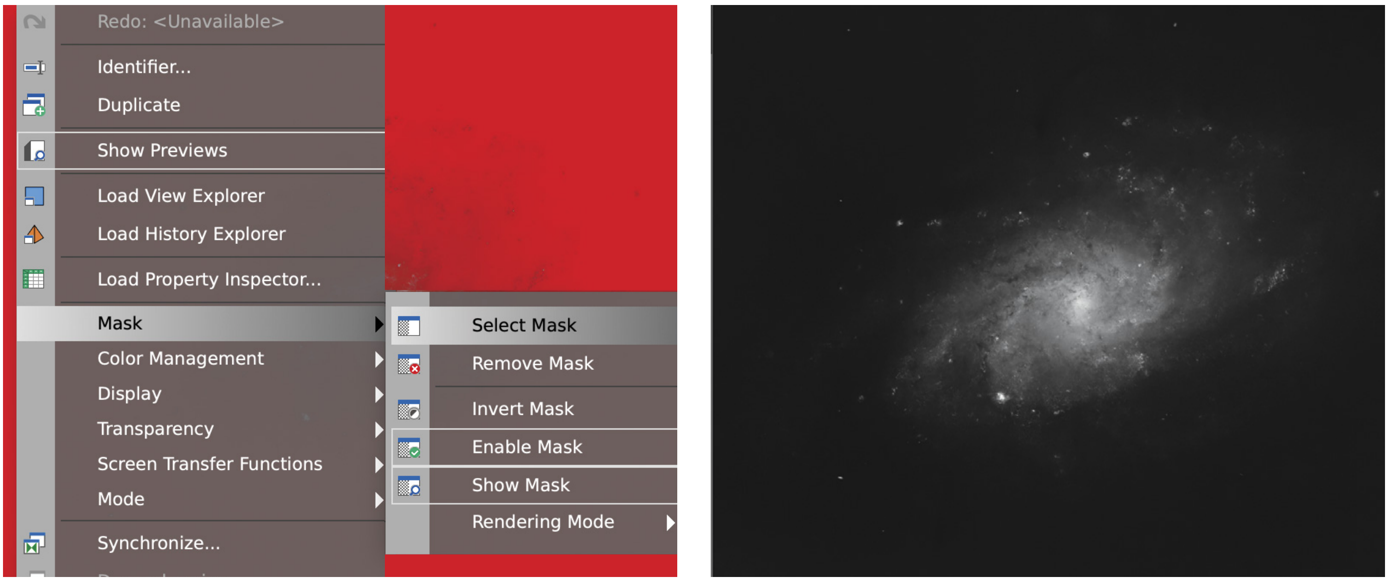
Note that you can run the ***CombineHaWithRGB*** script more than once with different masks, allowing you to control which regions get enhanced with each pass. Also, remember that the continuum-subtraction technique can be used for other narrowband filters. If you have multiple narrowband data to combine, consider using the similar ***CombineRGBandNarrowband*** script located in ***SCRIPT* > *Toolbox***. Like all the scripts in the Toolbox, both are well documented. With either script open, click on the farthest-right icon to open the documentation.

Adding O III to your galaxy images can also inject many more hues into your final result. The same process used to add Hα to the red channel can be applied with O III, but the latter is performed on both the green and blue channels, as the O III emission resides at 495.9 and 500.7 nm, just at the crossover between the blue and green colors of the spectrum. This O III nebulosity is far less prevalent than Hα, but it's noticable when imaging our nearest galactic neighbors.





▲ **MAKING MASKS** Use the ***ChannelExtraction*** process to extract the luminosity channel of a color photo to create a mask. Click ***CIE L*a*b**** in the ***Color Space*** section, then uncheck the boxes next to a and b in the ***Channels / Target Images*** section at right before applying.



▲ **SELECTIVE APPLICATION** To apply the mask, right-click on the target image, then navigate to ***Mask > Select Mask*** and choose the L-channel mask that you've extracted for this purpose.

An additional technique I've used toward the end of my workflow is to use the continuum-subtracted Hα image as a mask to isolate the H II knots for additional enhancement. By inverting the mask, I can protect the Hα regions from adjustments being made on other parts of the image.

Worth the Effort

Adding narrowband data to your color images of distant galaxies can highlight their vibrant, pink nebulae, not unlike M42 or other large, star-forming regions in the Milky Way. To get the best result on those extragalactic emission nebulae, consider adding continuum subtraction to your standard workflow when imaging spiral galaxies. While it does take some extra effort compared to typical galaxy photography, the technique can deliver an extra punch to your final picture.

■ Contributing Editor **RON BRECHER** photographs the night sky from his home observatory outside Guelph, Ontario. Visit his website at **astrodoc.ca**.

Fly Me to the Moon

National governments are ceding their monopoly over lunar exploration and inviting commercial enterprises to partner with them.

The first human-made object to land on the surface of the Moon was the Soviet Luna 2 probe, which mission controllers intentionally crashed into Mare Imbrium in September 1959. Between then and early 2024, 30 more impact probes, landers, and other craft — six carrying people — have successfully completed their missions on the lunar surface.

All of these missions were "big government" enterprises, funded by the national space agencies of the U.S., the Soviet Union, China, Japan, and India. The Moon was once the exclusive domain of these kinds of space agencies. Recently, however, the focus has shifted to a new wave of smaller, more entrepreneurial ambitions. Private companies are now building and launching lunar landers, carrying scientific instruments and technology payloads for NASA, other governments, and even private customers.

This commercial revolution is transforming how humankind explores — and maybe one day even settles — the surface of our closest neighbor in the solar system.

The Road to Commercialization

The U.S. Apollo missions of the 1960s and '70s proved that humans could land on and return from the Moon. But after Apollo 17, NASA canceled the program; astronauts haven't returned for more than 50 years.

Some robotic missions followed over the subsequent decades. But the high cost and risk associated with lunar landings — even superpowers suffer occasional failures — have generally kept access to the lunar surface rare.

In the 2010s, however, a new commercial era began to take shape. As NASA and other space agencies sought to reduce costs and accelerate innovation, they contracted private companies for "lunar delivery services" — in other words, the agency would pay to fly instruments to the Moon on private rockets and spacecraft. Instead of building all of its own robotic landers or rovers, or purchasing them from the large, long-established aerospace contractors, NASA has started accepting rides from newer companies.

The pivotal moment came in 2018, when NASA created

NASA / FRANK MICHAUX

LIFTOFF Firefly Aerospace's Blue Ghost lander launches from Kennedy Space Center aboard a SpaceX Falcon 9 rocket on January 15, 2025. Blue Ghost became the first commercial mission to successfully land on the Moon.

the Commercial Lunar Payload Services (CLPS) program, inviting companies with existing or emerging capabilities to bid for contracts. CLPS is a NASA initiative designed to foster competition, encourage innovation, and ultimately lower the cost of lunar exploration. The program issues "task orders" for specific missions, and both public and private companies bid to deliver payloads — ranging from scientific instruments to technology demonstrations — to various lunar locations.

This shift has manifested in other countries as well. Around the same time as NASA established CLPS (pronounced "clips"), two other entities initiated their first attempts at commercial lunar missions: the SpaceIL organization in Israel (propelled mostly by private philanthropy but also by the Israel Space Agency) and the publicly traded Japanese company ispace, working in collaboration with both the Japanese and Emirati space agencies. While neither of these missions was ultimately successful, they demonstrated that the push to enable cheaper, more frequent scientific access to the lunar surface is a truly global quest.

Payloads Bring the Paychecks

Between 2019 and 2024, NASA awarded 13 CLPS mission contracts to seven different companies. Each of these contracts committed the company to delivering science payloads to specific areas of the Moon using their own commercial landers and/or rovers (see table on page 37). Some of these missions have already launched, some plan to soon, and some never will: Two of the companies have since terminated their contracts due to bankruptcy or other fundraising challenges.

Of the CLPS missions that *have* launched so far, three out of four have either partially or completely failed. These failures highlight the higher risks of relying on less-experienced and lower-cost commercial space entrepreneurs: Although "big government" contractors are sometimes late and over budget, their generally higher costs help to decrease risks, and they usually get the job done.

NASA chose 11 different landing sites — five near the south pole — for these initial CLPS missions. Planners based those choices on both the general goals of the lunar science community and specific goals for NASA's Artemis program, intended to bring astronauts back to the Moon within the next decade. By focusing on the south polar region in particular, mission planners aim to use the robotic landers' instruments to test the hypothesis that extractable quantities of water ice are sequestered in permanently shadowed regions there. If so, then those water-ice deposits could be a resource for future astronauts and settlers on the Moon (*S&T:* Jan. 2021, p. 34). Indeed, demonstrations of *in situ resource utilization* (ISRU) experiments — which do things like search for water ice or a variety of extractable metals — have been regularly included among the payloads selected for CLPS missions thus far.

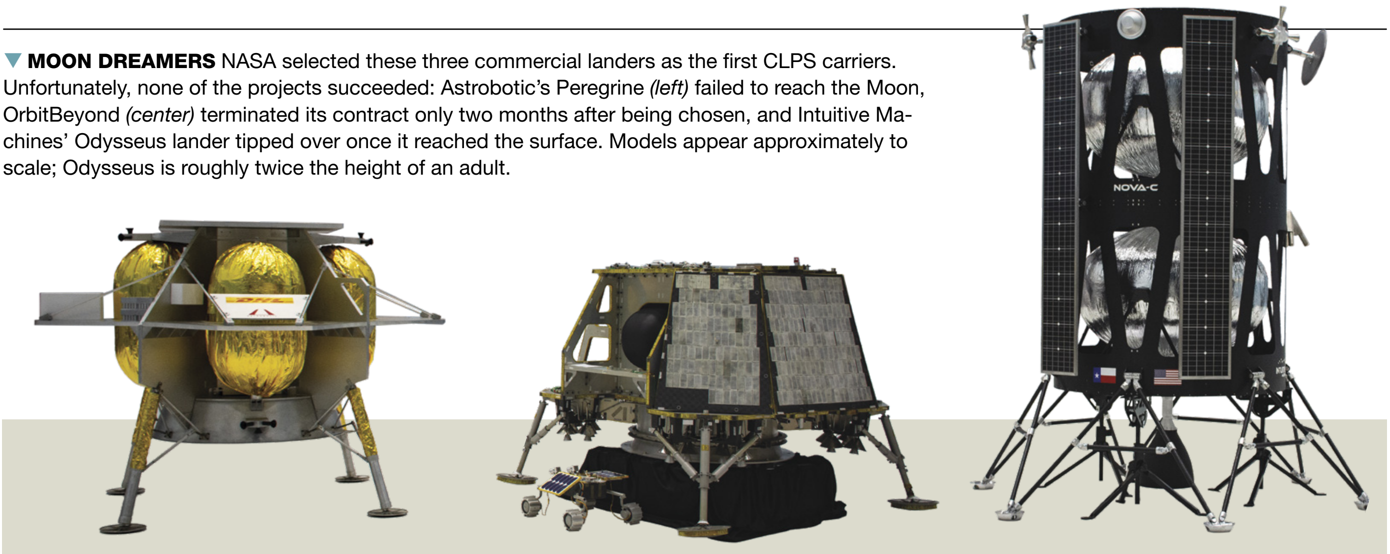
NASA typically pays in the range of $100 million for each lander, and it also pays for many of the science payloads, to the tune of approximately $1 million/kg, or about $2 million/lb. (That cost should drop as experience grows and competition intensifies.) Due to these budget constraints, the landers and the payloads that they can carry are relatively small compared with the typically larger and more costly traditional NASA spacecraft.

◀ **GOOD EFFORT** The Resilience lander, made by Japanese company ispace, crashed on the Moon during its landing attempt.

Still, advances in miniaturization and onboard computational capabilities are enabling even relatively small payloads to make important measurements, both for scientific research and for technology development. The results not only impact our understanding of lunar geology and composition but also inform future power, mobility, communications, precision landing, hazard avoidance, ISRU, and other engineering needs.

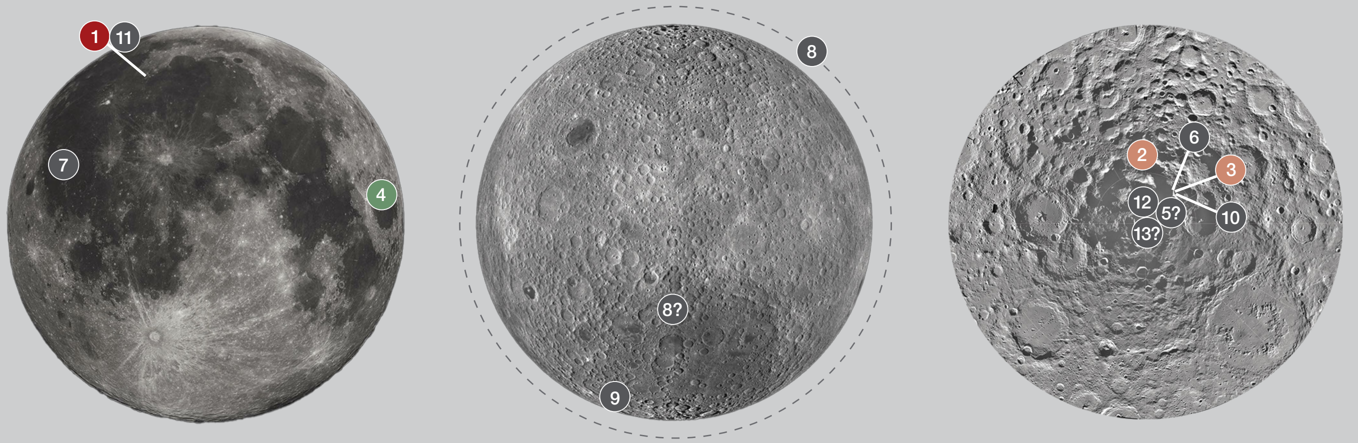
Importantly, these commercial providers realize that although the funding from government programs such as NASA's CLPS is substantial, it is still often not enough to cover expenses for the design, manufacture, test, launch, and operations of their missions. Thus, to earn some profit for their investors (or at least break even), many have to accommodate additional payloads from paying international, commercial, or even private customers.

Some of these other hosted payloads have been scientific, engineering, or technological in nature. Others have been artistic or cultural, such as a (miniature) art museum on the Moon, delivered to the lunar surface by the IM-1 Odysseus lander in 2024. In the commercial lunar sector, landers and rovers are not only primarily tools for scientific and technological advancement, but they are also vehicles for showcasing humanity's artistic and cultural heritage, extending our



▼ **MOON DREAMERS** NASA selected these three commercial landers as the first CLPS carriers. Unfortunately, none of the projects succeeded: Astrobotic's Peregrine *(left)* failed to reach the Moon, OrbitBeyond *(center)* terminated its contract only two months after being chosen, and Intuitive Machines' Odysseus lander tipped over once it reached the surface. Models appear approximately to scale; Odysseus is roughly twice the height of an adult.

THREE LANDER MODELS: REBECCA ROTH / NASA GODDARD; ISPACE RESILIENCE: ISPACE



NASA Companies Awarded CLPS Mission Contracts

Company	Mission Name	Award Date	Landing Date	Intended or Actual Landing Site	Notes/Status	Map Number
Astrobotic Technology (Pittsburgh, PA)	Peregrine-1	May 2019	Jan. 2024	Oceanus Procellarum, near the Gruithuisen domes	Propellant leak prevented landing attempt carrying five CLPS payloads	1
Intuitive Machines (Houston, TX)	IM-1 (Odysseus)	May 2019	Feb. 2024	Malapert A Crater near the lunar south pole	Nova-C lander tipped over after landing, limiting six CLPS payloads to only partial success	2
OrbitBeyond (Bridgewater, NJ)	Z-01	May 2019	—	Within Mare Imbrium	Terminated its contract in July 2019 due to “internal corporate challenges”	N/A
Masten Space Systems (Mojave, CA)	XL-1	Apr. 2020	—	Haworth Crater near the lunar south pole	Filed for bankruptcy in July 2022; contract terminated by NASA	N/A
Intuitive Machines	IM-2 (Athena)	Oct. 2020	Mar. 2025	Mons Mouton region near the lunar south pole	Nova-C lander tipped over after landing, limiting the CLPS payloads to only partial success	3
Firefly Aerospace (Austin, TX)	Blue Ghost 1	Feb. 2021	Mar. 2025	Near Mons Latreille in Mare Crisium	Fully successful deployment of 10 CLPS payloads	4
Blue Origin (Kent, WA)	Blue Moon MK1 Pathfinder	July 2024	Late 2025?	TBD near the lunar south pole	Will test future human landing technologies and might deliver a CLPS payload	5
Astrobotic Technology	Griffin-1	June 2020	Late 2025?	Nobile Crater region near the lunar south pole	Was to carry NASA’s VIPER rover, will carry commercial rover and CLPS payloads instead	6
Intuitive Machines	IM-3	Nov. 2021	Early 2026?	Reiner Gamma region in Oceanus Procellarum	Will carry four payload packages from NASA, ESA, and Korea	7
Firefly Aerospace	Blue Ghost 2	Mar. 2023	2026?	TBD on the lunar farside	Will deliver both a science/ communications orbiter and a lander with CLPS payloads	8
Draper Laboratory (Cambridge, MA)	Apex 1.0	July 2022	Late 2026?	In Schrödinger Basin on the lunar farside	Will carry three CLPS payloads plus other commercial payloads	9
Intuitive Machines	IM-4	Aug. 2024	2027?	Mons Mouton region near the lunar south pole	Will carry NASA and ESA science payloads	10
Firefly Aerospace	Blue Ghost 3	Dec. 2024	2028?	Oceanus Procellarum, near the Gruithuisen domes	Will deliver six NASA CLPS payloads	11
Firefly Aerospace	Blue Ghost 4	July 2025	2029?	Haworth Crater rim, south pole region	Will carry two rovers and three science payloads	12
Blue Origin	Blue Moon MK1	Sept. 2025	Late 2027	TBD, near the lunar south pole	Will carry NASA’s VIPER rover	13

● Failed after launch ● Launched, partially succeeded ● Never launched ● Fully successful ● Planned

MAP LOCATIONS SOURCES: NASA, FIREFLY AEROSPACE; NEARSIDE AND FARSIDE IMAGES: NASA LRO / JATAN MEHTA; SOUTH POLE IMAGE: NASA / JPL / USGS reach beyond Earth and leaving a legacy for future generations to explore.

There are also significant economic and strategic motivations at work. ISRU experiments and technology maturation are important for the sustainability of future lunar settlements. Water ice, for example, could be mined and split into hydrogen and oxygen for life support or rocket propellant, literally fueling a potential transformation in what is currently Earth-based space transportation economics by enabling on-the-ground propellant manufacturing, instead of requiring us to ship fuel to the Moon. Future, more capable commercial missions, based on early pathfinders like those in the CLPS program, could also deliver habitats, power systems, and other infrastructure needed for long-term human presence.

The political confrontation that played out in the 1960s "space race" between the U.S. and USSR has been replaced in some ways by an economic competition between the systems of government represented by the U.S. and other western nations and those of China and Russia. As this competition continues, space — and the Moon in particular — is seen by some as the ultimate high ground upon which America is keen to establish a foothold before rivals can claim key resources or strategic sites.

2025: A Banner Year

This past year has seen an exciting surge in lunar activity: Several notable missions from the first few years of NASA's CLPS selections launched or landed, and Japan's ispace made a second attempt to safely touch down on the Moon. These companies are each having to navigate the immense technical challenges of lunar landings, often with tighter budgets and less institutional experience than government agencies.

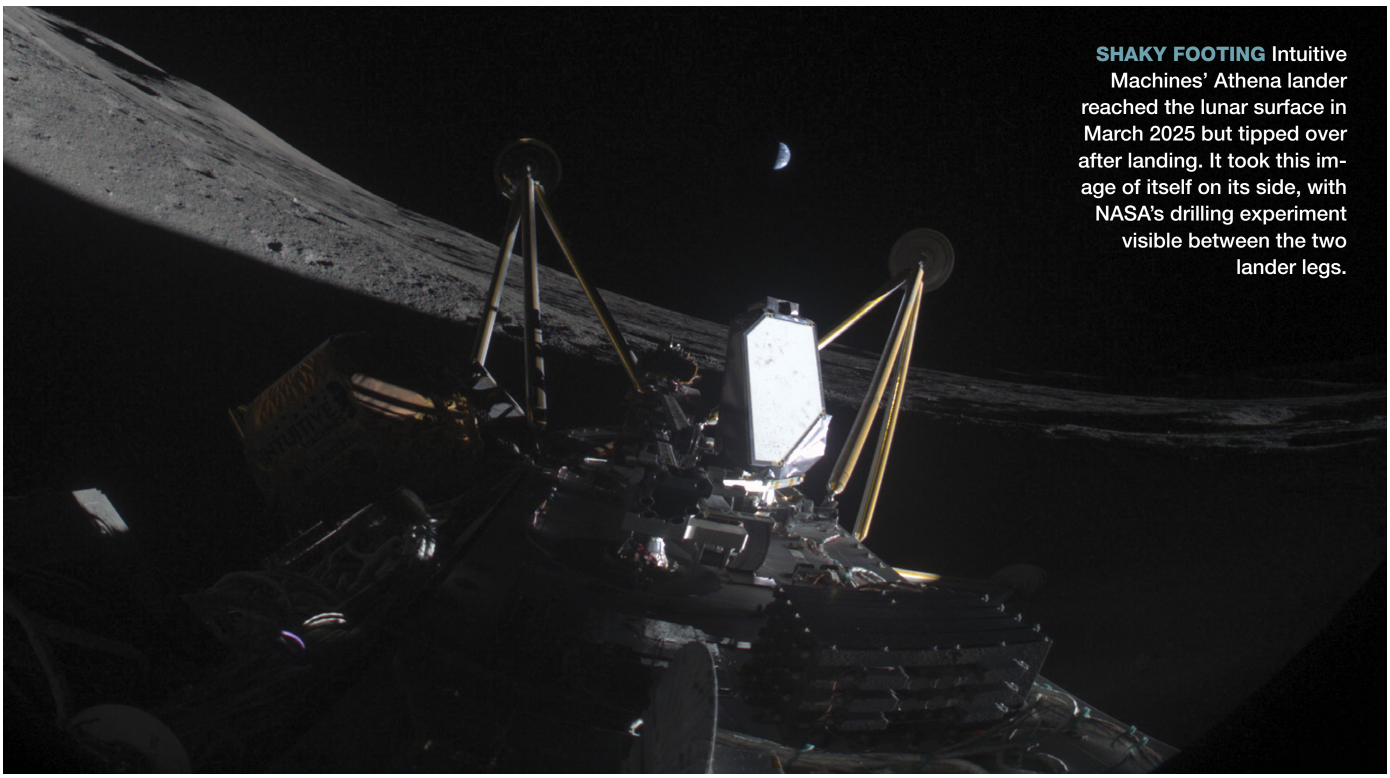
The results have been mixed. The Intuitive Machines IM-2 Athena lander launched on February 26th and then performed a successful slow descent to a site near the lunar south pole on March 6th. But it tipped over upon landing, completing only a small fraction of its intended science measurements before it lost power and died.

The ispace Resilience mission, meanwhile, carrying a small rover from Luxembourg as well as scientific and cultural payloads from Japan, Taiwan, and the United Nations, launched without mishap on January 15th but then crashed onto the surface of Mare Frigoris on June 5th because of a landing-system error.

Both of these commercial teams will be back for future attempts, they say: Not only did they collect important telemetry and other data, but they also amassed a large number of engineering and operational "lessons learned" by coming so close to success.

These failures join several that came before them: Until 2025, there had never been a fully successful commercial landing on the Moon. This fact might sound disparaging, but remember that it took NASA several attempts just to successfully *hit* the Moon with one of the Ranger impact probes back in the 1960s.

Happily, Firefly Aerospace broke the pattern of failures, achieving a triumphant landing only a few days before Athena's tilted touchdown. Firefly's Blue Ghost 1 lander, carrying 10 NASA CLPS payloads, successfully launched on January 15th from Kennedy Space Center and performed a perfect soft



SHAKY FOOTING Intuitive Machines' Athena lander reached the lunar surface in March 2025 but tipped over after landing. It took this image of itself on its side, with NASA's drilling experiment visible between the two lander legs.

INTUITIVE MACHINES

landing on the lava plains of Mare Crisium on March 2nd.

Traditional big-ticket NASA spacecraft typically allocate only around 10% or less of their total mass to scientific instruments. But twice that was devoted to science and technology payloads on Firefly's Blue Ghost. The instruments acquired spectacular data that scientists and engineers are going to be digging into for years. These include pictures of Earth interacting with the solar wind as well as measurements of radiation levels on the lunar surface, of how much the temperature decreases below the surface, and of how rough lunar dust is and how well it sticks to surfaces.

Successful technology experiments in turn included a demo of using Earth GPS signals for navigation on the Moon, a novel soil-collection and analysis system, an electrical dust-shielding system, and images and videos of the effects of the lander's rocket plume on the lunar surface. The lander also deployed a retroreflector mirror system, so that Earth-based lasers can track the slowly increasing distance between us and the Moon.

Blue Ghost 1 operated for two weeks, surviving and thriving under the harsh sunlight before succumbing to the freezing lunar night — an expected fate for landers or rovers relying on solar power for their energy and survival, as all CLPS craft have so far.

Several other missions are planned for later in 2025, although of course their actual launch and landing dates are always subject to change, based on not only the status of launch vehicles but also the vagaries of both governmental and private funding.

For example, Astrobotic's Griffin lander is set to attempt a payload delivery to the Nobile Crater region of the lunar south pole. Griffin is larger than the company's previous craft, Peregrine, which failed shortly after launch in early 2024. Griffin was initially intended to carry NASA's large VIPER rover, designed to map the locations of water ice and other resources. When NASA postponed VIPER for budgetary reasons (*S&T:* Nov. 2024, p. 8), Astrobotic pivoted to potentially delivering other CLPS payloads plus a different but similarly sized rover developed by another space startup, Venturi Astrolab. That vehicle, called the "Flexible Logistics and Exploration Lunar Innovation Platform" (FLIP) rover, is intended to pave the way for a larger lunar rover that the company is planning for the future (*S&T:* June 2025, p. 11).

Another potential 2025 CLPS achievement could be the launch and landing of Blue Origin's Blue Moon MK1 Pathfinder lander. Pathfinder is a prototype for the Blue Moon lander, which Jeff Bezos and his Blue Origin colleagues plan to use to carry NASA cargo and astronauts down to the lunar surface on the Artemis V mission early in the 2030s. Blue Moon Pathfinder will launch on the company's New Glenn rocket and deliver a NASA CLPS imaging payload designed to study the effects of rocket exhaust on the ground at the landing site. It will also test the 3D-printed BE-7 engine and some of the cargo-delivery capabilities planned for Blue's future human-rated landers.

Examples of Recent Artistic and Cultural Payloads

Lander	Payload	Notes/Status
Peregrine 1	Artwork: "The Lunar Codex" and "MoonArk" projects preserve digital and analog forms of art, literature, music, and other cultural artifacts, including goat DNA	Launched, but lander flew by the Moon without landing
Odysseus	Sculptures and digital art/music: Several artists provided physical and digital artwork and musical compositions in a radiation-proof container on the lunar surface, intended to represent Earth's diverse cultures preserved in the first "art museum" on the lunar surface	Reached surface successfully, although lander tipped over
Resilience	Time capsule: UNESCO created a coin-size digital memory disk, "Memory Disc V3," designed to preserve humanity's linguistic diversity and cultural heritage for millions of years	"Hard landed" on the lunar surface

Toward a Lunar Economy?

The commercial lunar-lander revolution is well under way. What began as government monopolies driven by the Cold War is now a competitive, innovative marketplace, with private companies hired to deliver science, technology, and infrastructure to the Moon.

The rest of this decade is likely to be just as interesting as this past year. At the time this article went to press, there were still seven additional active NASA CLPS missions contracted for landings in 2026 and beyond, as well as many other commercial efforts from companies and agencies outside of the U.S. These missions are scheduled to deliver dozens of science, engineering, and technology-demonstration payloads to diverse and interesting locations on the Moon.

Add to that the promise of the planned Artemis III, IV, and V human lunar-landing missions (currently scheduled for late 2028 and early 2030) — both of which involve and leverage significant entrepreneurial space systems and capabilities — and the result is stacking up to be an extremely busy and exciting time on the Moon.

Of course, landing on the Moon remains a formidable challenge. Companies face the same technical hurdles as government agencies — navigation, propulsion, a harsh thermal environment — but often with fewer resources and lower heritage hardware. The early commercial successes and failures, especially those that have struggled to land in rugged or bouldery terrain, have highlighted several must-haves for going forward: the need for active hazard avoidance or other autonomous onboard landing smarts; the need for more robust communications and navigation systems that can work even when landings don't go perfectly; and of course the need to survive as long as possible in the harsh lunar environment, where radiation, abrasive dust, and huge temperature swings between day and night are all trying to kill spacecraft. Still, every mission, successful or not, incrementally advances the state of the art and brings the dream of routine lunar access for all stakeholders — both government and commercial — closer to reality.

In the meantime, many of the existing lunar space companies, and many more new ones, are working on larger landers capable of delivering heavier and more complex payloads, including habitats and rovers. NASA's next phase of CLPS ("CLPS 2.0") envisions delivery of essential infrastructure such as power sources, habitats, and mobility systems to support long-term exploration and eventual settlement. Eventually, perhaps, ISRU will move from demonstration to operational scale, with commercial propellant production and storage facilities on the horizon.

If current trends continue into the future, then as launch and operation costs drop and reliability improves, more international agencies and private companies could very well seek routine lunar access for science, commerce, and even tourism purposes.

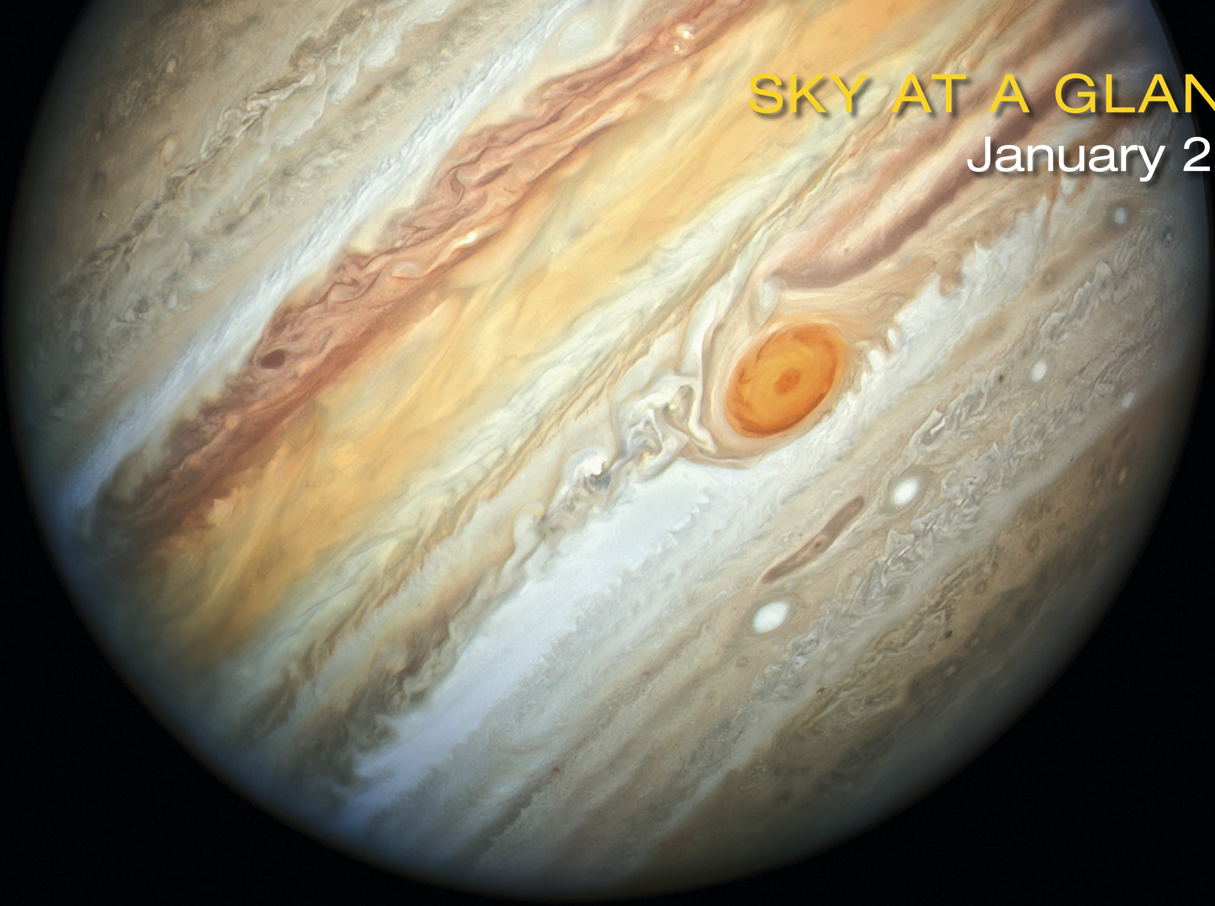
Still, for now, national governments remain the key customers and regulators. Along with the United Nations and other global agencies working under existing and new treaties, these space agencies will need to cooperate to fill gaps in international law and to ensure fair access to lunar resources.

In short, in just the next few decades, we could see the emergence of a true lunar economy, one that could reshape not only how we explore space but also how we live and work on Earth and beyond. As competition intensifies and technologies mature, the Moon could soon become a bustling hub of scientific discovery, resource prospecting and extraction, and even human activity — a stepping stone to the rest of the solar system.

■ Contributing Editor **JIM BELL** is a professor of astronomy and planetary science at Arizona State University. He's been involved in more than a dozen NASA missions to the Moon, Mars, and asteroids, is a past president of The Planetary Society, and enjoys writing popular-science books and articles about space exploration.

SUCCESS Firefly's Blue Ghost lander safely touched down on the Moon with its 10 payloads. It casts its shadow here shortly after arrival, with Earth on the horizon.

FIREFLY AEROSPACE



SKY AT A GLANCE
January 2026

3 **EARTH** passes through perihelion, its closest point to the Sun for 2026, at around 12:16 p.m. EST.

3 **DUSK:** Face east-northeast to see the full Moon rise flanked by Pollux some 3¼° to its left and Jupiter about 3° to its right. Turn to page 46 for more on this and other events listed here.

3–4 **ALL NIGHT:** The Quadrantid meteor shower peaks tonight, but the full Moon will severely hamper viewing opportunities.

6 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 9:13 p.m. PST (see page 50).

6 **EVENING:** The waning gibbous Moon trails Leo's brightest beacon, Regulus, by about 6¼° as they climb above the eastern horizon.

9 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 9:02 p.m. EST.

9–10 **ALL NIGHT:** Jupiter reaches opposition (turn to page 48 for details). This month, mighty Jove blazes in Gemini where it's positioned right of Pollux.

11 **MORNING:** The last-quarter Moon pops above the east-southeastern horizon where it hangs some 5¼° below Virgo's lucida Spica. The gap between the pair widens as they climb higher into the sky.

14 **DAWN:** Turn to the southeast to see the waning crescent Moon delicately perched 3½° upper right of Antares, in Scorpius.

22 **DUSK:** The waxing crescent Moon poses some 6° lower right of Saturn in the west-southwest. The duo draw closer as they set in the west.

26 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 10:58 p.m. PST.

27 **DUSK:** The Moon, two days past first quarter, gleams left of the Pleiades in Taurus. Look high in the southeast to take in this sight.

29 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 10:47 p.m. EST.

30 **DUSK:** Look toward Gemini in the east to see the waxing gibbous Moon forming a triangle with Jupiter and Pollux. The gas giant is positioned some 3½° lower right of the Moon.

31 **DAWN:** Spot a trio of objects as they sink toward the west-northwestern horizon. Jupiter leads the way, followed by the almost-full Moon about 5° upper left with Pollux bringing up the rear by another 3¾°.
—DIANA HANNIKAINEN

▲ Jupiter arrives at opposition this month and will be visible all night long from dusk to dawn. This Hubble Space Telescope image, taken when the planet was near opposition in June 2019, reveals features on Jupiter, including the Great Red Spot, in exquisite detail. NASA / ESA / A. SIMON (GODDARD SPACE FLIGHT CENTER) / M. H. WONG (UNIVERSITY OF CALIFORNIA, BERKELEY)

JANUARY 2026 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 3
10:03 UT

LAST QUARTER
January 10
15:48 UT

NEW MOON
January 18
19:52 UT

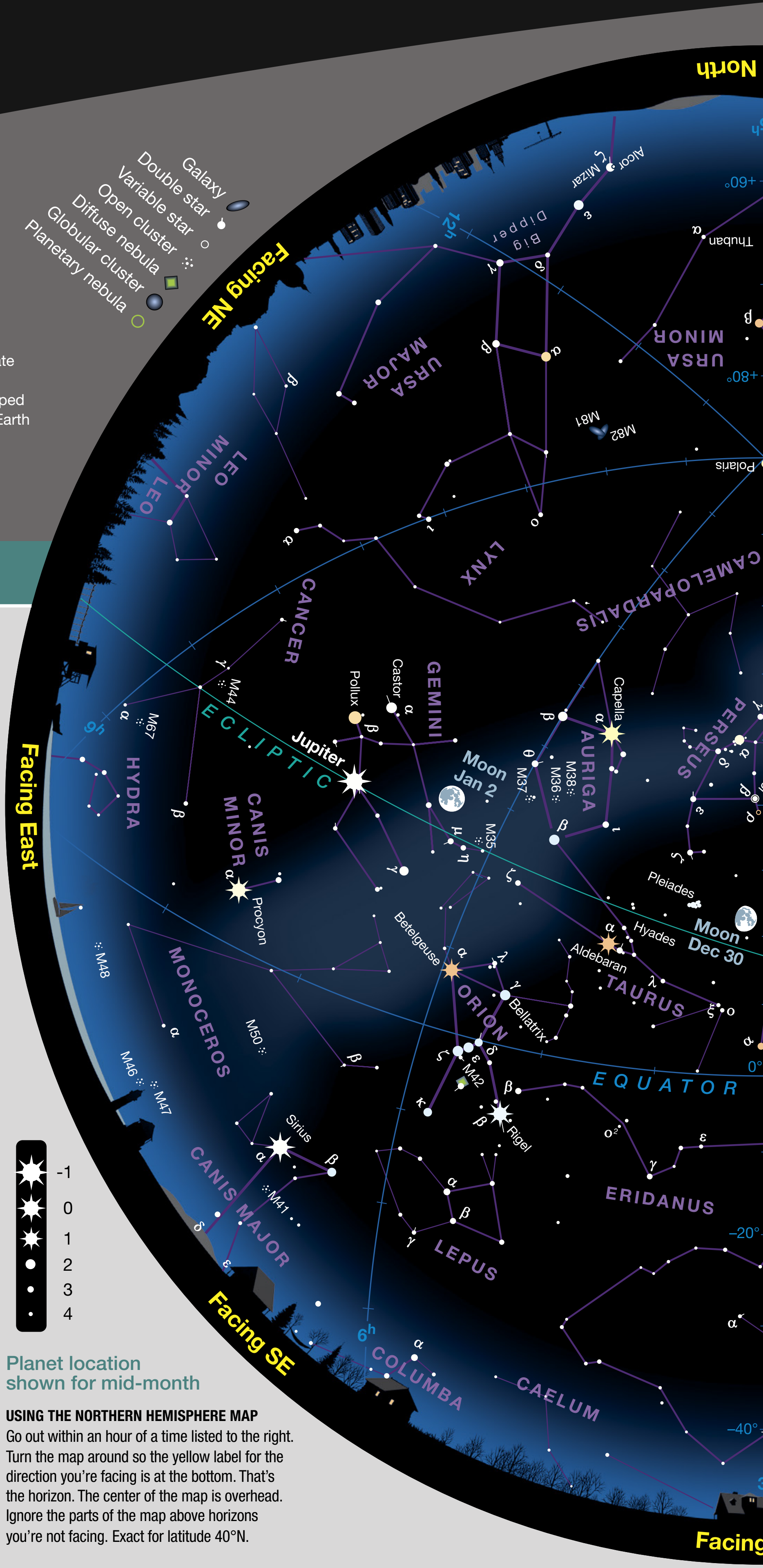
FIRST QUARTER
January 26
04:47 UT

DISTANCES

Perigee	January 1, 22^{h} UT
360,348 km	Diameter 33′ 10″
Apogee	January 13, 21^{h} UT
405,438 km	Diameter 29′ 28″
Perigee	January 29, 22^{h} UT
365,871 km	Diameter 32′ 40″

FAVORABLE LIBRATIONS

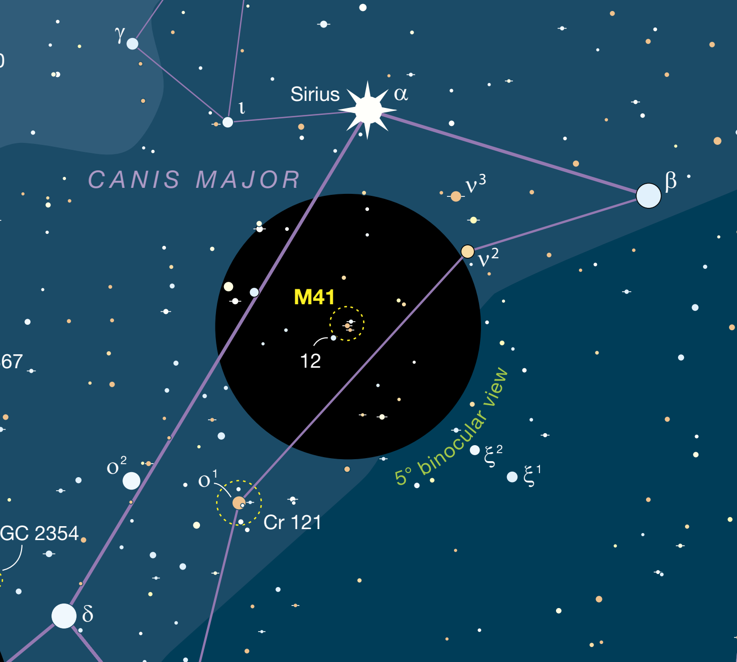
• Wilson Crater	January 1
• Malapert Crater	January 2
• Newton Crater	January 29
• Scott Crater	January 30

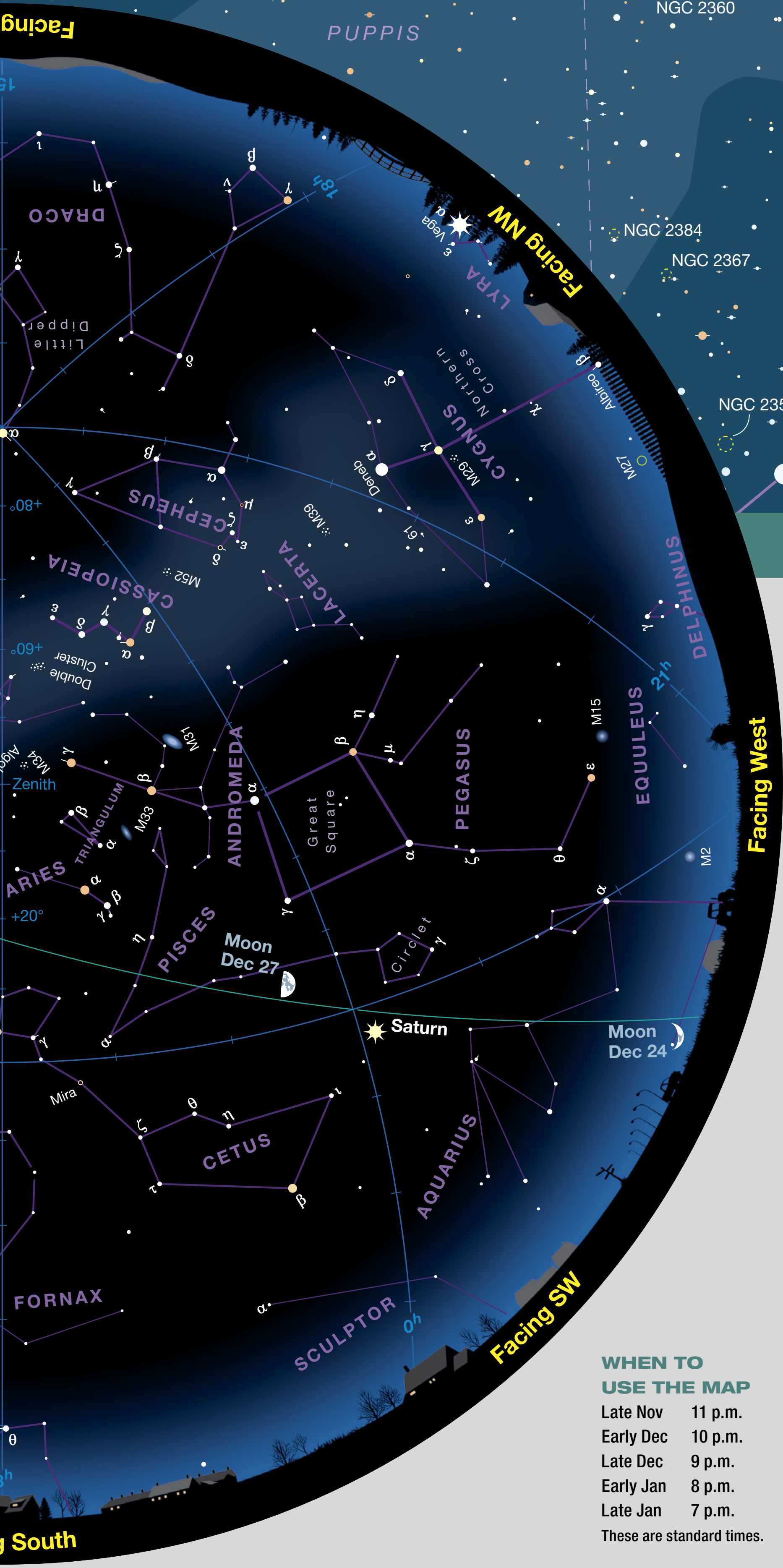


Planet location shown for mid-month

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 Charismatic Cluster in Canis Major

Our target this month is the open cluster **M41** in Canis Major, the Great Dog. I was surprised to see that I hadn't covered it before in this column. M41 is big, bright, and easy to find — I check in on it virtually every night it's above the horizon.

The cluster is located almost exactly 4° south of Sirius, the brightest star in the night sky. Typical binoculars will fit both the star and the cluster into a single view. In most depictions of Canis Major, M41 sits right at the center of the Dog's chest — at the heart of the constellation in more ways than one. At magnitude 4.5, the cluster is visible to the naked eye under good conditions, and spanning more than ½° across, it shows considerable detail even in 10×50 binoculars. A couple of dark lanes run through the cluster at nearly right angles, and to my eyes the brightest stars jump out as sets of nested kite shapes and parallelograms. M41 is sometimes known as the Little Beehive Cluster for its similarity to M44 in Cancer, the Crab. I like both objects, but I find the Canis Major cluster always gives me a greater sensation of depth.

A 6.1-magnitude star designated 12 Canis Majoris appears perched on the southeastern margin of M41, but in reality, it's not physically related to the cluster. The star is about 700 light-years away, while the cluster itself is about 2,400 light-years distant. A *B*-type giant, 12 Canis Majoris is theoretically a blue-white star. I've never had much luck picking out any tint, even compared with the red and yellow giants populating M41. But the perception of star color varies widely among observers, so have a look yourself and see if you can detect these subtle hues.

■ **MATT WEDEL** is regularly torn between seeking out new objects and revisiting old favorites to get to know them better — an excellent problem to have.

JANUARY 2026 OBSERVING

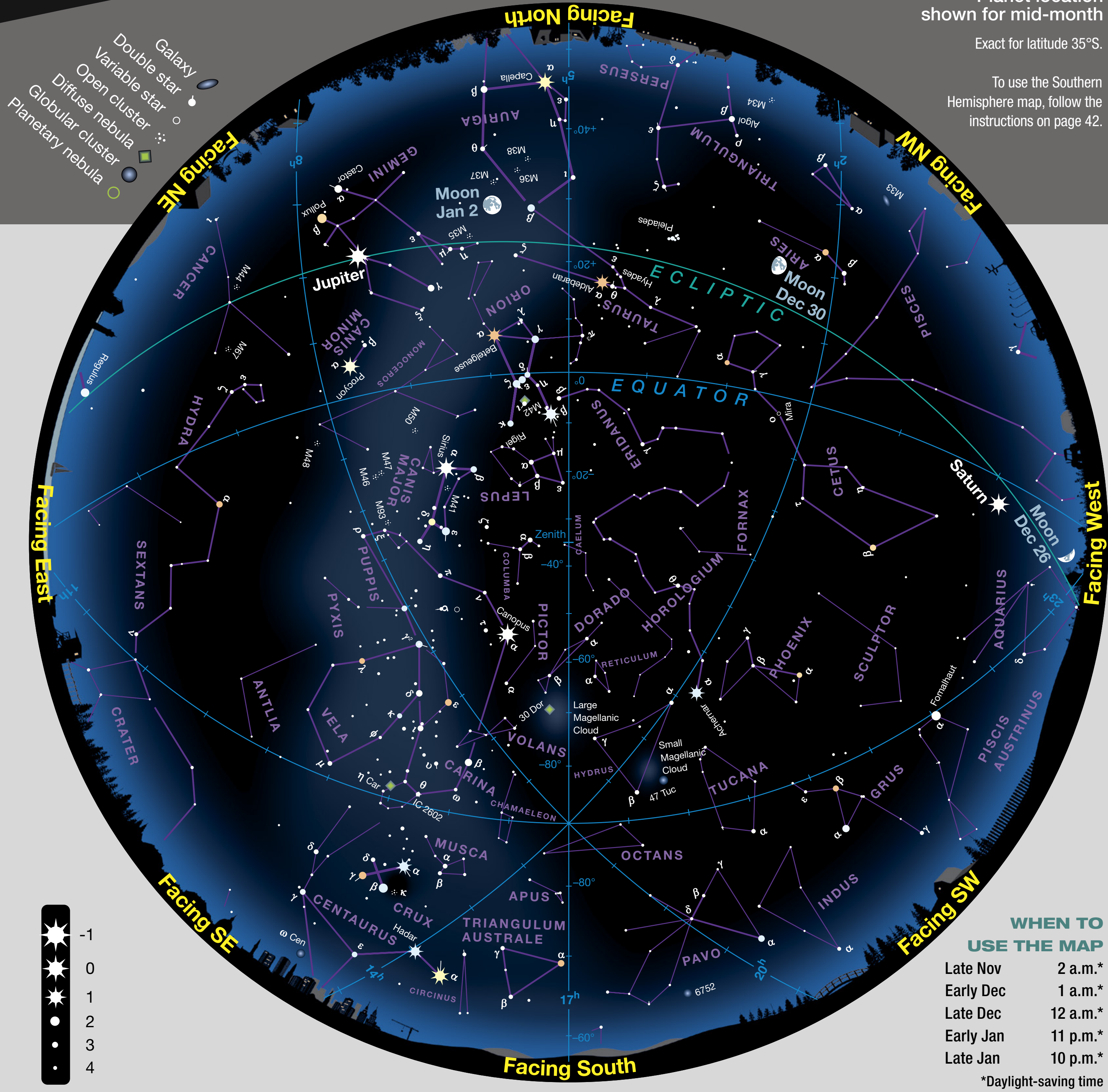
Southern Hemisphere Sky Chart

by Jonathan Nally

Planet location shown for mid-month

Exact for latitude 35°S.

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



WHEN TO USE THE MAP

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

*Daylight-saving time

PICTOR, the Painter, is a tiny, seemingly unremarkable southern constellation. Just three of its stars are marked on the chart above, and only the 3.2-magnitude binary Alpha (α) Pictoris is labeled. Proceeding northwards from Alpha, we come to orange giant Gamma (magnitude 4.5), then bluish Beta (3.9). Of the three, it's Beta that's most notable. Located just 64 light-years away, it's famous for being surrounded by a disk of dusty material. This feature was the first of its kind discovered at optical wavelengths and subsequent observations have revealed a second disk embedded in the first. Two exoplanets are confirmed to be orbiting Beta and there might be more. Not only that, but dust particles ejected from the Beta system are thought to account for most of the interstellar meteoroids zipping through our solar system. ■

Hitch a Wagon to the Stars

Join us on a celestial carriage ride around the northern sky.

In the May 2025 Stories in the Stars column, I explored the origins of the Big Dipper's name. Then, in the October 2025 issue's From Our Readers department, Pavel Otavsky of Golden, Colorado, shared that the Big Dipper is known as the Big Wagon in the Czech Republic. In part, he wondered which other cultures and nations saw the Dipper's stars as a wagon. Let's find out.

The first terrestrial wagons appeared around 3000 BC in Mesopotamia (present-day Iraq and Syria). Initially used to transport people and goods, wagons changed the course of Mesopotamian history. It seems fitting, then, that skywatchers of the time saw a *margidda*, meaning "great wagon" or "long chariot," among the stars of the Big Dipper. The Big Dipper's bowl was the wheeled carriage, while the three stars in the Dipper's handle represented the vehicle's yoke. You'll find the asterism this month low in the northeast, as shown on the Northern Hemisphere Star Chart on pages 42–43.

In the *Iliad* and *Odyssey*, both attributed to the Greek poet Homer and presumed to have been written around the 8th century BC, the seven bright stars of the "Great Bear" are also referred to as "the Wain," which means wagon. For instance, in the *Odyssey*, Odysseus, on his journey home, navigates the sea by watching the "Pleiads, or watched the late-setting Bootes slowly fade, or the Great Bear, sometimes called the Wain." In Anglo-Saxon mythology, the Big Dipper is the Wagon of Woden (or Wodan, among other variants of the name) — their supreme god, who was largely associated with wisdom and death.

In Norse mythology, the Big Dipper was Odin's Wagon. In the third volume of his *Teutonic Mythology* (translated by James Stallybrass in 1883) Jacob Grimm tells us that the "phenomenon of howling wind is referred to as Odin's wagon," while in Sweden, "On hearing a noise at night as of horses and carts, they say . . . 'Oden far förbi'" (Odin passes by). So, as you look up at night at the Wain, be sure to keep your other senses open.

The Norse also associated the Big Dipper with the goat-drawn wagon belonging to Odin's son Thor — the popular hammer-wielding god of thunder. Among his many roles, Thor was constantly protecting the *AEsir* gods (of which he was one), and their fortress *Asgard*, from spiritual beings known as the "giants," who were determined to drag natural order back to primordial chaos. And what better place to keep vigil over the heavens and Earth than from his wagon in the sky, positioned keenly near the north celestial pole? Norse legend has it that if you hear a peal of thunder, it's the rumble of Thor's wagon as the vigilant god wheels it around the vault of the sky.

Imagery of the Big Dipper as a wagon was also widespread across Europe. In a chapter titled, "Anglo-Saxon Manual of Astronomy," published in the 1841 *Popular Treatises on Science Written During the Middle Ages*, we learn that "Arcton is the name of a constellation in the north part, which has seven stars, and . . . which untaught men call carle's-wain" — a reference to the medieval emperor Charlemagne (which is derived from the French *Charles-le-magne*, meaning Charles the Great) who ruled much of Western Europe from AD 768 to 814. Carle's Wain became Charles's Wain.

According to the *Oxford Dictionary of English Etymology*, "the name appears to have arisen through assoc[iation] of the star-name *Arcturus* with *Arturus* (Arthur) and the legendary connexion of Arthur with Charlemagne." Indeed, in early England, the Big Dipper was also Arthur's Wain, though the courtiers of King Charles I (1600–1649) connected it to his name. But these are but a few examples, of "Wain" being used to represent the Big Dipper throughout Europe, and mainly to honor royal figures or those with supernatural powers.

▲ In some Norse myths, the stars of the Big Dipper are imagined as Thor's Wagon, which is drawn by two he-goats. As the protector of humanity and his tribe of deities, Thor rounds the heavens in his wagon, keeping a tribe of spiritual beings known as giants at bay. This image titled *Thor's Fight with the Giants*, is an 1872 oil on canvas by Swedish artist Mårten Eskil Winge.

NATIONALMUSEUM, STOCKHOLM / WIKIMEDIA COMMONS / PUBLIC DOMAIN

Charles's Wain also made its way across the Atlantic to the United States. It's listed in Noah Webster's 1857 *An American Dictionary of the English Language*. And in the 1889 *Americanisms Old and New*, of wain, it says, "This Old English term is still colloquial in America" — as witnessed in American writer H. P. Lovecraft's 1918 short story "Polaris": "Down from the heights reels the glittering Cassiopeia as the hours wear on, while Charles' Wain lumbers up from behind the vapour-soaked swamp trees that sway in the night-wind."

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

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

Two Out of Five Ain't Bad

Jupiter and Saturn are the only planets adorning the January night sky.

THURSDAY, JANUARY 1

Let's begin the month with something of a departure by talking about what you *can't* see. If you keep a close eye on the night sky, you may have noticed something missing. Planets. Of the five naked-eye planets, only Jupiter and Saturn are currently visible. As the chart at the top of the facing page shows, **Mercury**, **Venus**, and **Mars** are bunched together near the Sun and out of view this month. This isn't a terribly uncommon occurrence, but it is a bit unusual. Of course, Mercury comes and goes so quickly that it's never gone for long. You can expect to observe it next month when it puts on its best dusk showing of the year. Venus has its conjunction with the Sun on January 6th but won't reappear as the Evening Star until February 2nd. As for Mars, well, let's just say it's plodding along. It has its conjunction with the Sun on January 9th, just three days after Venus. At that point it begins its agonizingly slow climb into the morning sky, where it at last becomes naked-eye visible in mid-May.

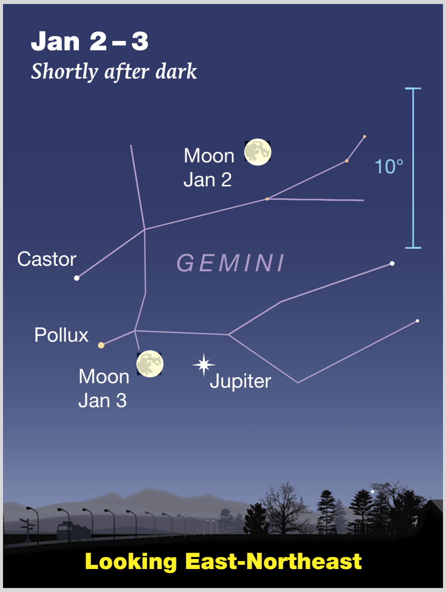
SATURDAY, JANUARY 3

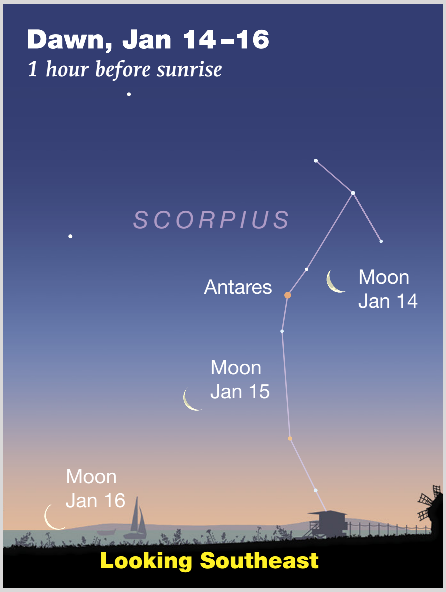
Shortly after sunset this evening, turn and face east-northeast. There, you'll see the very nearly full **Moon** rising alongside **Jupiter**. The Moon was *exactly* full earlier in the day (at 5:03 a.m. EST), so at this moment it's 99% illuminated. It's no coincidence that Jupiter and the Moon lie opposite the Sun's position in the sky. Indeed, you can think of full Moon as when Earth's natural satellite is at "opposition" — something that typically occurs once a month. (Every now and then it happens twice instead, the second full Moon being popularly referred to as a Blue Moon.) And what of Jupiter? It, too, is positioned across the sky from the Sun, which is unsurprising since its opposition date is exactly one week away, on January 10th. The gas giant reaches that position at roughly 13-month intervals, which is why there was no Jupiter opposition at all in 2025, the most recent one having occurred in December 2024. (Turn to page 48 for more on observing Jupiter.)

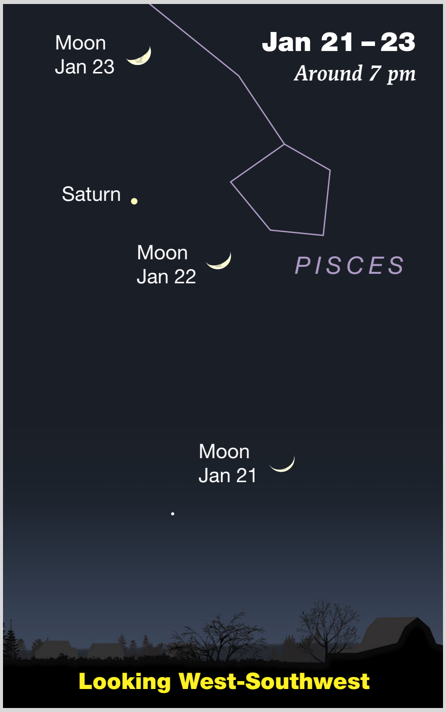
WEDNESDAY, JANUARY 14

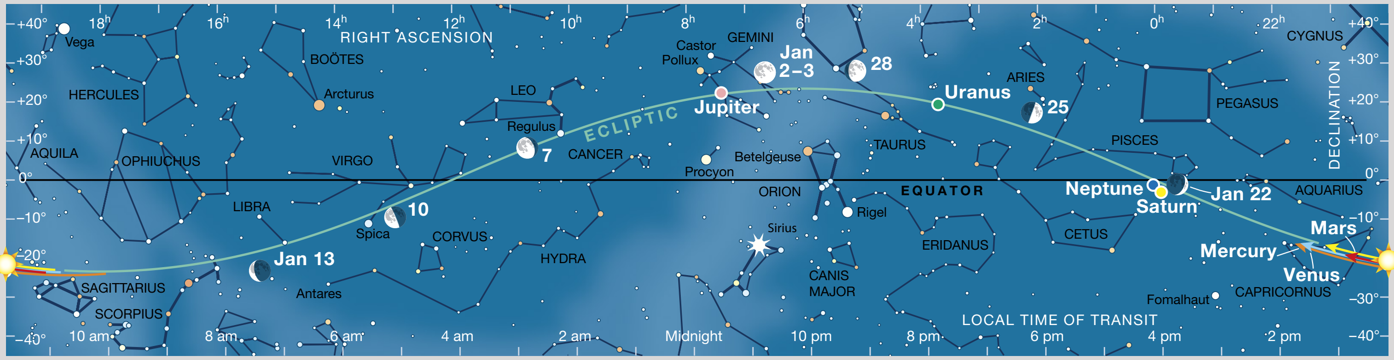
As it does every month, the **Moon** has several close encounters with the handful of bright stars strung out along

▼▶ 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. The blue 10° scale bar is about the width of your fist seen at arm's length. For clarity, the Moon is shown three times its actual apparent size.





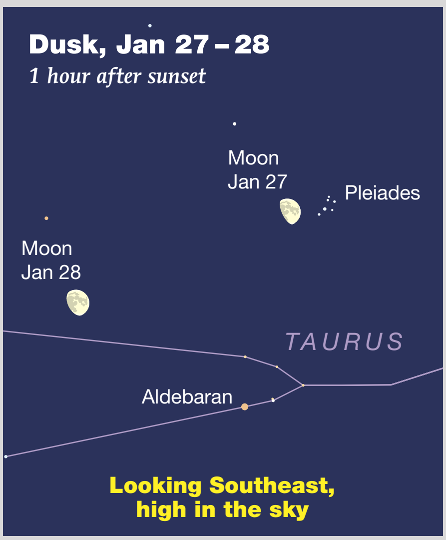




▲ The Sun and planets are positioned for mid-January; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

the ecliptic. At dawn on January 6th a waning gibbous sat less than 3° right of **Regulus**, in Leo, and on the 10th, the last-quarter Moon was 5½° right of **Spica**, in Virgo. But the most visually arresting pairing this month takes place on the morning of the 14th as a 16%-illuminated, waning lunar crescent approaches to within 3° of **Antares**, the flickering heart of Scorpius, the celestial Scorpion.

Why do I highlight this conjunction over the others? Simply because the Moon is such a slender crescent that its light doesn't overwhelm the star's glint. The other reason is the attractive contrast between Antares's ruddy color next to the silvery gray of the Moon (warmed to a slightly yellowish hue by its low elevation). Because the lunar crescent is closing in on the star as dawn approaches, the later you look and/or the farther west you're located, the narrower the gap is between the duo. Indeed, skywatchers on the West Coast can shave one full degree off the figure quoted above. And luckiest of all are observers in *the* Lucky Country, Australia — they get to see the Moon eclipse the star! But if you're in the U.S. and wondering when you'll get your chance to see an Antares occultation, the answer is May 10, 2028. Be sure to mark your calendar.



TUESDAY, JANUARY 27

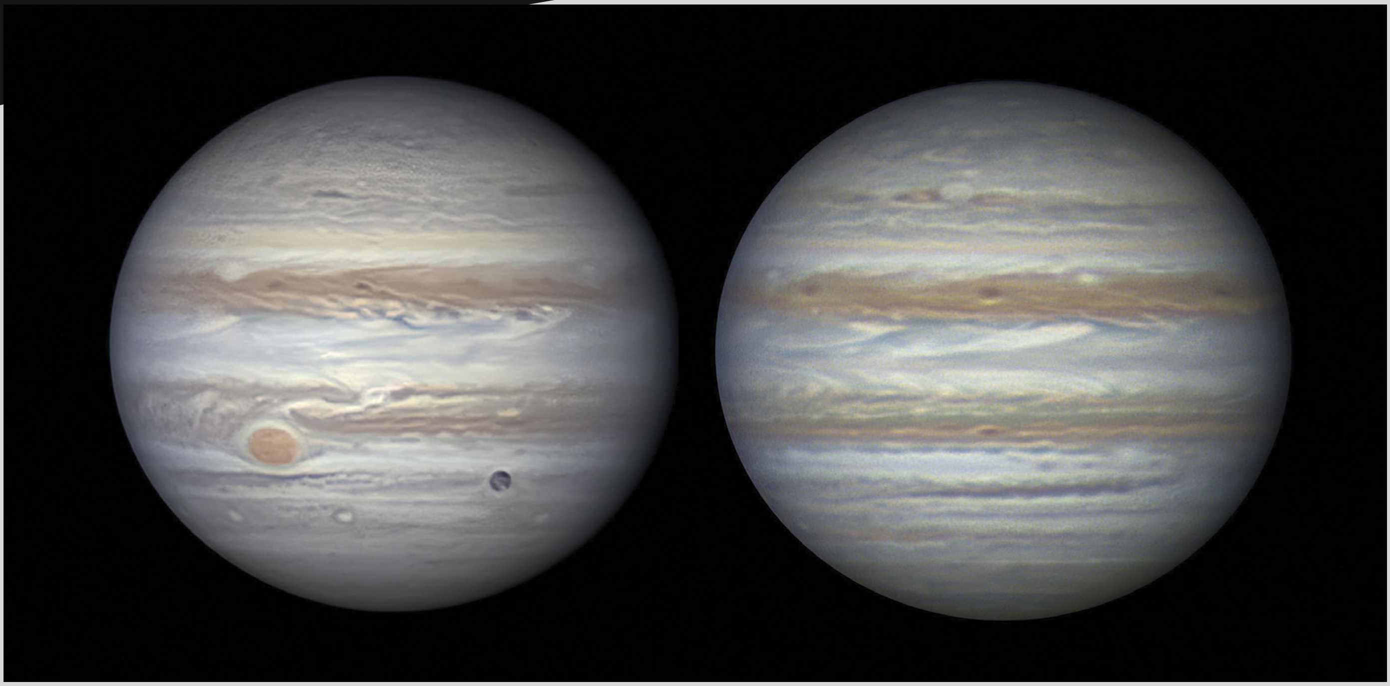
Since we last checked in, the **Moon** has glided sunward through the dawn sky, transitioned from old to new, re-emerged at dusk as a narrow crescent, and grown past first-quarter phase. Tonight, it's a waning gibbous in the evening sky, parked less than 2° left of the **Pleiades** cluster in Taurus. The 70%-illuminated lunar disk throws off a lot of light — enough to make the cluster stars tricky to see without optical help. Binoculars are the ideal choice as they allow you to see the stellar pinpricks of the brightest Pleiads competing for attention in the same field as the silvery luminance of the Moon.

Pairings between the Pleiades and the Moon generally occur once a month. However, as the year progresses, the Moon becomes less and less obtrusive as its phase changes from waxing gibbous to first quarter to thin crescent for these meet-ups. In other words, it pays to be patient. The upcoming conjunctions will be better as the lunar disk diminishes and the effect of its light on the cluster's stars is reduced. However, at the same time, the Pleaides sink lower and lower into the west and eventually vanish in evening twilight's glow.

FRIDAY, JANUARY 30

The month ends much as it began — with a meet-up featuring the **Moon** and **Jupiter**. Nearly four weeks after their earlier rendezvous, the lunar disk has lost a little of its luster. On the 3rd it was virtually full, whereas this evening it's a 96%-illuminated waxing gibbous when it's closest to Jupiter, at around 10 p.m. EST. What makes tonight's scene fun to watch, however, is the Moon's gradual eastward drift. At dusk, it's one corner of a lopsided box that includes Jupiter and Gemini's two brightest stars, **Castor** and **Pollux**. However, if you continue to monitor the Moon's journey across the constellation, at around midnight EST, you'll see it cross an imaginary line connecting Jupiter and Castor. And then at roughly 4 a.m. on the morning of the 31st it sits in the middle of a neat three-in-a-row line it forms with Pollux and Jupiter. The Moon advances by its own diameter every hour, but it's not often that it has such conspicuous signposts to make its motion easy to gauge.

■ Consulting Editor **GARY SERONIK** keeps a close eye on the Moon's comings and goings from his backyard in British Columbia's Okanagan Valley.



Jupiter Rules!

The solar system's most telescopically rewarding planet is at its best for 2026.

Jupiter was the chief Roman deity and king of the gods. And at opposition, the namesake planet holds sway in the night sky. When the speedier Earth lines up with Jupiter on the same side of the Sun and the two worlds are closest, the solar system's largest planet can shine as bright as magnitude –2.9. Venus may be brighter, but Jupiter spends far more time above the horizon at night, making it the most impressive planet far more often than Venus, which mostly keeps to the twilight sky.

Jupiter's opposition occurs on January 10th, when the gas giant gleams at magnitude –2.7 and presents a 46.6″-wide, slightly flattened disk in telescopes. It shines high in Gemini and reaches a maximum northern declination this apparition of +22° 58.6′ on March 13th. This is good news for observers in the Northern Hemisphere. Jupiter's path across the sky mimics that of the summer Sun, guaranteeing many happy hours of viewing with minimal interference from the poor seeing conditions usually present at lower altitudes.

January opens with Jupiter moving westward in retrograde motion. The planet spends the 17th through the 19th slipping just ½° north of the tasty double Delta (δ) Geminorum. The primary star's magnitude is 3.6, and its 8.2-magnitude companion shimmers 5.5″ to the southwest. I so enjoy it when planets deliver bonus cosmic goodies.

Many observers consider Jupiter the most rewarding planet to observe in a telescope. Its disk is impressively large and striped with colorful, swirling clouds wracked by powerful storms. Who could ask for more? It also has the shortest day of any planet in the solar system, a bit less than 10 hours. Its rotation is noticeable in as little as half an hour. Indeed, if you view Jupiter early in the evening this month, you can see an entirely different hemisphere five hours later that same night.

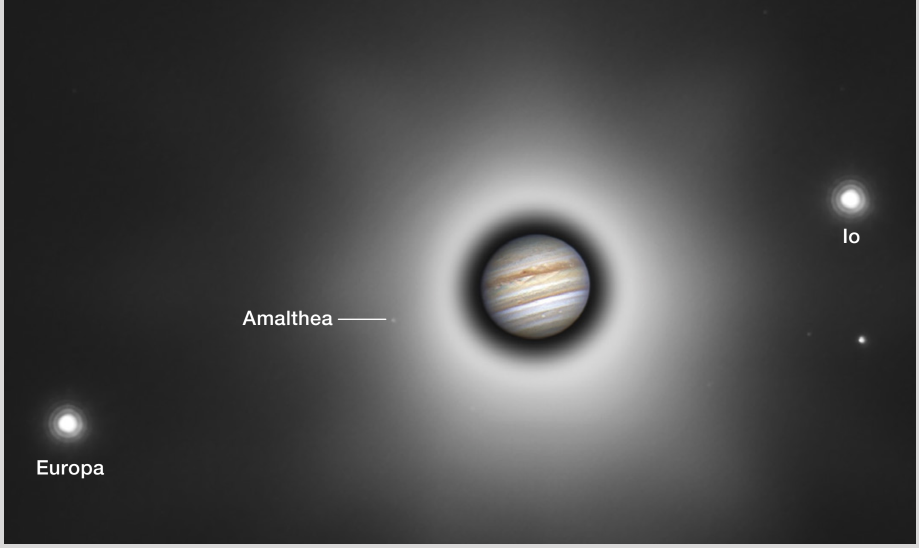
Jupiter's "surface" is all atmosphere and crossed by alternating dark belts and light zones. The two equatorial cloud belts are easiest to discern and require only a small telescope. Although they appear muted at low magnification, larger telescopes magnifying 200× or greater reveal deep, reddish-brown hues. Scientists think the colors arise from sulfur and phosphorus gases dredged up from the planet's interior. Additional belts and zones are visible in most telescopes, depending on the magnification used and how steady seeing conditions are at the time.

▲ *Left:* Jupiter's famous (and shrinking) Great Red Spot is obvious in this photo made on September 7, 2025. Ganymede is seen hovering above the South Temperate Belt. *Right:* The opposite hemisphere presented itself three nights earlier. Although Riverside, California, amateur Brian Martin captured both images with a 16-inch reflector, many of the details presented are visible in a 6-inch instrument.

Jupiter is also dynamic. New features can pop up or disappear at any time. I've watched the normally rusty-brown South Equatorial Belt (SEB) virtually disappear under thick, ammonia-rich clouds. A year or two later, changes in atmospheric circulation whisk the clouds away and reveal the lower-lying dark clouds again. Fresh storms frequently brew up too, like last year's outbreak of bright clouds in the SEB (*S&T:* Nov. 2025, p. 52). Jovian tempests also take the form of red or white ovals lodged within and between the dark belts. Graceful bluish festoons often adorn the planet's Equatorial Zone like crepe paper streamers at a child's birthday party.

Jupiter's famous Great Red Spot (GRS) has been slowly contracting over the years. We still don't know if this supersized anticyclonic storm will eventually fade away or return to the prominence it had in the late 19th century. In March 2025, scientists announced that they had used the Hubble Space Telescope to measure the GRS, which was approximately 16,500 kilometers (10,250 miles) wide, equal to 1⅓ Earth diameters. Contrast that with historic observations from the late 1800s that pegged the feature's length at around 41,100 km, or images from the twin Voyager spacecrafts that showed a diameter of 23,300 km in 1979.

Each observing season provides another opportunity to keep track of the GRS's evolution and changing color, which varies from salmon, to cherry, to butterscotch. A 3-inch or 4-inch telescope shows the spot, but you'll need steady air and a magnification of 150× or greater for a clear view. The best time to view the GRS is around the time it transits the planet's meridian. GRS transits are listed starting on page 50.



▲ This composite image made on July 4, 2018, shows Jupiter and its moons Europa, Amalthea, and Io. (The dot below Io is a 12th-magnitude field star.) Amalthea glowed at magnitude 14.5 when the main photo was captured. Jupiter was recorded separately, shortly after the initial image.

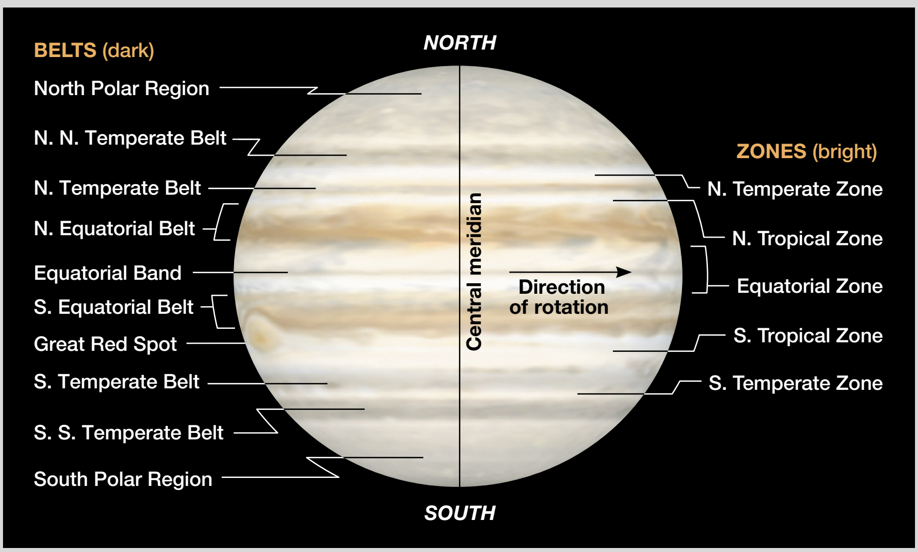
Nothing beats the antics of the Galilean moons Io, Europa, Ganymede, and Callisto. Their nightly dances enthrall even the most experienced observers and are a constant source of delight for newcomers. Even steadily held binoculars will usually show two or three of the moons. Each of the four satellites is roughly the size of our own Moon, and all are visible as tiny disks through a 6-inch telescope used with sufficient magnification. Astrophotographers equipped with larger instruments and planetary cameras routinely record surface features on these little disks.

Looking for an extreme Jovian challenge? Try seeking out the planet's fifth moon, Amalthea. It was the last Jovian satellite to be discovered visually. American astronomer Edward Emerson Barnard cornered it with the 36-inch Lick refractor in 1892 (see page 22). At magnitude 14.1, it's very dim and only lies about 38″ from the planet's glare at maximum elongation.

Even observers working with large scopes have described sighting Amalthea as exceedingly difficult. Keith Venables of Camberley, England, spotted it in both 16-inch and 18-inch reflectors fitted with a homemade occulting bar made from aluminum foil to block the planet's light. Allan Wade of Newcastle, Australia, spent close to 100 hours searching with his 32-inch before finally seeing the elusive moon, reporting, "I'm very proud of that achievement, it was probably the most difficult observation I've done over the last 40 years."

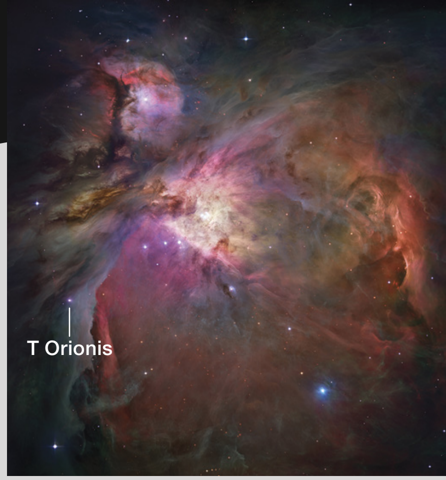
Not only do the Galilean moons align in eye-catching arrangements, but they also cast shadows on the Jovian disk, disappear and reappear at the planet's limb during occultations, and are often eclipsed by Jupiter's shadow. Each month features dozens of such occurances which you'll find listed in the table presented on page 51.

I'll be keeping a close eye on the one occuring on the morning of January 10th. That's when Callisto's shadow appears as a fuzzy, dark ring surrounding the moon itself — all thanks to the geometry of opposition day. Callisto crosses Jupiter from 2:01 a.m. to 5:56 a.m. EST. Don't miss it!



UPITER BELT/ZONE DIAGRAM: *S&T*; AMALTHEA: WAYMEN ASKEY

Youthful Star T Orionis



▲ Using the Hubble Space Telescope, astronomers have revealed more than 3,000 infant stars within the Orion Nebula. One of them — T Orionis — is literally coming alive before our eyes as it clears its cocoon of natal dust.

EVERY TIME YOU look at the Orion Nebula in a telescope you've likely also seen the temperamental variable star T Orionis. It lies near the nebula's core, about 10′ southeast of the Trapezium cluster. Baby stars abound in the nebula, and many of them show fluctuations in their light as they ride the rocky road of youth to the relative stability of the main sequence.

Astronomers classify T Orionis as a *Herbig Ae/Be* star, a massive, fledgling sun still undergoing gravitational contraction. When its core is finally hot enough to fuse hydrogen into helium, the star will settle down, like our Sun did some 4.5 billion years ago. In its current phase, the youthful star exhibits continuous light variations easily detectable visually. They're caused by changes in the rate the star accretes matter from its birth cloud as well as variations in the density of dust and other solids in the thick, circumstellar disk that surrounds it.

T Orionis ranges from magnitude 9.5 to 12.5, but you'll usually catch it between magnitude 10.0 and 11.0. It varies irregularly, so you never know exactly what to expect. If you want to try your hand estimating the star's brightness, pop over to **aavso.org** and create a customized field chart.

Now that you know it's been right in front of you all this time, make a point of puting the newcomer on your observing list this month.

Minima of Algol

Dec.	UT	Jan.	UT
3	19:22	1	11:34
6	16:11	4	8:23
9	13:00	7	5:13
12	9:50	10	2:02
15	6:39	12	22:51
18	3:28	15	19:40
21	0:17	18	16:30
23	21:06	21	13:19
26	17:56	24	10:08
29	14:45	27	6:58
		30	3:47

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

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

Action at Jupiter

JANUARY IS JUPITER MONTH. The planet reaches opposition on the 10th — something it didn't do at all in 2025. Because Jupiter hits that mark at roughly 13-month intervals (398.88 days, to be exact), if an opposition date falls in December (as it did in 2024), the following year will be opposition free. Opposition means Jupiter is visible all night long and transits the meridian at local midnight. Mid-month, the planet gleams at magnitude –2.7 from eastern Gemini where it presents a disk spanning a generous 46.5″.

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

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

January 1: 0:01, 9:56, 19:52; **2**: 5:47, 15:43; **3**: 1:39, 11:34, 21:30; **4**: 7:25, 17:21; **5**: 3:16, 13:12, 23:08; **6**: 9:03, 18:59; **7**: 4:54, 14:50; **8**: 0:46, 10:41, 20:37; **9**: 6:32, 16:28; **10**: 2:23, 12:19,

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

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

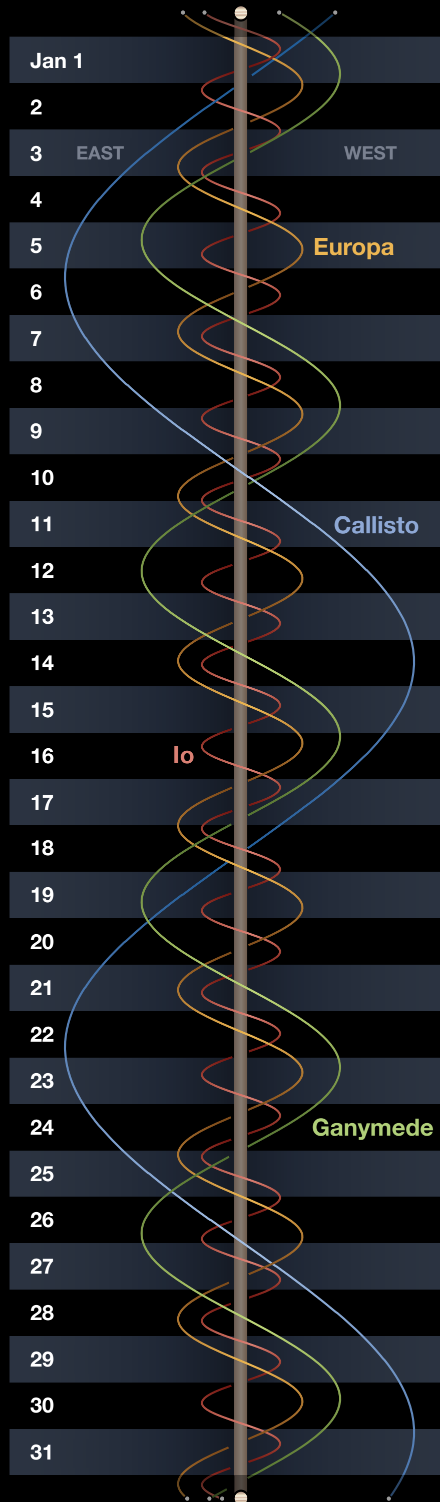
These times assume that the spot will be centered at System II longitude 89° on January 1st. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 89° and $1\frac{2}{3}$ minutes later for each degree more than 89°.

Phenomena of Jupiter's Moons, January 2026

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

Seeing the Invisible

Here's how one astronomer managed to observe the solar system in ultraviolet light.

The average person is capable of seeing light in a range of wavelengths between approximately 400 nanometers (nm) in the violet to 700 nm in the red. The ultraviolet (UV) portion of the spectrum extends from 400 nm down to about 10 nm and is largely invisible. Earth's protective ozone layer absorbs wavelengths shorter than 280 nm, so space-based telescopes are required to observe the shortest, highest-energy ultraviolet light. These instruments reveal a fascinating array of cosmic phenomena — notably extremely hot young stars, the gaseous debris from ancient supernovae, and solar flares and other transient events in the Sun's chromosphere and corona.

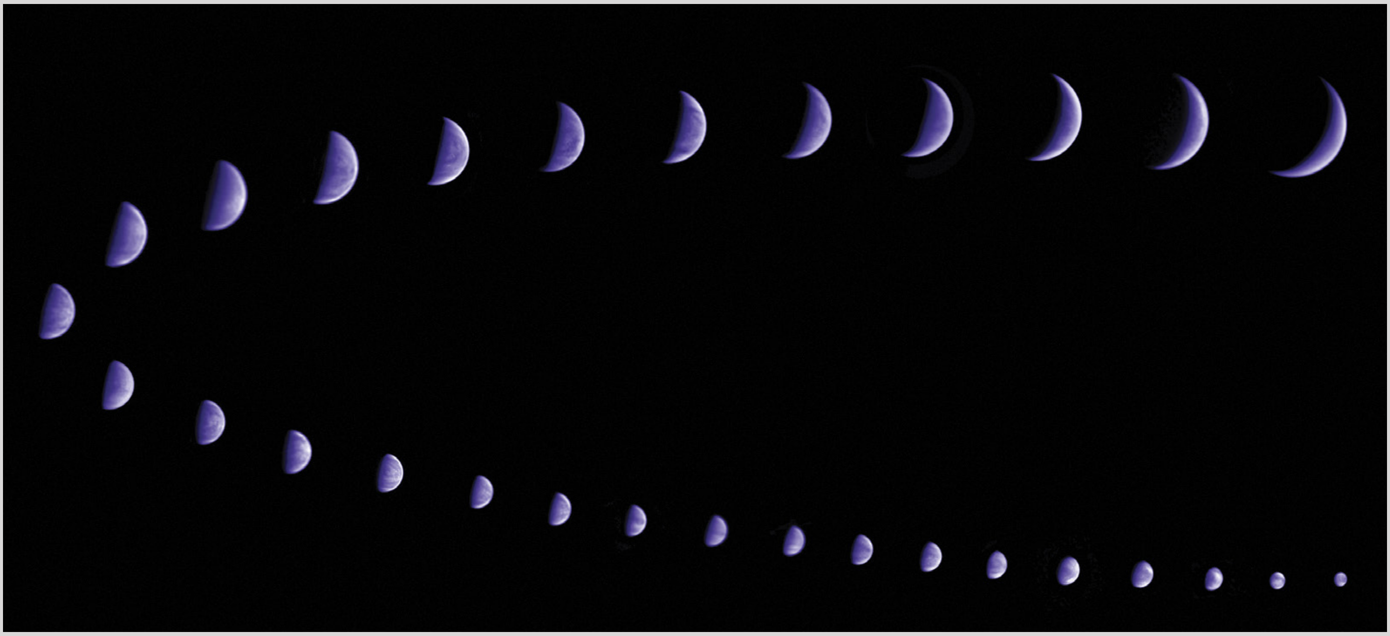
Many objects in the solar system take on unusual appearances in the near-ultraviolet region of the spectrum that's accessible to ground-based instruments. Almost four decades ago, one astronomer was actually able to make visual observations of the planets in the ultraviolet using a surgically altered eyeball.

British-born astronomer Ewen Whitaker (1922–2016) is best known for his enduring contributions to selenography and lunar cartography. Together with Gerard Kuiper, he founded the Lunar and Planetary Laboratory at the University of Arizona, which rapidly emerged as one of the world's leading centers for planetary research.

During the 1980s, Whitaker developed cataracts and chose to undergo corrective surgery. This routine procedure consists of removing the clouded, yellowed natural lenses and replacing them with artificial ones. These implanted replacements are made of polymethylmethacrylate, an extremely transparent plastic that is widely known by its trade names Plexiglas, Lucite, and Perspex. The extraordinary biocompatibility of this material with human tissue was discovered during World War II. An ophthalmologist observed that wounded Royal Air Force fighter pilots whose eyes were riddled with splinters from the Perspex cockpit canopies didn't suffer from the immune response rejection experienced by pilots with splinters from glass canopies.

Polymethylmethacrylate transmits about 90% of ultraviolet light between 320 and 400 nm. This spectral window in the near-ultraviolet makes up about

▼ This series of images shows dark bands in the cloud canopy of Venus in ultraviolet (UV) light changing day to day during the western elongation of 2007. The planet rarely displays any markings in visible light.



SEAN WALKER

95% of the ultraviolet rays that penetrate Earth's atmosphere. Known as UVA radiation, it causes suntans and premature skin aging and plays a role in the formation of non-melanoma skin cancers. Special UV-blocking coatings or dissolved pigments are added to replacement lenses to prevent damage to a patient's retina.

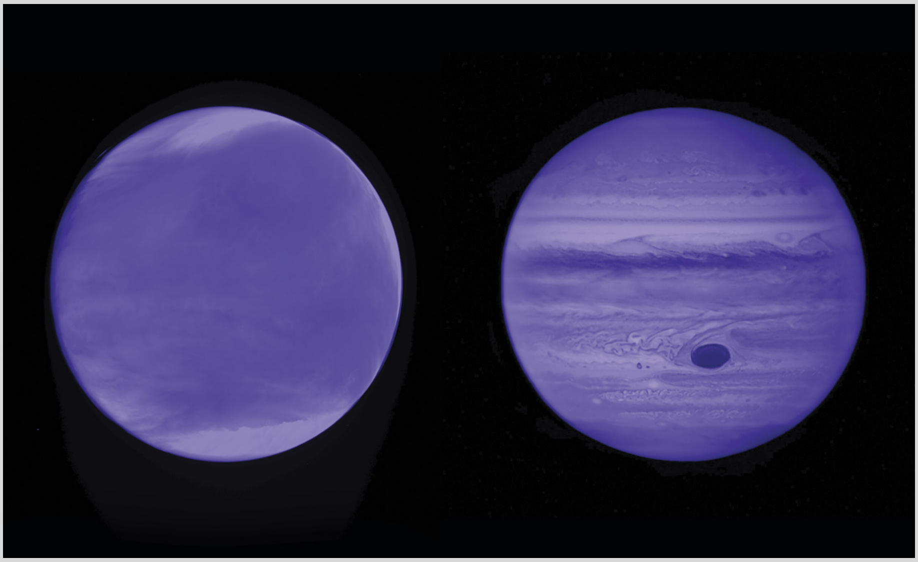
Whitaker's surgery wasn't entirely routine. Seizing the opportunity to fulfill a long-standing desire to make visual observations of the planets in the ultraviolet, he requested that a lens without UV-blocking coatings be implanted in his right eye and relied on a pair of custom eyeglasses to protect his retina in daylight.

Using a monochromator at the University of Arizona's Physics Department to test his spectral sensitivity, he was delighted to find that he could see down to 317 nm. He described the color sensation produced by UV radiation as "... indistinguishable from deep blue of the 410–430 nm range."

Predictably, the first target for Whitaker's altered eyeball was Venus. In visible light, the planet's dazzling cloudscape is usually as featureless as a frosted light bulb. While distinct markings are very rare, elusive shadings of extremely low contrast are sometimes glimpsed. Prominent markings appear only in UV images of the planet owing to the presence of UV-absorbing materials in the planet's upper cloud deck. These markings were discovered at Mount Wilson Observatory by Frank Ross, a pioneer in the photography of the planets through monochromatic filters. During a favorable eastern elongation of Venus in June and July of 1927, he obtained a series of photographs of the planet through the observatory's 60-inch and 100-inch reflectors in six regions of the visible spectrum as well as in infrared and ultraviolet light. The images taken through a UV filter transmitting wavelengths of 340 to 380 nm recorded diffuse dark streaks and bands running roughly perpendicular to the planet's terminator.

Six decades later, during a 10-day period in March 1988, Whitaker made a series of observations of Venus in broad daylight about two weeks before it reached greatest elongation from the Sun when it had achieved an altitude of 70° above the horizon as seen from southern Arizona. He placed his 6-inch Newtonian reflector in the shade of a patio roof to minimize local turbulence from solar heating and used a filter that transmitted wavelengths shorter than 410 nm to remove the unwanted visible light "noise" from the ultraviolet "signal." In visible light he saw "nothing more than the vaguest evanescent shadings" but was "agreeably surprised" that the UV markings were easy to see:

> *By mid-March the disk subtended an angle of almost 20 arcsec, which at × 100 is the same as the Moon seen with the naked eye and thus large enough for major features to be sketched. Indeed, on 1988 March 22 the five-day old Moon was near the zenith at mid-afternoon, making a direct comparison a simple matter. Under these conditions I estimated that the naked-eye contrast of the lunar maria was very similar to the contrast of the UV markings of Venus.*



▲Other major planets take on markedly different appearances in UV wavelengths. *Left:* The European Space Agency's OSIRIS spacecraft recorded Mars in UV during its flyby of the planet on February 24, 2007. At these short wavelengths, clouds in the upper atmosphere are visible with no trace of Martian albedo features showing through. *Right:* This 2023 Hubble Space Telescope image of Jupiter was recorded through its narrow bandpass 343-nm UV filter. The striking dark appearance of polar regions is due to light being absorbed by high-altitude hazes.

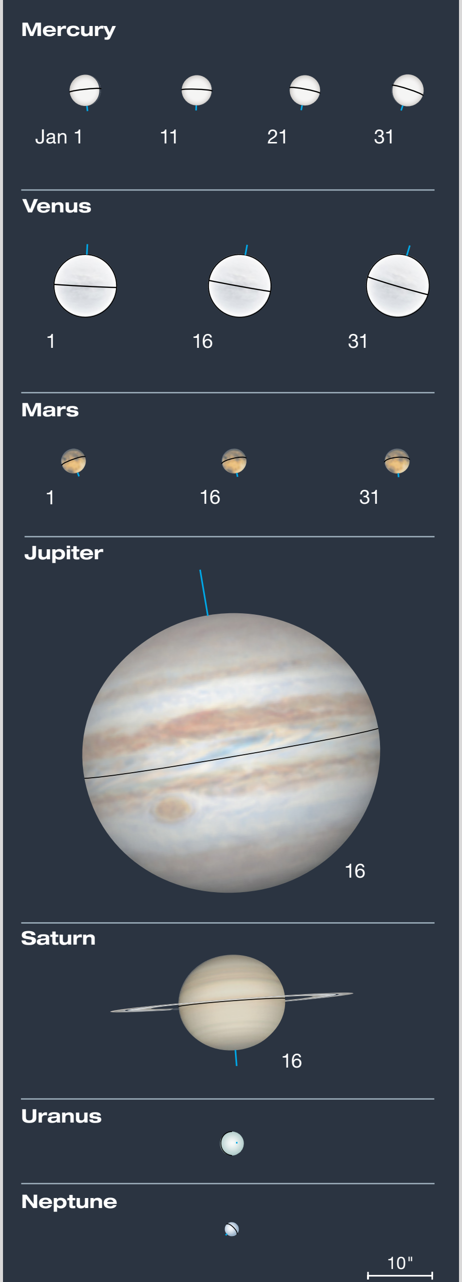
MARS: ESA / MPS FOR OSIRIS TEAM / MPS / UPD / LAM / IAA / RSSD / INTA / UPM / DASP / IDA / S. WALKER. JUPITER: NASA / ESA / HUBBLE SPACE TELESCOPE / M. WONG (UC BERKELEY) / G. KOBER (NASA / CATHOLIC UNIVERSITY OF AMERICA) / S. WALKER

Using the 16-inch Cassegrain reflector on the University of Arizona campus, Whitaker also trained his UV eye on other planets. Jupiter had an unusually flattened appearance due to the presence of polar hoods of dense, UV-absorbing hydrocarbon hazes. To his surprise, the planet's volcanically active satellite Io was invisible — the deposits of sulfurous materials covering its surface reflect very little UV light.

Whitaker had difficulty making out surface markings on Mars during the favorable 1988 opposition, but clouds and mists high in the planet's tenuous atmospheres stood out boldly. Saturn's globe displayed a bright limb and dark equatorial band, while the planet's rings appeared brilliant.

Whitaker's unique visual observations would require truly extraordinary measures to duplicate. However, you can use today's affordable dielectric UV filters combined with a monochrome CMOS sensor to capture the sights revealed to his altered eye.

■ Contributing Editor **TOM DOBBINS** is coauthor of *Epic Moon, A History of Lunar Exploration in the Age of the Telescope*, available at **shopatsky.com**.



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

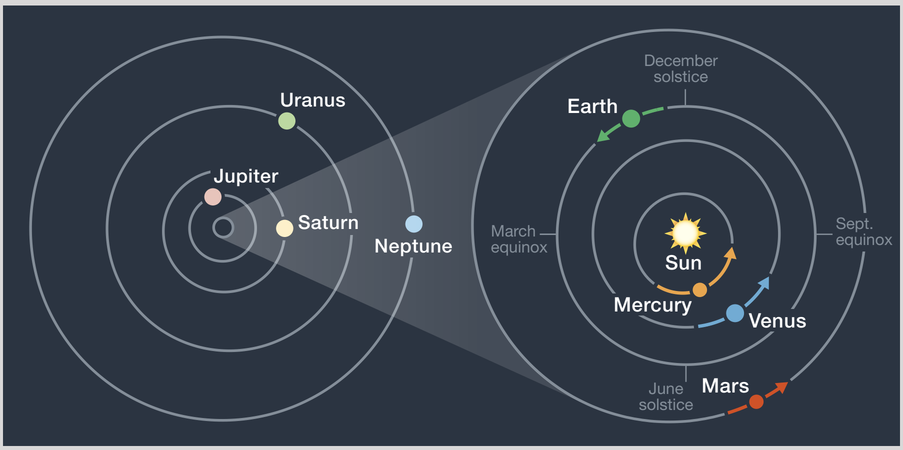
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during January. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury**, **Venus**, and **Mars** are lost in the Sun's glare all month • **Jupiter** rises around sunset and remains visible all night • **Saturn** is high in the southwest at dusk and sets in the late evening.

January Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	18^h 44.4^m	–23° 03′	—	–26.8	32′ 32″	—	0.983
	31	20^h 52.8^m	–17° 32′	—	–26.8	32′ 28″	—	0.985
Mercury	1	17^h 52.5^m	–24° 00′	12° Mo	–0.6	4.9″	95%	1.378
	11	19^h 00.9^m	–24° 13′	7° Mo	–0.9	4.7″	98%	1.426
	21	20^h 11.2^m	–22° 06′	2° Ev	–1.4	4.7″	100%	1.420
	31	21^h 21.6^m	–17° 29′	7° Ev	–1.3	5.0″	98%	1.349
Venus	1	18^h 38.7^m	–23° 39′	1° Mo	—	9.8″	100%	1.710
	11	19^h 33.2^m	–22° 34′	1° Ev	—	9.7″	100%	1.711
	21	20^h 26.4^m	–20° 22′	4° Ev	–3.9	9.8″	100%	1.708
	31	21^h 17.8^m	–17° 09′	6° Ev	–3.9	9.8″	100%	1.701
Mars	1	18^h 54.0^m	–23° 45′	2° Ev	+1.2	3.9″	100%	2.411
	16	19^h 43.8^m	–22° 17′	2° Mo	+1.2	3.9″	100%	2.397
	31	20^h 32.9^m	–19° 53′	5° Mo	+1.2	3.9″	100%	2.380
Jupiter	1	7^h 30.9^m	+22° 02′	169° Mo	–2.7	46.5″	100%	4.243
	31	7^h 14.3^m	+22° 39′	156° Ev	–2.6	45.8″	100%	4.305
Saturn	1	23^h 48.2^m	–3° 44′	76° Ev	+1.2	17.1″	100%	9.715
	31	23^h 56.8^m	–2° 43′	47° Ev	+1.1	16.4″	100%	10.147
Uranus	16	3^h 40.1^m	+19° 21′	122° Ev	+5.6	3.7″	100%	18.952
Neptune	16	23^h 59.9^m	–1° 27′	64° Ev	+7.9	2.3″	100%	30.304

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**.



A Bang and a Whimper

Observing these winter targets in and around the Pleiades is an exercise in extreme contrast.

Key elements of astronomy bewilder me. I can't fathom the Big Bang, the cosmic microwave background, or the accelerating expansion of the universe. My passion is for dark skies, not dark matter or dark energy. Above all, I can't imagine the vast cosmic works ultimately ending in a whimper.

Given my lack of astrophysical acumen, you'll be relieved to know that my Bang and Whimper sky tour has nothing to do with the inscrutable fine points of cosmology. It's mainly about a couple of strikingly different star clusters — a famous one in western Taurus and an obscure one in eastern Aries.

I executed my Taurus/Aries ramble on a moonless evening last January. To get underway, I set up two telescopes: a 4.7-inch f/7.5 apochromatic refractor and a 10-inch f/6 Dobsonian reflector. My tripod-mounted 10×50 binoculars helped me identify all the stops in the 15°-long star-hop.

Sisters Sighting

The project certainly opened with a bang, at **M45**, located northwest of 1st-magnitude Aldebaran in Taurus. Celebrated in classical mythology as the Pleiades, or Seven Sisters, M45 is one of the best known and most striking open clusters in the northern heavens. Six of the most prominent stars in the scintillating septet form a miniature dipper. Gazing without optics from my suburban yard last winter, I could see five Pleiads for sure, and occasionally six. Yet *nine* have names.

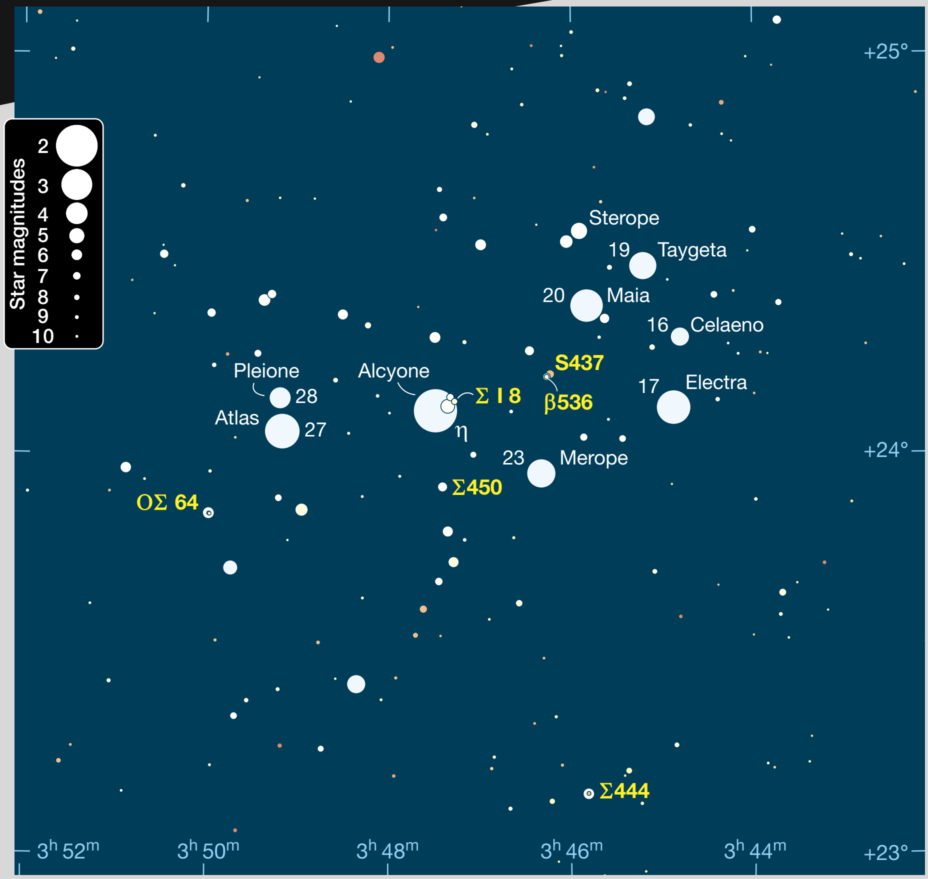
Gleaming at magnitude 2.9, Alcyone is the most resplendent Sister. Just to the east of it are 3.6-magnitude Atlas (the girls' father) and 5.1-magnitude Pleione (their mother), standing 5′ apart. Marking the cluster's northwestern corner are two stars of magnitudes 5.8 and 6.4, displaying only 2.5′ of separation. The naked eye perceives them as a single 6th-magnitude star, christened Asterope. The other five siblings are Taygeta (magnitude 4.3), Electra (3.7), Maia (3.9), Merope (4.2), and Celaeno (5.5). These nine family members span 1° of sky, though M45's official total diameter is a whopping 2°.

Immediately beneath the Pleiades is a 23′-long, bent chain of half a dozen 7th- to 9th-magnitude stars that leads the eye northward toward Alcyone. The chain was mostly a blur in my 10×50s, but with averted vision I picked up five of the six dots. The 4.7-inch apo refractor working at 30× captured all six. The topmost link in the chain is established by a double star, called **Σ450**, that consists of 7.3- and 9.4-magnitude components separated by 6.3″. Both telescopes split Σ450 at around 100×.

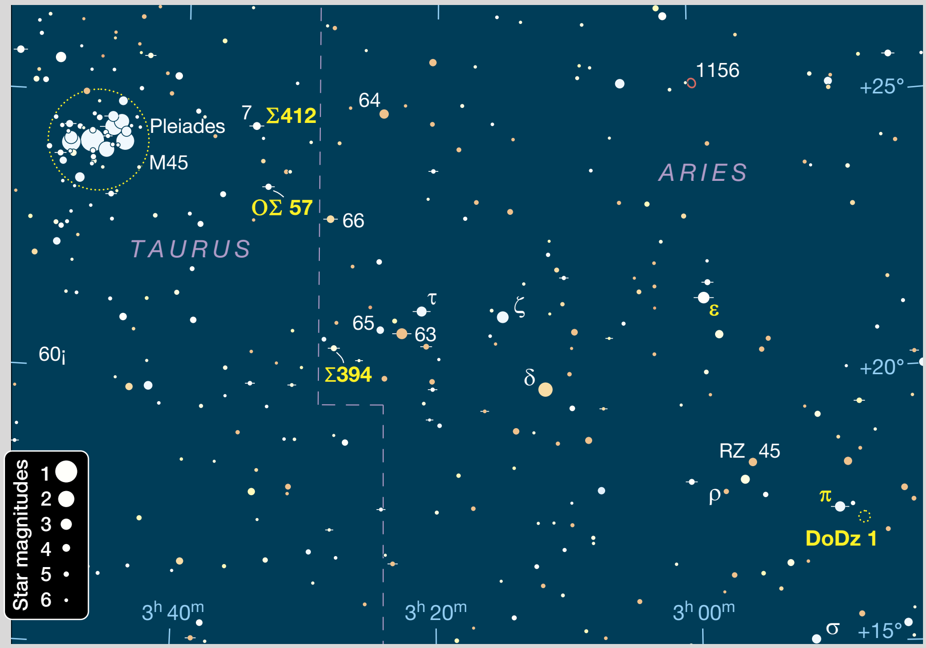
The Asterope pair on the Pleiades' northwestern corner is a slam-dunk double in binos. East of Alcyone, mom and pop (Atlas and Pleione) are even easier. But a test lies west of Alcyone, where three dim sparks — of magnitudes 6.3, 8.2, and 8.7 — form a triangular triple system, 86″ across, collectively named **Σ I 8**. My 10×50s detected the 6.3-magnitude star 2′ from Alcyone, but not the others. The

RON BRECHER

▲ **CELESTIAL SISTERS** The striking cluster of stars known as M45, the Pleiades, and the Seven Sisters lies only 446 light-years from Earth and covers an area of sky four times the width of the full Moon. Most of the cluster is enveloped in nebulosity that reflects the bluish light of the cluster's stars; however, these delicate wisps don't show in city-based scopes.



▲ **THE HEART OF THE MATTER** The glittering Pleiades, open cluster M45, is a can't-miss catch that marks the shoulder of Taurus, the Bull. In fact, M45's brightest member, 2.9-magnitude Alcyone, was long ago awarded the Bayer designation Eta (η) Tauri. The cluster includes a striking star chain near Alcyone, plus several double and multiple stars.



▲ **FROM A BANG TO A WHIMPER** Star-hopping southwest of glorious M45, through western Taurus into eastern Aries, reveals only one very inconspicuous cluster. Thankfully, the expansive region also includes several interesting double stars.

telescopes, of course, happily embraced Alcyone's entire srarry entourage.

Deeper inside M45 is South 437 (**S437**), an intriguing tandem sporting 7.7- and 8.1-magnitude stars, 38.8″ apart. Curiously, the brighter element exhibits a ruddy hue — a solitary orange dwarf amid the blue-white Pleiades. The dimmer star is a close binary listed as **β536** that holds a 9.4-magnitude secondary sun 1.1″ south of the primary. I learned of this challenging duo via an online article by *S&T* Contributing Editor Bob King. Bob's 10-inch f/6 Dobsonian resolved β536 at 218×; my identical Dob barely did so, even when the seeing was unusually steady.

Beyond the Sisters

Ready to ramble? From Atlas, a ¼° shift southeastward sweeps up a tight trio dubbed **OΣ 64**. It's a beauty. The 6.8-magnitude primary hosts siblings of magnitudes 10.2 and 10.5 lying 3.3″ and 10.1″ southwestward. The straight-line triple yielded to my reflector at 218×. The refractor, during instants of excellent seeing, succeeded at 258×.

A ½° curve of five stars of 7th- to 9th-magnitude decorates M45's southern boundary. The shallow crescent, oriented west-northwest by east-southeast, is centrally anchored by 6.9-magnitude HD 23410. The middle marker with its four flankers is a pretty sight; the two inner ones have wide 12th-magnitude companions that showed in the 10-inch at 95×. HD 23410 itself is a binary called **Σ444**. Its 10.1-magnitude secondary, 3.4″ northwestward, challenged my scopes. However, it was a definite pinpoint in the reflector at 169×. The refractor needed 258× to make the split.

Returning to the heart of the Pleiades, I pushed westward to 5.9-magnitude 7 Tauri. This lonely light is a double identified as **Σ412** thanks to its 9.9-magnitude companion, 22.4″ to the northeast. After 7 Tauri, I hiked 1.1° south-southwestward to **OΣ 57**, which consists of 7.2- and 7.7-magnitude stars 68.7″ apart, slanted northeast-southwest. My binos could barely split the pair, but it was a plump prize for the scopes. The "duo" is actually a quadruple system, each star hosting an ultra-faint attendant. Using the 10-inch at 218×, I glimpsed one of them: a 12.8-magnitude specter 32.9″ south of the main pair's brighter (southwestern) member.

From OΣ57, I headed southwestward 1¼°, crossing the border into Aries, to arrive at yellowy 66 Arietis. A further 2¼° hop landed on a loose clumping that includes 5th-magnitude 63 Arietis and 6th-magnitude 65 Arietis. Less than 1° southeast of the latter is **Σ394**, a superb binary comprising 7.1- and 8.2-magnitude stars separated by 6.9″. The double resolved nicely in both scopes at around 100×.

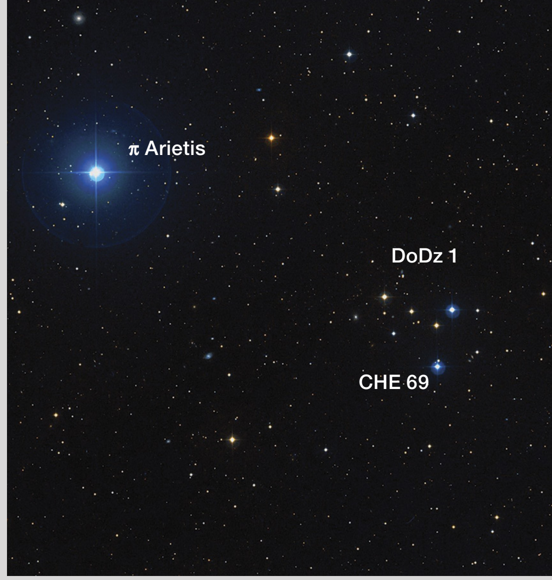
Back to 65 Arietis, I pushed westward 3° into a 4°-wide quadrilateral, whose northwest corner is marked by **Epsilon (ε) Arietis**, a tough binary. Epsilon possesses 5.2- and 5.6-magnitude components a scant 1.3″ apart. The tight tandem resisted resolution in the smaller scope, but my 10-inch was successful at 218×. It was a very satisfying sight.

After Epsilon, I dropped 3° south to the 6th-magnitude variable star 45 Arietis, also designated RZ Arietis. Orangey RZ decorates the northeastern corner of a 1¼°-long quadrilateral. On its southwestern corner is 5.3-magnitude **Pi (π) Arietis**. Another straight-line triple, Pi harbors an 8.0-magnitude secondary 3.3″ to the east-southeast, and a 10.7-magnitude tertiary 25.5″ farther out. The little lineup was attractive in the 10-inch at 169× and in the apo at 258×.

The Wimp

A ½° hop southwest of Pi Arietis is my wonderful wimp, **DoDz 1**. I first noticed the cryptic label on chart 79 of the *Uranometria 2000.0 Deep Sky Atlas*. The DoDz designation stands for Dolidze and Dzimselejsvili, two Russian astronomers who cataloged 11 obscure open clusters in the 1960s. (Madona Dolidze had archived 57 clusters previously; the DoDz collaboration resulted in 11 more.)

According to the 2003 book *Star Clusters* by Brent Archinal and Steven Hynes, DoDz 1 is magnitude 7.1, only 7.5′ across. It contains — wait for it — precisely eight stars. The diminutive DoDz



POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

▶ **WIMPY WONDER** Wimp, indeed — the object designated DoDz 1 isn't even a true star cluster. First noted in the 1960s by two Russian astronomers, DoDz 1 is merely a tight collection of unrelated stars. The bright star at upper left is 5.3-magnitude Pi (π) Arietis.

is no longer recognized as a true cluster; it's simply a compact asterism. But hey, it's there, so why not give it a look?

DoDz 1 is essentially a small triangle nested inside a larger triangle, the two figures lying almost at right-angles to each other. The six triangle stars range from magnitude 8.5 to 10.9, and the refractor registered them all. In addition, my trusty 10-inch snared two 12th-magnitude stars lined up north-south along the western periphery, plus two similar specks flickering on two sides of the bigger triangle. One of those elusive stars was a 12.8-magnitude ember lying 28.2″ north of 8.5-magnitude HD 17334 on the southern corner of the large triangle. Together they form an optical double with the obscure designation, **CHE 69**.

In mid-January, the Pleiades and their nearby friends are at the meridian soon after nightfall. The friends are certainly fun, but to enjoy them you'll have to tear your attention away from the glorious Pleiades!

■ Contributing Editor **KEN HEWITT-WHITE** can't resist straying off the beaten track, especially when it leads to celestial objects he's never seen before.

In and Around the Pleiades

Object	Type	Mag	Size/Sep	RA	Dec.
M45	Open cluster	–	~2°	$3^h\ 47.4^m$	+24° 07′
Σ450	Double star	7.3, 9.4	6.3″	$3^h\ 47.4^m$	+23° 55′
Σ I 8 AC	Double star	6.3, 8.2	182″	$3^h\ 47.5^m$	+24° 06′
Σ I 8 AD	Double star	6.3, 8.7	192″	$3^h\ 47.5^m$	+24° 06′
S437	Double star	7.7, 8.1	38.8″	$3^h\ 46.3^m$	+24° 11′
β536	Double star	8.1, 9.4	1.1″	$3^h\ 46.3^m$	+24° 11′
OΣ 64 AB	Double star	6.8, 10.2	3.3″	$3^h\ 50.0^m$	+23° 51′
OΣ 64 AC	Double star	6.8, 10.5	10.1″	$3^h\ 50.0^m$	+23° 51′
Σ444	Double star	6.9, 10.1	3.4″	$3^h\ 45.8^m$	+23° 09′
Σ412	Double star	5.9, 9.9	22.4″	$3^h\ 34.4^m$	+24° 28′
OΣ 57	Double star	7.2, 7.7	68.7″	$3^h\ 33.4^m$	+23° 22′
Σ394	Double star	7.1, 8.2	6.9″	$3^h\ 28.0^m$	+20° 28′
ε Arietis	Double star	5.2, 5.6	1.3″	$2^h\ 59.2^m$	+21° 20′
π Arietis AB	Double star	5.3, 8.0	3.3″	$2^h\ 49.3^m$	+17° 28′
π Arietis AC	Double star	5.3, 10.7	25.5″	$2^h\ 49.3^m$	+17° 28′
DoDz 1	Asterism	7.1	7.5′	$2^h\ 47.4^m$	+17° 16′
CHE 69	Double star	8.5, 12.8	28.2″	$2^h\ 47.4^m$	+17° 13′

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

Dive Deep into Thor's Helmet

Explore this Wolf-Rayet star and its nebula.

▲ **THOR'S HELMET** The central bubble of NGC 2359, a.k.a. Thor's Helmet, has an angular diameter of about 4.5′, which converts to 7.8 light-years. The overall nebula's size is 9′ × 6′, so it appears large enough to see well in amateur telescopes. Turn the page 90° to the left to see the helmet, but looking straight-on at this photo makes the nebula look more like an octopus! North is up in all images.

It was a cold and windy night; the sky was spectacularly dark and clear — and even though I was wearing all my winter observing gear I still had to shelter in my van every so often to warm up (for Chickahominy Reservoir in central Oregon is our scene), while my 28-inch f/4 telescope struggled against the frigid and erratic gusts.

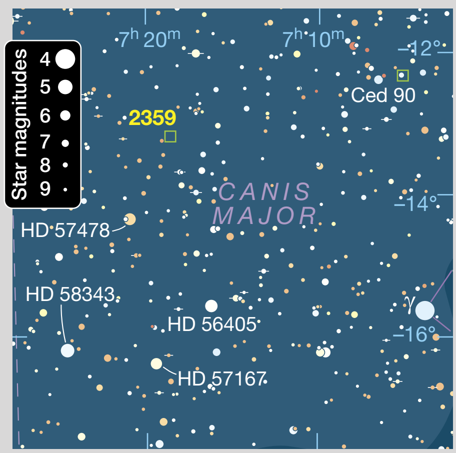
This was during the same fabulous observing trip in March 2021 when I had extraordinary views of three objects I previously reported on: the Cygnus Loop (*S&T:* Sept. 2021, p. 28); NGC 4565 (*S&T:* May 2023, p. 20); and M78 (*S&T:* Jan. 2024, p. 12). My primary interest for that trip was the Cygnus Loop, so the others were just icing on the cake. But what icing! Right now, though, it's **NGC 2359**'s turn.

While most nebulae require photography to reveal their distinctive and beautiful shapes, in NGC 2359's case much of its structure can be seen visually. And a basic understanding of what kind of nebula it is and why it looks the way it does makes it a much more interesting sight in the eyepiece.

Star and Bubble

The central part of NGC 2359 is a wind-blown bubble around the very hot Wolf-Rayet star **WR 7**. Also cataloged as **HD 56925**, this 11.6-magnitude star is additionally categorized as a WN4 star, which indicates its spectra feature several prominent nitrogen emission lines. WR 7 is about 13,400 light-years away and is huge — 13 times more massive than our Sun. It's the pre-supernova stage of a yellow supergiant, luminous blue variable, or a red supergiant star.

WR 7's fast stellar winds crash into slower outflows and the surrounding interstellar medium to create the wind-blown bubble. The intense ultraviolet light from WR 7 causes the resulting bubble to fluoresce, while its central region is filled with a plasma so hot it emits X-rays. The inner bubble, powered by the shocked stellar wind, comprises about 70 solar masses of material and interacts with an outer shell made up of shocked circumstellar gas.



◀ **ELUSIVE TARGET** Use Gamma (γ) Canis Majoris as your starting point to star-hop to Thor's Helmet.

NGC 2359 is more than just a wind-blown bubble, though. The long, curved horn along its southern edge is the H II region Sharpless 2-298. This neutral-hydrogen feature is referred to as "filament B" in the professional literature and has a mass of 85 to 115 solar masses, with the other streamers containing somewhere between 105 to 280 solar masses.

Throughout the young life of NGC 2359 — aged at approximately 100,000 years — WR 7 has been losing mass via its stellar winds. The fast wind is depleting the star at about 3×10^{-6} solar masses per year, while the slow wind is losing 9.6×10^{-5} solar masses per year. Over time this adds up. Eventu-

THOR'S HELMET: TREVOR JONES OF ASTROBACKYARD ally, when WR 7 has lost enough mass, it will become gravitationally unstable, collapse, and explode as a supernova.

Human beings were hunter-gatherers using stone tools when this mass-loss process began, and it's only in the past 158 years that we've figured it out.

The First Observation

The English astronomer William Herschel came upon NGC 2359, which he cataloged as V 21, on January 31, 1785. His discovery notes on his observations with his 18.7-inch speculum-mirror reflector are wonderful:

> *A broad, extended nebulosity, in the form of a parallelogram with a short ray southwards from the south preceding corner. The nebulosity [is] between the milky and resolvable, almost of an equal brightness, but very faint. The parallelogram ab^t. 8′ long and 5 or 6′ broad, but ill defined. I was doubtfull a[t] first but on giving a sidemotion to the telescope so as to compare it with the other parts of the heavens it appeared very plainly.*

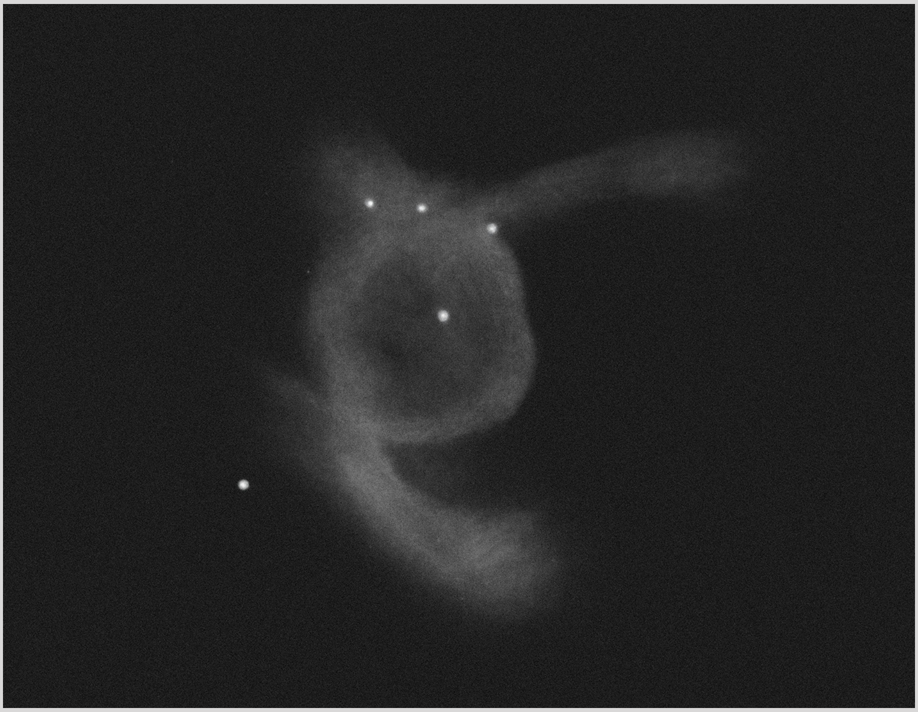
This shows how careful an observer Herschel was. Note that he thought the nebulosity was partially resolvable into stars — this was due to some foreground stars that he saw over the soft glow of the nebulosity. I wonder what he would have made of this object if he'd had an O III filter.

Small Scope

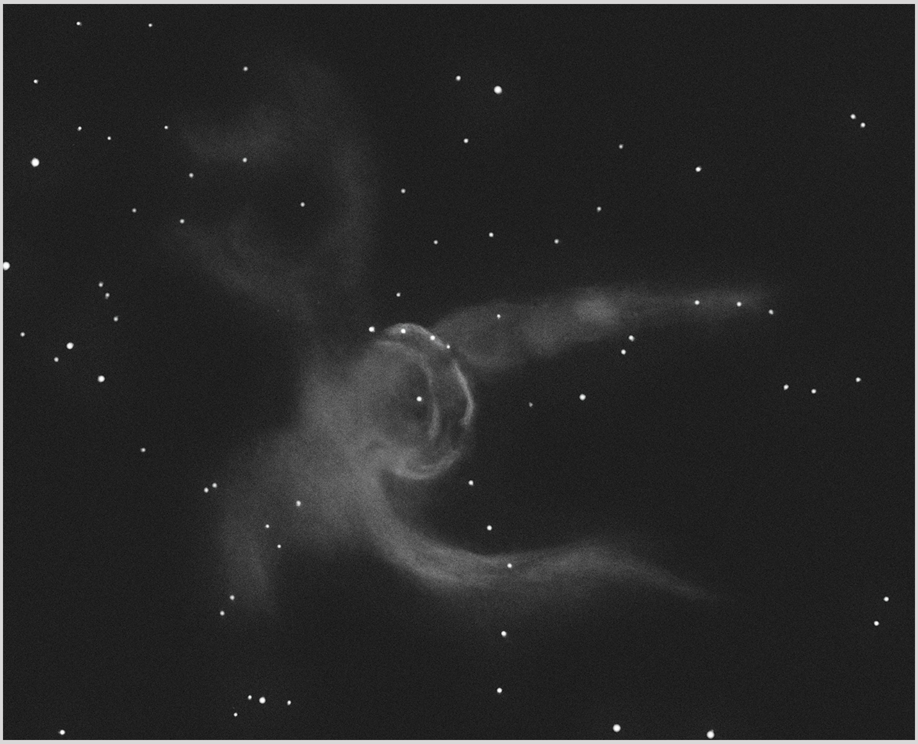
Contributing Editor Steve Gottlieb observed NGC 2359 with a finderscope in 2007:

> *The circular central region of Thor's Helmet was easily visible at 13× in my 80-mm finder using an O III filter (24-mm Panoptic), though the "horns" of the helmet were not seen.*

This is impressive. Getting a good view of any nebula with such a modest instrument takes preparation, experience, and good conditions. Could a novice duplicate Steve's observation from their backyard? Only one way to find out.



▲ **SMALL SCOPE VIEW** The sketch above shows NGC 2359 as I saw it through my 8-inch f/3.3 Dobsonian with an O III filter. I plotted only the most prominent stars while sketching at the eyepiece — there were many more! WR 7 is the star in the center of the wind-blown bubble.



▲ **LARGE SCOPE SPLENDOR** This sketch shows what I saw on a wonderful March 2021 night with my old 28-inch f/4 scope. The sharpness of the outer perimeter of the western side of the wind-blown bubble was rather dramatic, as was the southern horn, Sh 2-298. Everything outside the helm is preexisting interstellar medium being energized by WR 7. As dramatic as all this was, my eye kept being pulled to what looked like a "big, circular nebulous area" to the upper left, but it's just an area outlined by more filaments faintly glowing in ionized oxygen.

HOWARD BANICH (2)

Larger Optics

My view through an 8-inch f/3.3 Dobsonian was rather special:

> *Pretty good! Thor's Helmet shows its main structure with the O III, and is faintly seen without the filter too with a beautiful Milky Way starry back drop. This will look even better when it's near the meridian, as its less than halfway there right now. 59×, 21.60 SQM [Sky-Quality Meter].*

I made this observation at 9,200 feet in the overflow parking lot just below the Maunakea Visitor Information Center on the island of Hawai'i. As usual, the transparency of the sky was fabulous, so I'll be hard-pressed to ever have a finer view of Thor's Helmet with an 8-inch scope. Not that I'll stop trying any time soon.

Large Scope

My first observation of Thor's Helmet was in 1994 using my old 20-inch f/5 Obsession:

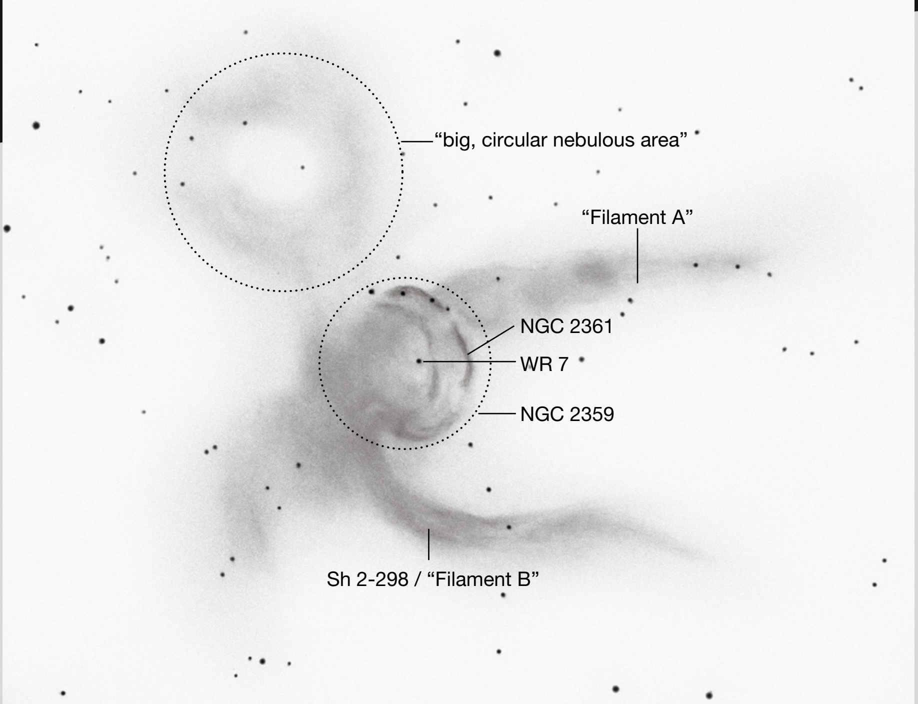
> *The final, and most visually pleasing sight of the evening was NGC 2359, the "Double Bubble Nebula." Very nice — it looks quite a lot like its photos and was helped by the Deep Sky, UHC, and O III filters with the O III giving the best view. One to come back to! 132×*

Beyond these notes, I remember seeing NGC 2359 and **IC 468** printed on my copy of the original version of the *Sky Atlas 2000* right next to each other, thinking this could be great — two objects in the same field of view! However, it turns out there was only one. I was amazed to see Thor's Helmet — the NGC object labeled — and only recently learned that IC 468 had incorrectly been conflated with NGC 2359. The coordinates that its discoverer, French astronomer Camille Bigourdan, gave it are for a triple star about a ¼° to the west.

However, the identification complications don't end there. In addition, a bright segment of the western edge of the wind-blown bubble is designated **NGC 2361**. Bigourdain as well as German astronomer Wilhelm Tempel noted seeing it in 1877. But as pointed out by Danish astronomer John Louis Emil Dreyer in his first *Index Catalogue*:

> *This is probably V.21, for which H [William Herschel] gave the R.A. 07^h 12^m 02^s.*

Dreyer further commented that NGC 2361 is one of the bright areas of NGC 2359.



▲ **HUNTING FOR DETAILS** Use this labeled version of the sketch made at the eyepiece of my 28-inch to follow along with the text. Also note that the entire nebulous complex is considered to be NGC 2359.

Through the Big Scope

This brings us back to my March 2021 observation with my 28-inch f/4 scope:

> *Well now, isn't this a lovely view! There's a big, circular nebulous area on the (north)eastern side I'd only suspected before, but the most amazing sight is how structured and long the horns are — spectacular! The rim of the outer bubble is thin, and rather bright in spots, but my favorite part is the southern horn — it looks slightly twisted as it progresses from its base outward. Quite a bit of detail here as well, an incredible feature. The entire nebula is incredible though. 155×, 253×, O III filter, 21.94 SQM.*

The "big, circular nebulous area" became more distinct the longer I sketched, but it also became more puzzling. I didn't remember a second bubble, and when I returned home, I found that it's a roughly oval area outlined by faint interstellar medium filaments. Cool!

Hydrogen-alpha

This past January, I was curious to see what Thor's Helmet looked like from my backyard with my 30-inch f/2.7 scope, a night-vision device, and a hydrogen-alpha filter. I was hoping for an explosion of additional detail. However:

> *This was my main object of the night — and it's a big fizzle. I've had brighter and more detailed views visually! . . . Phooey. . . 20.43 SQM.*

Oh well, more technology isn't always better.

■ Contributing Editor **HOWARD BANICH** penned the opening paragraph with an affectionate nod to Edward Bulwer-Lytton, coiner of the famous phrase, "It was a dark and stormy night." You can reach him at **hbanich@gmail.com**.

HOWARD BANICH

DENSE MATTER by Kai Hebeler, Achim Schwenk & Anna Watts

Journey into Neutron Stars

MARK GARLICK / SCIENCE PHOTO LIBRARY

Precise new measurements of collapsed stellar cores provide a window into the strange stuff they're made of.

Neutron stars represent the densest material in the universe this side of a black hole. They are the remnant cores left over when massive stars die in supernovae, and they rely on extraordinary forces to resist the crush of gravity. While ordinary matter is made of atoms — in which tiny nuclei are surrounded by mostly massless space — inside neutron stars, atoms are squeezed so closely together that their nuclei touch and combine to form an incredibly dense liquid. A droplet the size of a sugar cube would rival the mass in Mount Everest! These objects can thus pack one to two Suns' worth of mass into what is essentially a gigantic, spherical drop of neutrons about as wide as Manhattan is long.

This dense material forms in the core of a collapsing star because protons and electrons combine to create neutrons (as well as ghostlike neutrinos, which escape the star). This transformation is a dramatic change in the star's composition: From a relatively fluffy ball of hydrogen, helium, and heavier elements — in which nuclei made of protons and neutrons are surrounded by swarms of electrons — the star becomes about 95% neutrons and 5% protons and electrons, all crammed together in a city-size space.

At least, mostly neutrons are what we *expect* to find just below the crust. But deep in the interior, gravity squashes matter so profoundly that the central density can climb to at least five times that of an atomic nucleus. We don't understand the behavior of matter at such high densities. It's impossible for us to send a spacecraft to drill down into a neutron star and find out what lies within. Nor can we easily recreate the conditions in a laboratory: Although we can make miniature fireballs of dense matter by smashing nuclei together, they are short-lived, not as neutron-rich, and difficult to measure directly. Theory is tricky at these high densities, too, because the particles move around so quickly and interact so strongly with one another. But we can glean insights from afar. New developments are enabling more precise observations of neutron stars, giving us an indirect look beneath the surface and revealing the nature of the universe's densest matter.

From the Outside

One way to figure out what's inside neutron stars is to understand the relation between their masses and sizes. While the pressure of high-density matter stabilizes these stars against gravitational collapse, not all matter exerts the same pressure: Gravity squashes "softer" matter more easily, but "stiffer" matter will resist. That stiffness (or squishiness) determines how large a neutron star of a given mass will be.

▲ **NICER** The Neutron Star Interior Composition Explorer (NICER) watches pulsars from its berth on the International Space Station (ISS). One of the ISS solar panels is visible in the background.

NASA

If neutron stars are in fact mainly neutrons all the way down to their cores, that matter could be fairly stiff and unyielding to additional pressure. More massive neutron stars would thus have correspondingly larger radii.

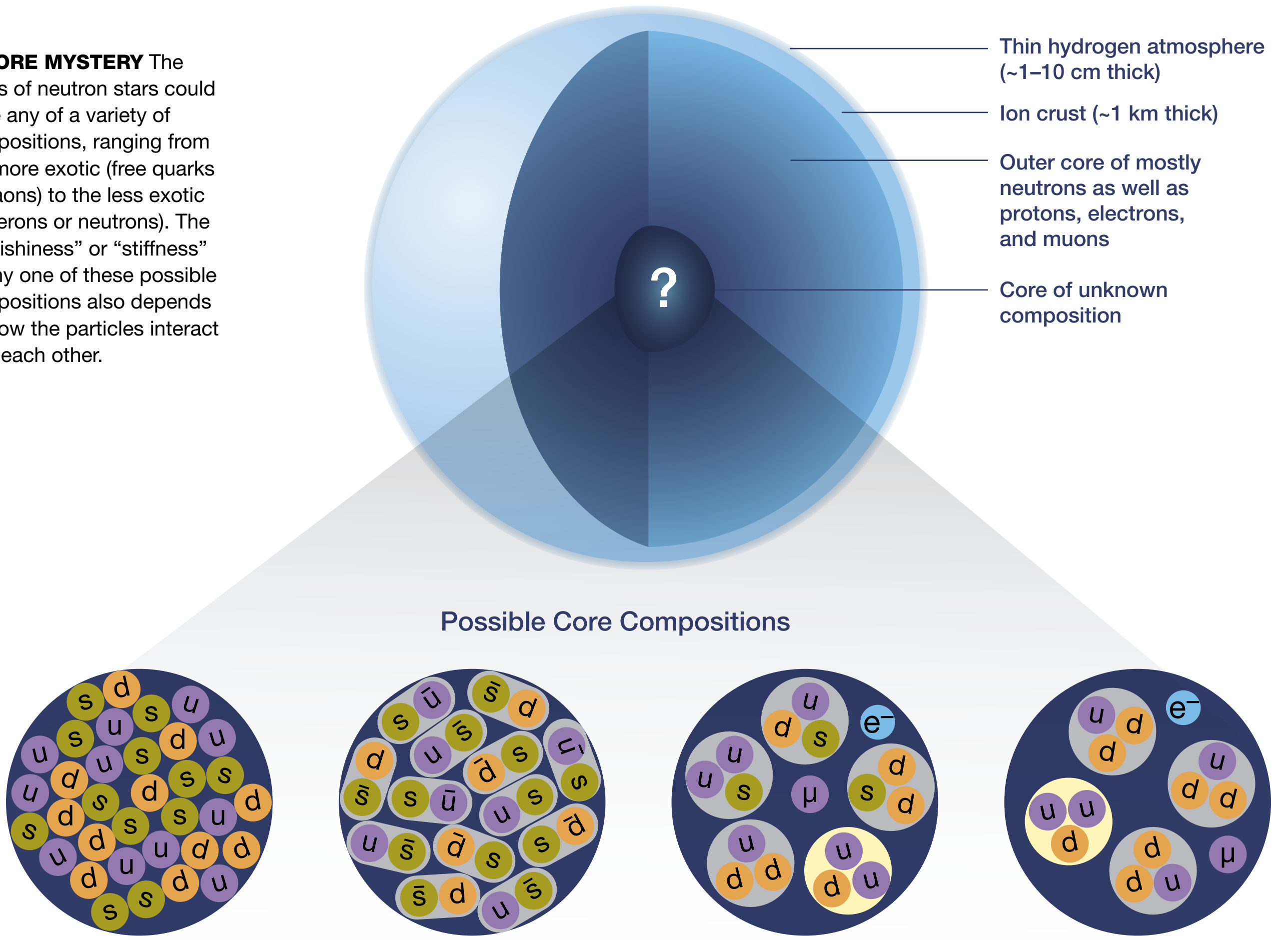
But it's also possible that these stellar cores contain exotic matter, including particles that are unstable and short-lived when created in the laboratory. At high densities, those exotic particles exert less outward pressure than neutrons, so they squeeze together more tightly. Cores with such particles would thus be smaller than those made of neutrons, and more massive neutron stars in this scenario wouldn't have radii as large. Therefore, if we can accurately measure the masses and radii for a collection of neutron stars, then we can pin down what kind of matter would crunch down to the sizes we observe.

Put in technical terms, what we really want to know is the *equation of state* that encodes the relationship between the matter's pressure and density. That equation can in turn give the relationship between mass and radius.

And the equation of state doesn't just tell us about what particles dense matter consists of — it also tells us how those particles interact with one another.

At the extreme densities inside neutron stars, we don't know this equation yet — we have to figure it out empirically. But measuring the masses and radii of such small, far-away neutron stars takes some work.

CORE MYSTERY The cores of neutron stars could have any of a variety of compositions, ranging from the more exotic (free quarks or kaons) to the less exotic (hyperons or neutrons). The “squishiness” or “stiffness” of any one of these possible compositions also depends on how the particles interact with each other.



Quarks
Neutrons might break down, setting *up* and *down* quarks free. *Strange* quarks also join the mix.

Kaons
Up, down, and strange quarks might pair with antiquarks to form exotic particles called *kaons*.

Hyperons
Strange quarks might be incorporated into neutron-like particles called *hyperons* which mingle with neutrons, protons (yellow background), electrons, and muons.

Neutrons
Or, the core might simply be neutrons, with a smattering of electrons, protons (yellow background), and muons.

BEATRIZ INGLESSIS / *S&T*

We already have a good understanding of neutron star masses from radio observations of binary systems containing a neutron star. These stars’ lighthouse-like beams produce regular pulses of radio waves, making them *pulsars*. Radio astronomers can track both the pulsar’s spin and its orbit around its companion, revealing gravitational effects that depend on the neutron star’s mass. Utilizing these effects, astronomers have found pulsars with masses in the range of 1.1 to 2.1 solar masses.

There are theoretical limits, too. Based on simulations of the core-collapse supernova explosions in which neutron stars form, for example, finding a neutron star with a mass lower than that of the Sun is thought to be unlikely.

A theoretical upper limit on neutron star mass, however, is more uncertain. If you were to keep adding mass to a neutron star, there would come a point at which the internal pressure could no longer support the star against gravitational collapse. But the mass at which collapse occurs depends on the internal composition: The stiffer the matter inside the star, the higher the maximum mass. The fact that we’ve detected neutron stars with masses up to the equivalent of 2.1 Suns already limits the pressure that can exist inside neutron stars, ruling out some models with exotic particles whose interactions are not repulsive enough to support such a large mass.

Measuring the radius is even more challenging, because neutron stars are tiny, and even the closest one is hundreds of light-years away. Resolving a neutron star in an image, even with our most powerful telescopes, is impossible.

Instead, to measure a neutron star’s size and heft, we turn to Einstein’s general theory of relativity, which comes into play in these stars’ extreme gravitational fields. Because a neutron star is so dense, the gravitational field at its surface is more than 100 billion times stronger than Earth’s. As a result, radiation from the stellar surface has to fight its way out to reach us, losing energy in the process. The wavelengths of escaping radiation thus lengthen to “redder” wavelengths; the amount of this *gravitational redshift* depends on how compact the star is.

The strong gravitational field also bends the light's path. So when we observe a neutron star, we see not just the hemisphere facing us but also part of its back side as well. Both redshift and light-bending effects are stronger in more compact stars, thus giving us a measure of mass and radius.

The pulsar's rapid spin also affects escaping radiation in curious ways, providing clues to the star's size. Rotating at rates up to several hundred times per second, the surface of a neutron star can move at an appreciable fraction of the speed of light. A larger star spinning at the same rate as a smaller one will have a faster surface velocity, so we would measure stronger relativistic effects on the star's radiation.

A neutron star's mass and radius thus leave their imprint on the photons that make their way to our telescopes. It's our job to tease it all apart.

The Pulse of a Star

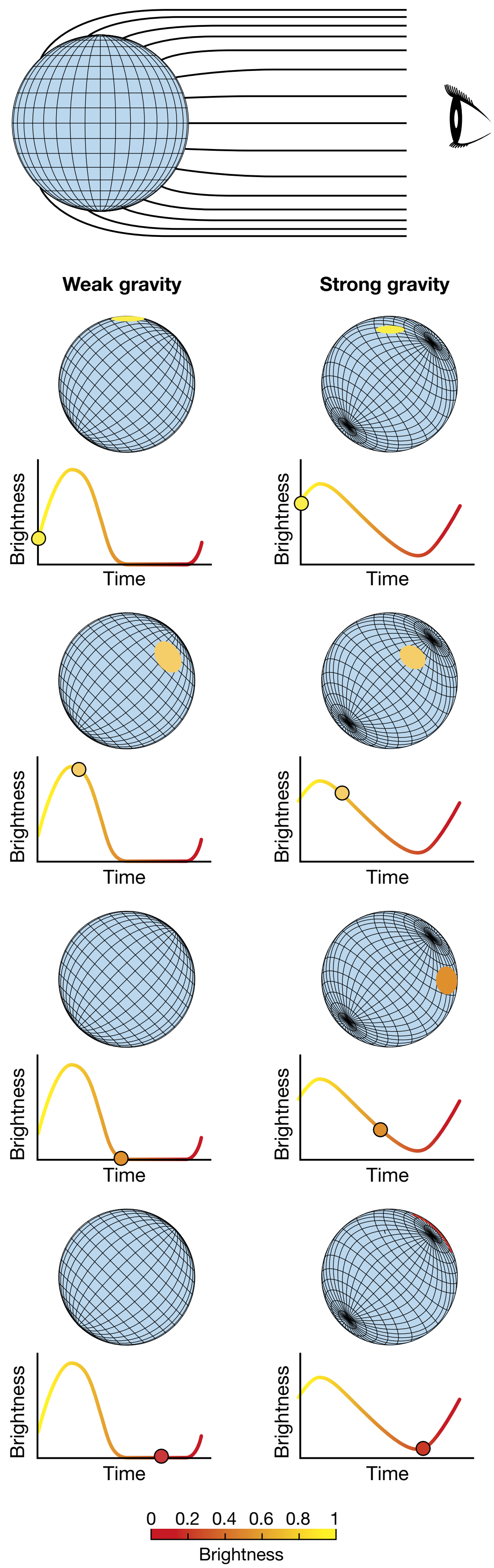
NASA's Neutron Star Interior Composition Explorer (NICER) is an X-ray telescope designed to take pulsars' precise pulse (*S&T:* Jul. 2017, p. 16). Since it was installed on the International Space Station in 2017, NICER has been collecting data on a special set of neutron stars. These older remnants have siphoned material from a companion, thereby spinning themselves up to millisecond rotation periods.

The X-rays that NICER observes come from the millisecond pulsar's magnetic poles, heated to 1 million kelvin by the bombardment of charged particles flowing within the star's magnetic field. These neutron stars appear to pulse because the hotspots whirl around with the spinning star, whipping in and out of view. NICER records the energy and arrival time of every incoming X-ray. The information from many pulses is then folded into a single *pulse profile*, which shows how the emission changes as the star turns.

To convert the observed pulse profile of a neutron star into a measurement of its mass and radius, we create a model to encapsulate what's happening to the photons on their way from the star to the telescope.

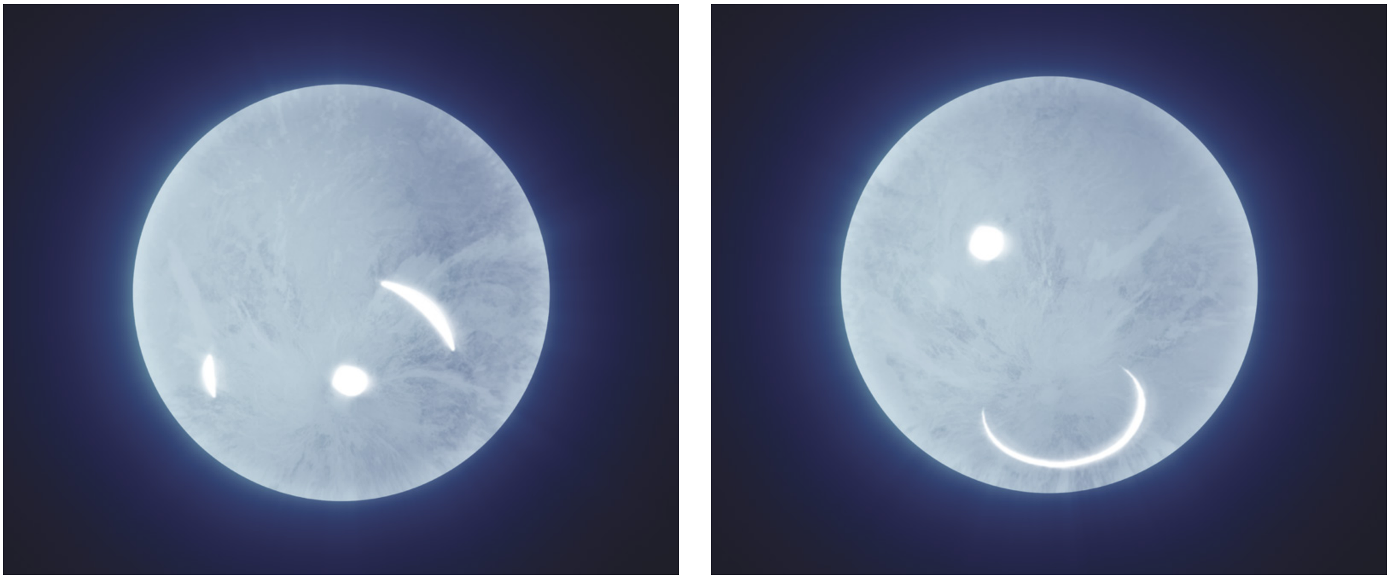
Near the star, the size, shape, location, and temperature of the magnetic poles influence the shape of the pulse profile. Pulsar magnetic fields — among the strongest in the universe — are complex, and while theorists have some general ideas about the poles' properties, concrete predictions are in short supply. So our models of the pulse profile have to include a range of possibilities for what these fields might look like.

There are other important ingredients that we need to factor into our models, too — from the influence of the star's



▶ **SEEING THE FARSIDE** The strong gravity of neutron stars bends light originating from the farside into our line of sight. Both mass and size play a role in determining the surface gravity: The more massive and/or the more compact a neutron star is, the more of its surface we can see. Stronger surface gravity distorts and redshifts the emission from hotspots, with the amount of redshift depending on whether the surface is turning toward or away from our view. The mass and radius thus affect the appearance of a neutron star's pulse profile (shown here as brightness vs. time).

LEAH TISCIONE / *S&T*; SOURCE: NASA'S GODDARD SPACE FLIGHT CENTER CONCEPTUAL IMAGE LAB



▲ **ONE-SIDED SPOTS** For the pulsar known as J0030+0451, NICER pulse profiles support two different configurations for the hotspots on its surface (shown here as if viewing the pulsar's south pole directly). Either way, the data suggest the hotspots are not symmetric and not on opposite sides of the pulsar from each other — instead, the hotspots, whether two or three, must all be in the pulsar's southern hemisphere.

NASA / GSFC / CI LAB (2)

wafer-thin atmosphere, most likely made of hydrogen atoms, to the way that NICER processes X-rays.

Then, we must also account for the fact that not all of the detector pings that NICER records are X-rays coming from the pulsar. Other sources in the field of view might also be emitting X-rays, or energetic particles known as *cosmic rays* might hit the detectors in a way that make them mimic X-rays.

We can turn to the European Space Agency's XMM-Newton X-ray observatory for help in disentangling pulsar photons from fiendishly complex backgrounds. XMM-Newton cannot capture the arrival time of each photon to the precision that NICER can, but its sharper images give us the ability to distinguish target pulsars from other nearby sources. Its sharper resolution also helps us distinguish source photons from the cosmic X-ray background. By comparing our models against NICER and XMM-Newton data simultaneously, we can understand and eliminate background contamination.

Taking all of these factors into account as we build our model of the pulse profile, we then send the model and the data to a supercomputer, which crunches through all of the possibilities to home in on the pulsar's most likely properties.

The results are rather amazing. Not only do we measure mass and radius, we also figure out where the magnetic poles are on the surface and what they look like. In doing so, we are essentially mapping city-size stars that lie hundreds to thousands of light-years from Earth.

And what maps they are! The traditional cartoon of a pulsar has a dipole magnetic field like that of a bar magnet, elegant and symmetric. In this scenario, the magnetic poles would be identical circular spots on opposite poles. The picture that is emerging from the analysis of NICER data, however, is much more complex. The two magnetic poles can be elongated arcs or rings rather than spots, and they can differ substantially from each other. They don't even need to be on exact opposite sides of the star.

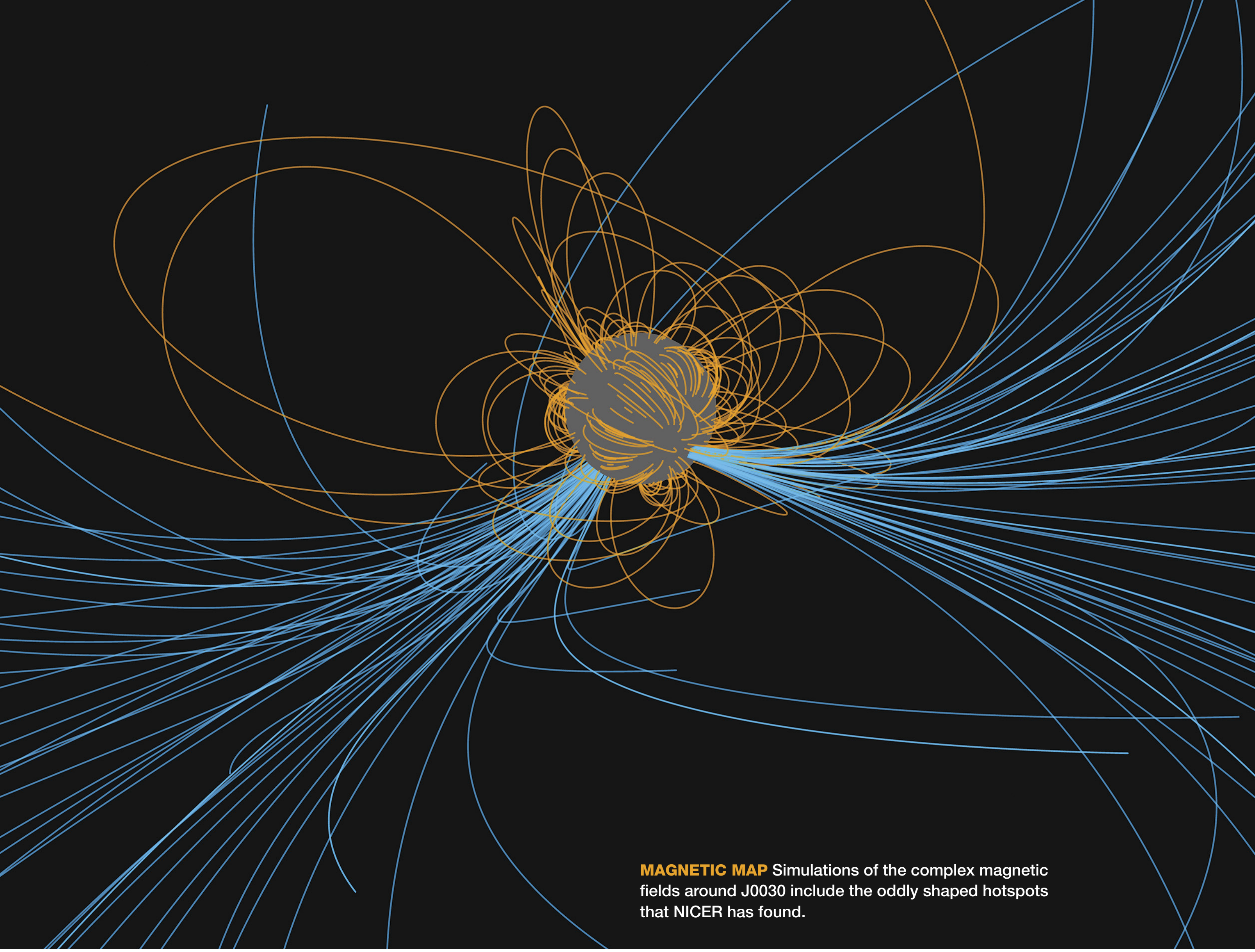
All of this points to complicated, tangled magnetic fields sticking out of the neutron star's surface. Is this complexity a legacy of the progenitor star and the supernova in which the neutron star was born? Or did the stream of gas that the neutron star siphoned from its companion star, spinning itself up in the process, somehow also deform the magnetic field? These questions remain to be answered.

The X-ray data have enabled us not only to make good surface maps but also to obtain the best simultaneous measurements yet of mass and size for four pulsars so far. A fifth one has proven trickier to analyze, but at least our measurements of its mass and radius are consistent with the other four. (Only seven pulsars are bright enough for NICER to investigate in such detail, and each one requires a great deal of observing time.)

Another important measurement has come from gravitational-wave astronomy, in which merging massive bodies warp the fabric of spacetime. The landmark detection of gravitational waves from a pair of merging neutron stars in 2017 (*S&T:* Jan. 2018, p. 10) enabled astronomers to measure both of those stars' masses and the degree to which each one deformed under the influence of the other's gravitational field as they spiraled together. Since that deformation depends on the matter's properties, we can translate it into a measurement of the radius.

Insight into Interiors

Previous work had put neutron stars' radii somewhere in the range of 10 to 15 kilometers. The NICER and gravitational-wave results — which together span a range of masses — suggest that neutron stars are in the middle part of this



MAGNETIC MAP Simulations of the complex magnetic fields around J0030 include the oddly shaped hotspots that NICER has found.

NASA / GSFC

range, with both extremely small and extremely large stars disfavored. That in turn means that the most extreme forms of matter, both stiff and soft, are largely ruled out. Many in-between options, though, are still in play.

Each pulsar mass and radius that NICER measures corresponds to a specific combination of density and pressure inside the neutron star. Therefore, a single star's mass and radius correspond to a single point on the curve defined by the equation of state. In principle, measuring enough pulsars at different masses and radii would outline the entire equation of state and thus the properties of matter at various densities. That would tell us not only which particles dense matter transforms into but also how those particles interact with one another and the surrounding neutrons.

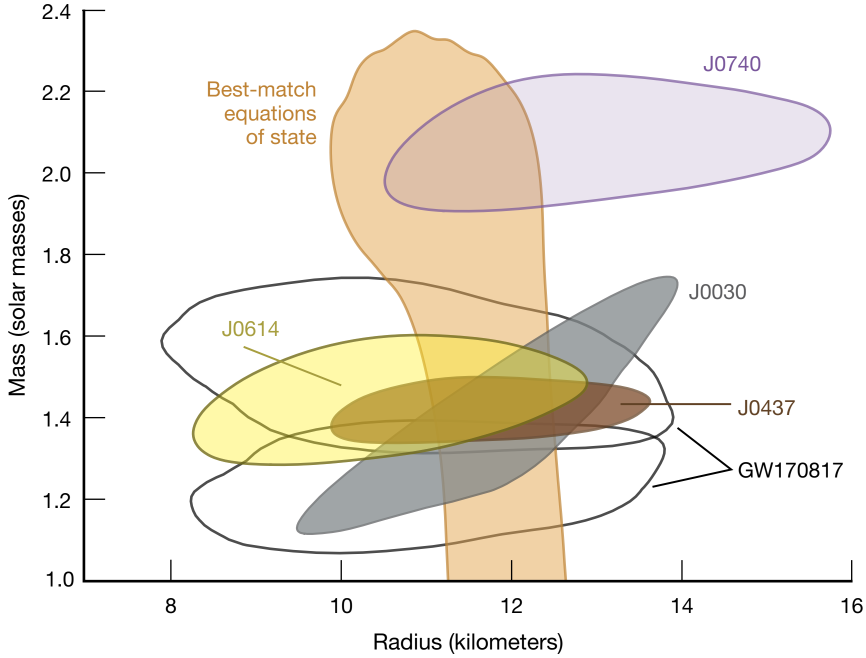
In practice, however, our mass and radius measurements will never be perfectly precise — they always come with a degree of uncertainty. Still, the more measurements we obtain, and the smaller the uncertainties are for each of the measurements, the more we will learn about the nature of dense matter.

Scientists have long suspected that, at the highest densities, matter as we know it might break down. Neutrons and protons are each made of elementary particles called *quarks*, which come in several flavors. Two flavors (called *up* and *down*) combine to make neutrons and protons. One theory is that, in neutron stars' cores, quarks are set free from their confinement in neutrons and protons. The quarks might even assemble to create new particles such as *hyperons*, which include a third kind of quark (called *strange*) that neutrons

Maximum Mass

Current NICER results suggest only a small chance that a neutron star's central density can rise to more than eight times that of an atomic nucleus — any higher, and the object should collapse to form a black hole. This finding means the boundary between neutron stars and black holes is almost certainly below 2.4 solar masses.

▶ **RESULTS** This plot of neutron star mass vs. radius shows four of the five NICER pulsars, labeled with the first four numbers of their designations. (Measuring the radius of a fifth NICER pulsar required different assumptions, so it's not included here.) The colored contours show the range of mass and radius estimates possible for each pulsar. Also shown are the estimates for the neutron stars that merged to create the gravitational-wave signal GW170817. The gold contours show the possible equations of state that best match the measurements so far. Stiffer options are preferred, with the squishiest varieties ruled out. But if squishy particles interact with one another in a way that makes them stiffer, then they're still in the running. (All contours show mass-radius estimates at a 95% confidence level, meaning there's only a 5% chance a given pulsar's mass and radius lie outside the contour.)



and protons don't have. Another suggestion is that quarks might pair up with antiquarks to form exotic particles such as *pions* and *kaons*.

The formation of hyperons, pions, or kaons would initially make matter in the neutron star core softer than it would be with only neutrons and protons. But for the five pulsars NICER has measured so far, the masses and radii suggest that — at least for matter with around two or three times the density of an atomic nucleus — the stars' cores are on the stiffer end. This means that if squishier particles such as hyperons, pions, or kaons are in fact present, interactions between individual particles must make them more resistant to compression than expected.

More exotic options — such as free-floating quarks — are still possible, albeit with some constraints. Even though experiments at heavy-ion colliders have not found evidence for quark matter at a few times nuclear density, the NICER and gravitational-wave results leave the possibility open. But the observations indicate that, if quark matter does exist at the highest densities, then — like with the other exotic particles — its interactions must make it resistant to compression. For example, recent theoretical calculations have pointed to ways quarks could pair up (without actually bonding into a new kind of particle), making them less compressible than a completely free quark liquid. More precise observations of neutron stars might tell us whether this solution is plausible.

And what if there are no strange states of matter, and neutron star cores are mostly just neutrons all the way down? Currently, we know very little about how neutrons interact when they are squeezed together to such extreme densities. Astrophysical observations might be the most promising tool to gain insights into the behaviors that occur in this uncharted territory.

What Next?

Even with only a few neutron stars measured so far, scientists have ruled out the most extreme scenarios. And if strange, exotic particles exist in neutron star cores, then they're interacting in ways other than what we expect.

More observations will help us better understand not only what dense matter is, but also how it behaves. We hope that NICER, which had small holes in its thermal shields patched during a spacewalk in January 2025, will continue to operate until the International Space Station reaches the end of its life around 2030. NICER's future measurements will make more exact measurements of neutron star radii, both for the stars that have been studied so far and for some new ones.

Additional constraints on the properties of matter at high densities will come from observations of gravitational waves as well as monitoring neutron stars as they cool, a process that's sensitive to their composition (*S&T:* Nov. 2024, p. 9). And the next generation of radio telescopes will make even more precise measurements of neutron star masses. Laboratory experiments with heavy-ion collisions and *hypernuclei* — atomic nuclei in which neutrons or protons are replaced by hyperons — will also help us assess whether exotic things like hyperons or quark matter could survive in neutron star cores.

But ultimately it is only by combining nuclear theory and experiment with astrophysical observations that we will finally understand what dense matter looks like, and how it truly behaves.

■ **KAI HEBELER** is Lecturer of Theoretical Physics and **ACHIM SCHWENK** is Professor of Theoretical Nuclear Physics, both at the Technical University of Darmstadt, Germany. **ANNA WATTS** is Professor of High Energy Astrophysics at the University of Amsterdam in the Netherlands.

The Pleiades

One of the most alluring jewels of the winter night sky is also one of my favorite celestial objects: the Pleiades, the brightest open cluster in the entire sky, located in Taurus, the Bull. Open clusters are loose collections of stars that share a similar origin — they're forged at the same time in the same stellar furnace. The members of open clusters can number anywhere from a few tens to a few hundred thousand — around 1,000 shimmering gems make up the Pleiades.

Most people can spot six individual stars (referred to as Pleiads) with their eyes alone, depending on sky conditions. A few might be able to make out seven. Extremely keen-eyed observers can spot many more — Contributing Editor Steve O'Meara reported seeing up to 17!

The cluster really starts to sparkle with the aid of binoculars. It's an exercise I love to share with novice stargazers — I ask them to first look at the cluster with their eyes alone, then I invite them to try again with binoculars. I never tire of the "oohs" and "aahs" that follow as they take in that sight.

Even more striking is the view of the Pleiades through a telescope. If your skies are dark enough, you might catch a glimpse of some of the nebulosity enshrouding the brighter cluster stars. The Pleiades were born about 120 million years ago and are currently passing through a dusty region of the galaxy. It's a truly inspiring sight!

The cluster is known by many names in different cultures. We often refer to them as the Seven Sisters, which reflects their roots in Greek mythology: They're named for Atlas, the Titan who was made to forever hold up the heavens, and his family. The brightest star in the cluster is Alcyone, followed by her sisters (in order of magnitude) Maia, Electra, Merope, and Taygete. Atlas is the second-brightest member, while the Sisters' mother, Pleione, is the elusive seventh brightest star.

The Pleiades is such a popular target that we've covered it in innumerable places in the magazine throughout the ages. In fact, turn to page 55 for an article on how to best enjoy cluster and other celestial targets nearby. To read more about the history of the cluster in various cultures around the world, see page 36 in the November 2024 issue.

I hope you'll enjoy exploring the Pleiades as much as I do!

—DIANA HANNIKAINEN

Photograph by
Sean Walker

QHYCCD miniCAM8

This highly versatile astronomical CMOS camera is made to suit a wide range of imaging interests.

QHYCCD miniCAM8

U.S. Price: $799.00 color camera with filters

qhyccd.com

*Prices subject to change

What We Like

Compact size with built-in filter wheel

Suitable for planetary and deep-sky imaging

Filter sets for photographic and scientific imaging

What We Don't Like

Custom-size filters currently available only from QHYCCD

NOSTALGIA ASIDE, there's not much I miss about the three-plus decades I spent doing emulsion-based astrophotography before going digital. One exception, however, is the cost of trying the latest stuff. When manufacturers introduced a new film, it only cost a couple of bucks to buy a roll and try it out. Today the stakes are way higher with new astronomical cameras costing hundreds to thousands of dollars. Astrophotographers typically must decide on their main imaging goals when making a purchase. This can be challenging for people interested in a variety of imaging activities, especially those just getting started in astrophotography. If you're in this category, the new QHYCCD miniCAM8 is worth a close look.

Built around Sony's 8-megapixel, back-illuminated, IMX585 CMOS detector, the miniCAM8 is available in monochrome and one-shot color versions. The thermoelectrically cooled detector has an 11.2 × 6.3-mm array of 2.9-micron pixels, making it well matched for deep-sky imaging with many of today's short-focus astrographs, and for planetary imaging with longer-focus instruments.

Weighing only 570 grams (20 ounces) with a 10.5-cm (4.1-inch) body diameter, the camera itself is lightweight and compact, especially considering that it has a built-in eight-slot filter wheel. There's no shutter, but with one filter slot fitted with an opaque mask it's easy to take dark frames. The filter wheel uses custom-size filters measuring 19 × 12 mm, and to the best of my knowledge are currently only available from QHYCCD.

Nevertheless, there are impressive filter sets sold separately or as attractively priced combo packages with the camera. For the color camera there is a combo set with three light-pollution filters and an ultraviolet/infrared cut filter. There are three combo sets for the monochrome camera. For deep-sky imaging there's a set of LRGB color filters plus 7-nm-bandpass filters for hydrogen-alpha (Hα), ionized oxygen (O III), and ionized sulfur (S II). A set for planetary imaging includes LRGB filters plus ones isolating methane, ultraviolet, and sodium wavelengths. And for photometry there's a set for the ugriz′ Sloan bands. (Details for the filter transmission characteristics are on the QHYCCD website.)

▲ Able to fit in the palm of your hand, QHYCCD's new miniCAM8 has a built-in 8-position filter wheel and a fan-assisted two-stage thermoelectric cooler. The silver cylinder contains desiccant for drying the air inside the 8-megapixel CMOS detector's chamber, which has heaters on the chamber window to keep it free of condensation.

Perhaps because of the filter's relatively small size, these combo sets *including* the camera are attractively priced at $799, $999, $999, and $1,099 for the color, deep-sky, planetary, and Sloan combos, respectively. There's also a custom-made off-axis guider ($159 not including guide camera) rounding out the miniCAM8 family.

Personally, I prefer monochrome cameras because of their versatility for narrowband and scientific imaging. But I'm increasingly impressed by the deep-sky images many astrophotographers create with one-shot color cameras these days. That and my own results shooting under light-polluted suburban skies while testing the ZWO SeeStar S50 (*S&T:* March 2024, p. 66) and Celestron Origin (*S&T:* January 2025, p. 66) prompted me to borrow the color version of the miniCAM8 from the manufacturer for this review.

Hindsight, however, is 20/20 and it turns out this wasn't the best choice for

ALL IMAGES ARE BY THE AUTHOR

me as a product reviewer. Unlike the SeeStar and Origin telescopes, which image with dedicated apps that are tuned to their color detectors, my limited skill processing astronomical one-shot-color images wasn't doing justice to the results I was getting with the miniCAM8. They were okay, but I knew they could be better. To remedy this, my colleague Sean Walker did the final processing of the astrophotos appearing with this review.

Starting Out

The first order of business with the miniCAM8 is to follow the instructions on the printed card shipped with the camera (you may need a magnifying glass to read the card's microscopic typeface). They simply say to go to QHYCCD's website and download the camera's PDF user's manual. It includes details for installing the camera's filters and QHYCCD's "All-In-One" software package (also downloaded from the website) on your computer.

It's nice that the camera comes with an appropriately sized cross-point screwdriver and silicone-tipped plastic tweezers to help install the filters in the filter wheel since neither are common items in a typical home toolkit. The job is straightforward but should be done in a clean, well-lit environment to prevent dust from getting on the filters and the CMOS chamber window — the window and filter backsides are nearly impossible to clean once the filter wheel is placed back in the camera.

▲ The Whirlpool Galaxy, M51, was captured with the miniCAM8 and the Astro-Tech AT150EDL (6-inch f/5.9) refractor reviewed in last November's issue, page 68. It was created from 70 minutes of total exposure through the camera's UV-IR cut filter.

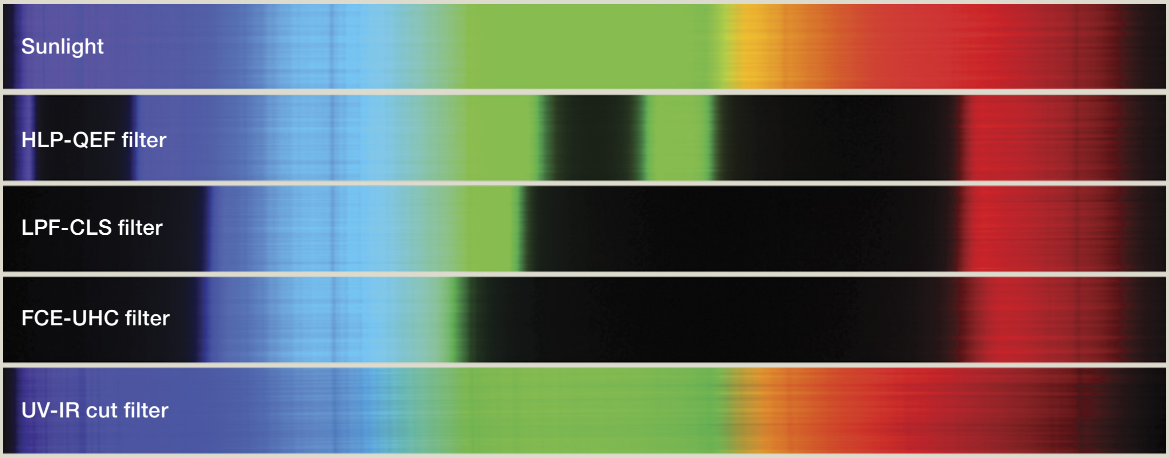
The filters have no markings on them and are only identified by a sticker on the outside of the pouch holding the filter package. The sticker shows each filter's location in the package. The LRGB and narrowband filters (with the exception of the deep-red Hα and S II filters) are pretty easy to identify by eye. But the three light-pollution filters in the set I had all looked similar.

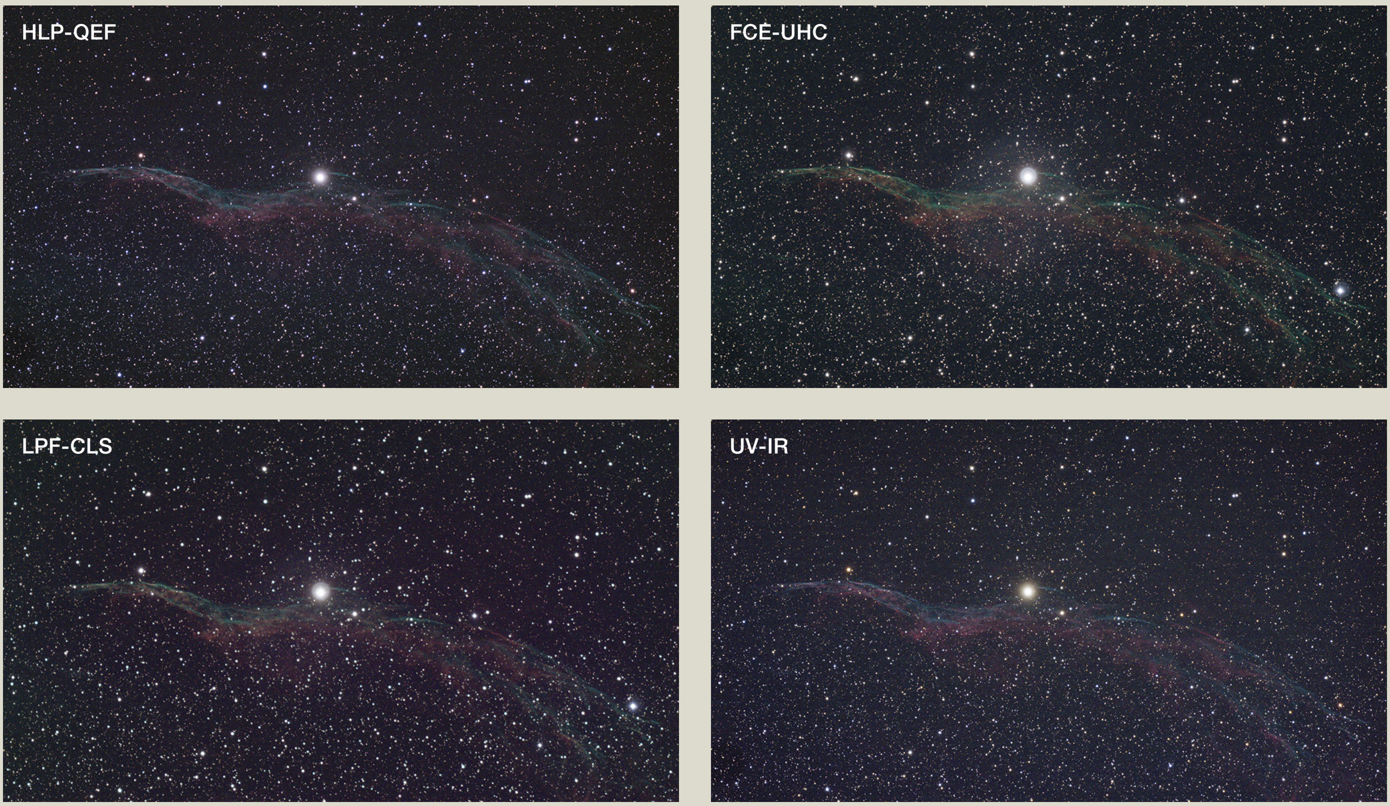
Furthermore, the filter labels on the pouch sticker didn't match those for the transmission curves on the QHYCCD website. Trial-and-error shooting at night might be one solution, but I decided to check the filters using my small home-built spectrograph. The photos on page 74 shows the result along with each filter's dual identification from the sticker and website.

◀ The camera ships with a screwdriver for the tiny screws on the filter wheel as well as special tweezers for handling the filters. It also comes with standard 1¼-inch and 2-inch telescope adapters.

▶ The only way to identify the light-pollution filters supplied with the color-camera combo is by the sticker on the pouch for the filter package (see the accompanying text for details).

▶ Because the filters supplied with the camera didn't have the same labels as the filter-transmission curves published on the QHYCCD website, the author used a small spectrograph to test each filter's passband. Each spectrum here is marked with its dual identity from the filter package and website transmission curve.





▲ Each of these 11-minute exposures of the western portion of the Veil Nebula was made with a Takahashi FSQ-106 astrograph and the indicated filter. Only minor color differences are seen in the results for this emission nebula using the different filters in the author's modestly light-polluted sky.

A small byproduct of this test is the noteworthy match between the website transmission curves and the filters' actual wavelength passbands.

Included Software

With the filters identified and installed it was time to head outside. There are two cable connections to the camera. One is the for the supplied 1.8-meter (6-foot) USB 3.0 computer cable and the other is the same length wire for the included 12-volt DC power adapter. Unlike some small, cooled CMOS cameras that only use DC power for the cooling system, the miniCAM8 requires it for camera operation as well.

The miniCAM8 "All-In-One" software includes various required drivers and two Windows-based programs for controlling the camera. There's also an ASCOM driver for those who want to operate the camera with their own ASCOM-compliant software packages. The basic control program supplied with the camera is *EZCAP_QT,* but to make a long story short, I don't recommend it. I couldn't get it to play well with the camera on my first night.

On the following night I switched to the other supplied program — *SharpCap,* created by Robin Clover in the United Kingdom. Many readers are likely familiar with this software since it's widely used with a range of popular cameras for planetary and deep-sky imaging. To make sure you're working with the latest version of *SharpCap* it's a good idea to download and install it from the developer's website (**sharpcap.co.uk**) rather than use the version in the "All-In-One" package. I already had *SharpCap* on my computer so I simply checked that I had the most up-to-date version.

SharpCap is a feature-filled camera-control program that may seem a bit overwhelming to first-time users, but it doesn't take long to figure out the basic camera controls, and the software has an extensive built-in, illustrated help menu that I found noteworthy for its clearly presented information. In addition to explaining how to access various functions, it explains why you might want to use them and how to apply them to your workflow. I wish all help files were this good.

The version of *SharpCap* that's supplied with the camera (and also freely available for download from the software's website) requires a pro license to unlock many of the program's advanced features. It takes only moments to purchase a license online and last May I paid $18 for a one-year license. My advice is to get the license before you even start using the miniCAM8 since it's well worth the cost.

Images begin appearing on *SharpCap*'s screen as soon as the camera is connected. You can adjust the exposure, camera gain, and computer display settings on the fly to use these images for framing your target and determining the settings you'll use for saved images.

There are multiple settings for recording video and still files. For most of the images appearing with this review I used a feature called ***Live Stack*** (found in the menu bar), with settings that automatically saved a series of 10 aligned and stacked 60-second exposures as a single FITS file (instructions for live-stacking with *SharpCap* are discribed in *S&T:* May 2023, p. 58). These stacks were later combined and

▲ The globular cluster M13 in Hercules was captured with a Takahashi FSQ-106 astrograph and an 11-minute exposure through the UV-IR cut filter.

processed with other astronomical image-processing programs just as if they were conventional single 10-minute exposures. *SharpCap* has the option of automatically calibrating the individual Live Stack images with dark and flat-field frames before they are saved as the stacked image.

Running the miniCAM8 at –20°C — a temperature easily maintained by the camera's two-stage thermoelectric cooler even on warm summer evenings — the raw images were so clean that I often dispensed with dark-frame calibration. The need for flat-field calibration depends, of course, on the imaging optical system. If I were intent on creating the finest deep-sky images I would always calibrate data with a complete set of darks, biases, and flat-field exposures.

The light-pollution filters in the combo set I tested are primarily for emission nebulae since they transmit wavelength bands around the Hα and O III emission lines. They are less effective at improving images of reflection nebulae, galaxies, and star clusters. As the images of the Veil Nebula on the facing page show, there wasn't a huge difference in the results shooting through the three filters under my moderately light-polluted suburban skies. In brighter skies, I expect the filters to be more effective, especially the FCE/UHC filter.

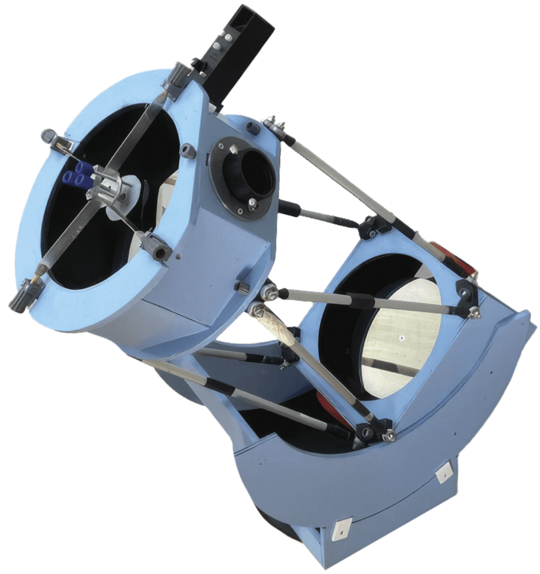
After a night or two learning the basics of deep-sky shooting with *SharpCap* I found the miniCAM8 a joy to use. And hardly a night passed when I didn't discover features of the software that further simplified and improved my imaging workflow. I wish that hardware and software like this were available when I first began doing digital imaging. But the good news is that it's here now, especially for those just getting into astronomical imaging.

■ **DENNIS DI CICCO** has been shooting the night sky since the time when Kodak Tri-X film was cutting-edge technology for astrophotographers.

▶ The rear of the camera housing contains the power port and USB 3.0 connection. Also visible is the fan mounted on the heatsink fins for the camera's thermoelectric cooler.

A Cool Cat in France

This project makes a Cat out of a Newt.



▲ Lucas Sifoni's corrected hyperbolic Newtonian, affectionately named Kermit II, is designed to give sharp, wide-field views with a built-in field corrector.

FRENCH TELESCOPE MAKER Lucas Sifoni began stargazing with a "hobby killer," a fork-mounted, 76-mm Newtonian with Ramsden eyepieces. He knew something was wrong when he got better, more spacious views by holding a stack of loose lenses up to the tube (side note: I, too, have a drawer full of assorted achromats). He wanted the view to be sharper and wider, and this desire drove a series of optical letdowns that eventually led him to build the coolest cat(adioptric) I've ever seen.

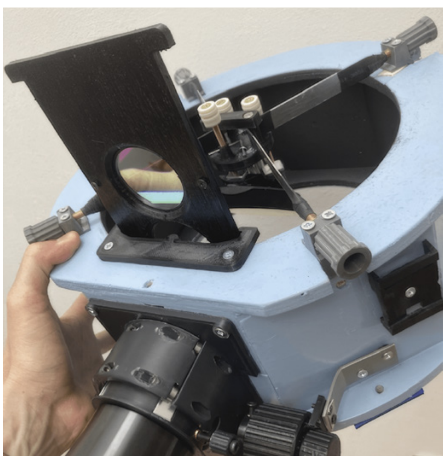
A general assumption in observing is that the bigger the scope, the better — but there are many reasons to hang onto a small, rich-field scope. They travel better, often are easy to set up, and can soak in wider, starrier views. That "starriness" gives rise to the idea of field richness — and small, fast telescopes maximize this notion. These were the driving forces behind Lucas's projects.

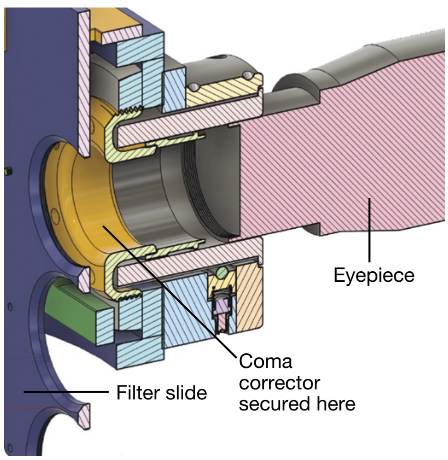
So, at age 26, he ground and polished his first mirror: an 8-inch f/3.5. This was an enormous feat for a first-time mirror maker, and the result was so good that it produced outstanding planetary views despite its fast focal ratio. And with a 58-centimeter (23-inch) tube, it crammed a lot of aperture into an extremely portable 4-kilogram (9-lb) package. A passenger in the backseat of Lucas's car might be slightly cramped with the scope stowed at the person's feet. By comparison, the ubiquitous 8-inch f/6 Dobsonian typically weighs about 25 kg, travels in two pieces, and fills the whole backseat — no room for passengers.

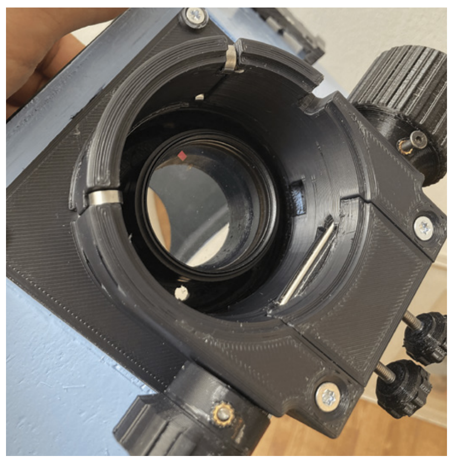
Stunning sights of the solar system aside, Lucas still didn't find the views he was after. As the focal ratio of a Newtonian mirror trends downward, coma creeps in. To the eye, this is a radial blurring of off-axis detail that increases as you move away from the center of the field. It's worse the lower your f/ratio gets, and eyepieces with wide field stops show the distorted edges even more. Fortunately, commercial coma-correcting optics are widely available.

The f/ratio or "speed" at which a coma corrector becomes mandatory is hotly debated. But it's agreed that a good one won't come cheap, and this writer can attest that coma ramps up severely under f/4. Even those who tolerate coma might feel nausea in the f/3 ballpark — radially elongated stars that evoke the look of "warp speed" in science-fiction movies.

As a budget-strapped, wide-field observer, Lucas found the coma overwhelming in his favorite eyepiece — an APM HDC-XWA 20mm 100°. So, he grabbed a Baader MPCC Mark III (Multi-Purpose Coma Corrector for Newtons) from a local retailer and 3D-printed individual spacer rings to attach it to his eyepieces, as each







▲ *Left*: The upper tube assembly of Kermit II showing Lucas's homemade 2-inch filter slide and dual-speed Crayford focuser. *Middle*: This cutaway view shows the guts of the focuser. Note the threaded adjuster that the coma corrector screws into and the homemade filter slide. *Right*: The focuser seen with its drawtube removed to show the embedded coma corrector mounted at a fixed distance. This arrangement makes each eyepiece come to focus at the proper spacing for the corrector to be most effective.

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requires a different spacing for optimal correction.

This cleaned up coma beautifully, though it came at the cost of sharpness across the entire field — stars never quite snapped into focus. So after one too many nights of fumbling with threaded adapter rings in the dark, he hit the online forums to see why things were amiss. There, he dug up a note from optician Ed Jones talking about the MPCC, including some computer analysis. The primary mirror's shape this Rowe-style corrector would best match wasn't a typical Newtonian parabola, but actually a *hyperbola*, a type of conic section.

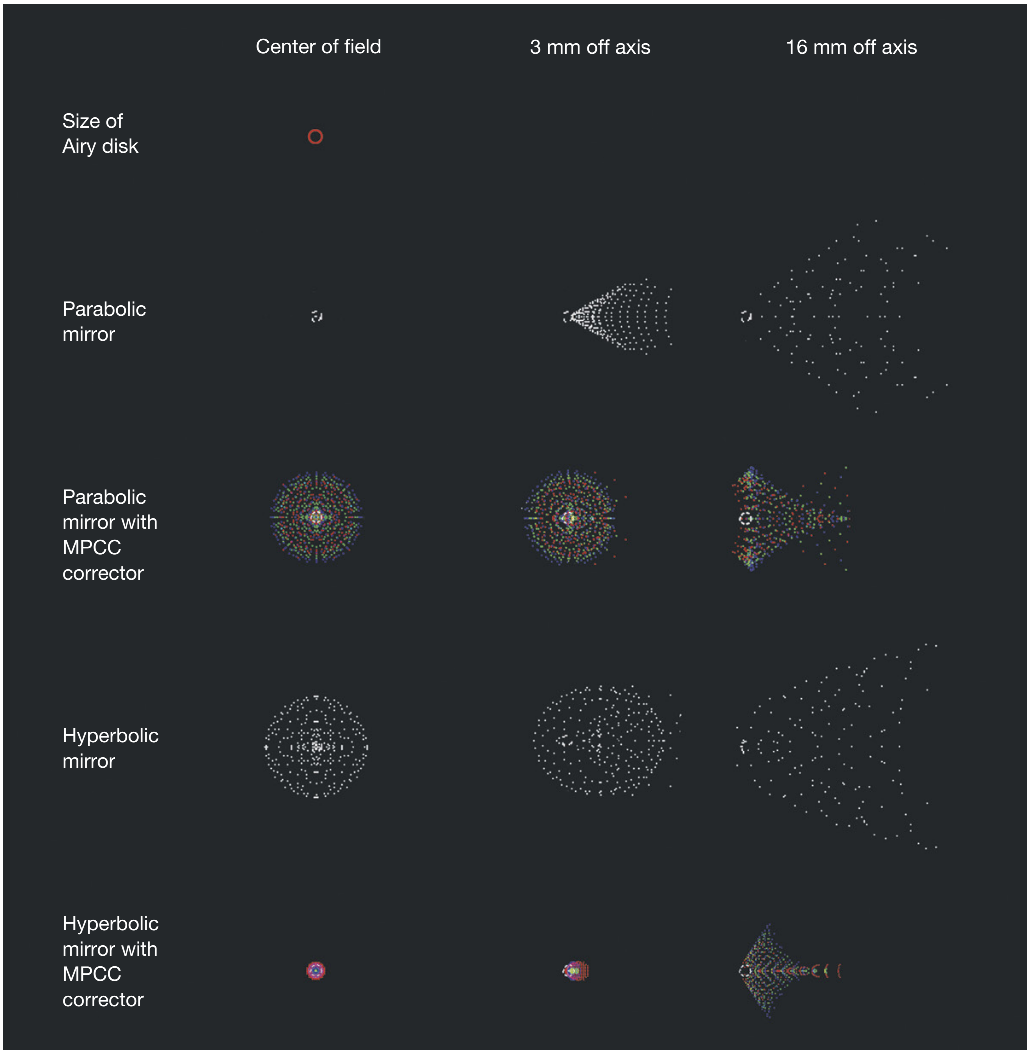
Lucas asked around about making a mirror to match his MPCC. "We buy correctors to correct mirrors, you're making a mirror to match a corrector? That's nuts!" scoffed one experienced mirror maker. But Lucas used *CORRECT 3* (**https://is.gd/Correct3**), an optical ray-tracing software, to test his idea. The spot diagrams it generated were promising: sharp stars with soft fringes. Armed with a Bath interferometer, grinding out the mirror's unusual conical shape seemed quite doable.

He then posted an ad online seeking a "truly awful 8-inch mirror" to refigure and quickly found one in the form of an astigmatic, massively overcorrected f/4. Removing enough glass to push it to f/3.6, he was able to produce a conic shape rarely seen in amateur circles. After one coating, a pile of laser-cut wood, and some 3D-printed structures later, he was ready to test.

The resulting scope is beautiful and modern. By the second revision, Lucas added a homemade filter slide, dual-speed focuser, and more. He soon abandoned using tedious spacer rings to mount the MPCC. At my urging, he designed and 3D-printed a threaded interface for the corrector inspired by a similar system offered by Starlight Instruments. This essentially turned the Newtonian into a catadioptric system with a fixed corrector lens.

The idea may not be nuts, but the views certainly were. While there was some false color at high magnifications, low powers hid it well and the stars were tight. His HDC-XWA 20mm produced a wide, 2.8° field. This fits expansive targets like the Pleiades, the Andromeda Galaxy (M31), or the entire Veil Nebula. From dark, rural skies, he's enjoyed views of the North America Nebula (NGC 7000).

"Fast scopes are quite uncommon in France," Lucas shares, though the stunning views through his scope have driven other ATMs to get onboard. "The following summer, I had the pleasure of looking through a 10-inch f/3 Newt that Fred Burgeot, a French astronomy sketcher, had built after looking through my fast scope."



▲ These spot diagrams produced with *CORRECT 3* show the star shapes in two telescope systems with and without the MPCC corrector. They simulate star images at the center of the field as well as 3 and 16 millimeters from the center which correspond to the edge of the fields in the author's 8-mm Plössl and APM 20-mm eyepieces. Optical aberrations smaller than the size of the Airy disk appear as a pinpoint star.

Readers can find the open-source files for Lucas's creations by name-searching him on **printables.com** or **thingiverse.com**.

■ Contributing Editor **JONATHAN KISSNER** has yet to play with *CORRECT 3* but is already aboard the fast-scope train with his coma-corrected 6-inch f/3 Newtonian.

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ATACAMA NIGHTS
Fernando Menezes
The photographer gazes at the Milky Way as seen from the Atacama Desert in northern Chile on April 18, 2023. The nuclear bulge at the core of our galaxy in Sagittarius hangs right of center, while the colorful Rho Ophiuchi complex with Antares glimmers high overhead (top).
DETAILS: *Canon EOS 6D camera and 24-mm lens. Total exposure: About 1 minute at f/3.5, ISO 3200.*

◁ **DOUBLE ENTRY**

Bob Fera and Steve Mandel

The barred spiral galaxy NGC 1291 (also designated NGC 1269) in Eridanus displays tightly wound spiral arms forming a ring surrounding its unusual inner bar. Several additional galaxies are visible through the arms.

DETAILS: *PlaneWave CDK17 Corrected Dall-Kirkham telescope with Moravian C3-61000 Pro camera. Total exposure: 19 hours through LRGB filters.*

▽ **STARS ABOVE STARPOINT**

Greg Meyer

The stars appear to arc around both the north and south celestial poles as seen above the photographer's Starpoint Australis portable observatory set up north of Ash Fork, Arizona.

DETAILS: *Insta360 X4 Action Camera. Total exposure: 4¼ hours at f/1.9 on June 1, 2025.*

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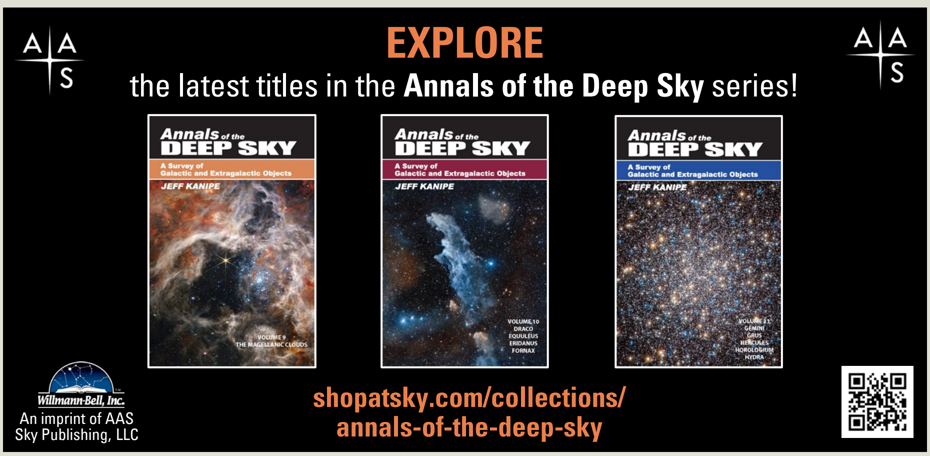

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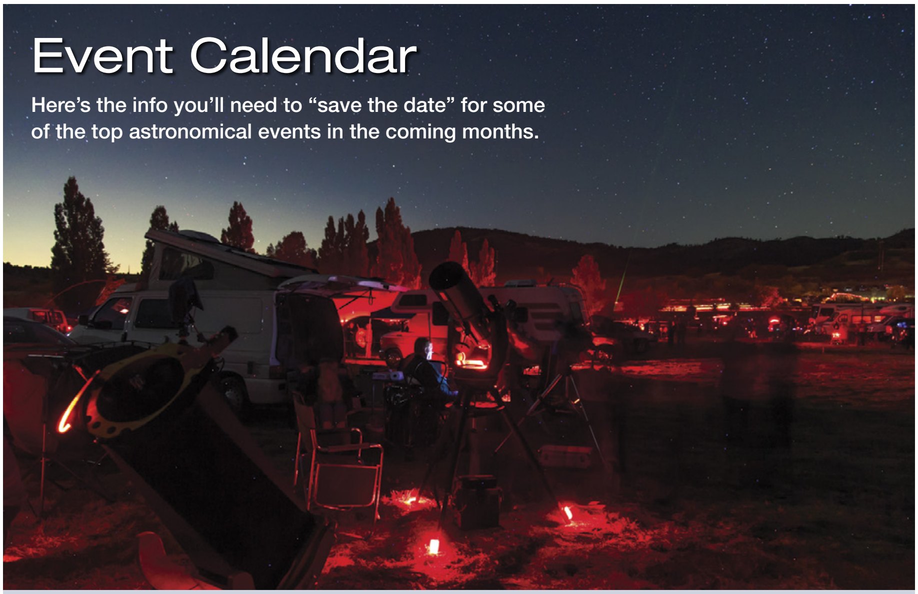
Event Calendar

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



KEVIN BAIRD / FLICKR / CC BY-NC-ND 2.0

February 16–22
WINTER STAR PARTY
Scout Key, FL
scas.org/winter-star-party

April 11–12
NORTHEAST ASTRONOMY FORUM
Suffern, NY
neafexpo.com

April 12–19
TEXAS STAR PARTY
Fort Davis, TX
texasstarparty.org

April 22–25
MIDSOUTH STARGAZE
French Camp, MS
rainwaterobservatory.org/events

April 25
ASTRONOMY DAY
Everywhere!
astronomyday.astroleague.org

June 6–13
GRAND CANYON STAR PARTY
Grand Canyon, AZ
https://is.gd/GrandCanyonStarParty

June 10–14
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

June 11–14
CHERRY SPRINGS STAR PARTY
Cherry Springs State Park, PA
cherrysprings.org

July 12–17
NEBRASKA STAR PARTY
Valentine, NE
nebraskastarparty.org

July 14–18
WASHINGTON STATE STAR PARTY
Jameson Lake, WA
tmspa.com

July 14–21
OREGON STAR PARTY
Indian Trail Spring, OR
oregonstarparty.org

August 10–16
ALMOST HEAVEN STAR PARTY
Spruce Knob, WV
ahsp.org

August 13–16
STELLAFANE CONVENTION
Springfield, VT
stellafane.org

September 19
ASTRONOMY DAY
Everywhere!
astronomyday.astroleague.org

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

Raw Emotion High in the Andes

An inspirational trip to Chilean observatories breathed new life into one science communicator's motivation.

***AFTER MORE THAN** a decade of making science more accessible, exciting, and engaging, this past year left me wondering if I had anything left to give. Science communication started to feel like shouting into the void of space. Then a surprising source of inspiration reminded why we have to keep going:*

The cold was seeping into my bones when the stars started winking through the setting Sun's bright pink ombré. We were 5,000 meters (16,400 feet) above sea level on the Chajnantor Plateau in the Chilean Andes, surrounded by snow, radio antennas, and an otherworldly silence broken only by the soft crunch of footsteps and the puffing of crystalline breath. In the light of a waxing Moon, the Milky Way rose above the Atacama Large Millimeter/submillimeter Array (ALMA), unapologetic and bright. The world unfolded around us in ways I otherwise never imagined. And that was just 45 minutes into the 10 most inspiring days of my career.

That career has taken me to some amazing places — but for the first time, I wasn't at a major observatory for work. I was at ALMA as part of the Astronomy in Chile Educator Ambassador Program (ACEAP), a National Science Foundation–supported program that brings together educators, amateur astronomers, and communicators for training at world-class observatories in Chile. It's not a field trip, it's a transformation: a chance to experience large-scale science and engineering firsthand, and learn how to share that wonder and knowledge back home.

But to do that, we had to open ourselves up to new ways of knowing the universe. Under a blanket of stars in Vicuña, we stood humbled by the night-sky experience at the family-built Alfa Aldea observatory, within sight of the Vera C. Rubin Observatory. Nights later, a group of Likanantay people welcomed us to their fire and into their *cosmovision* — an ancient worldview that connects people to the universe. The night sky was so dark, it rearranged us and united us despite our different stories and lived experiences, a connection I felt to be powerful and universal.

I saw that force light up in a teacher from Spain, who saw the Moon "upside down" for the first time. Even with all his knowledge, that simple experience sparked his wide-eyed awe — proof that the universe can still surprise. I saw it again at Cerro Tololo Inter-American Observatory's Víctor M. Blanco Telescope, where a teacher from Queens learned that Blanco was Puerto Rican, just like him. His pride lit up the room — and the night. Suddenly, the science became personal. It became human. Seeing these reactions — bursting with raw emotion — gave me something that's been difficult to hold onto lately: hope.

Programs like ACEAP multiply those moments on a global scale, and transform people who already believe into louder, braver, more visionary astronomy ambassadors. But programs like ACEAP depend on continued public investment, such as funding the NSF, to help them tap into that powerful force, those people who *choose* to voluntarily develop themselves to inspire others. When that support is at risk, so too is our ability to nurture wonder, curiosity, and belonging in science. If we want to keep opening the universe to everyone, we have to keep making space for programs like this one . . . the ones that remind us that the sky is for everyone.

▲ *Top:* Optical engineer Bill Green of Copenhagen, Denmark, light-paints a heart at the Víctor M. Blanco Telescope at Cerro-Tololo Inter-American Observatory. *Above:* The last vestiges of sunset are no match for the Milky Way rising in unpolluted dark skies over CTIO.

■ **AMY C. OLIVER**, Fellow of the Royal Astronomical Society, is an informal science educator and communicator who is breaking barriers in STEM for underserved audiences.

LIGHT HEART: AMY C. OLIVER; CTIO: FEFO BOUVIER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Skygazer's Almanac 30°S 2026

FOR LATITUDES NEAR 30° SOUTH

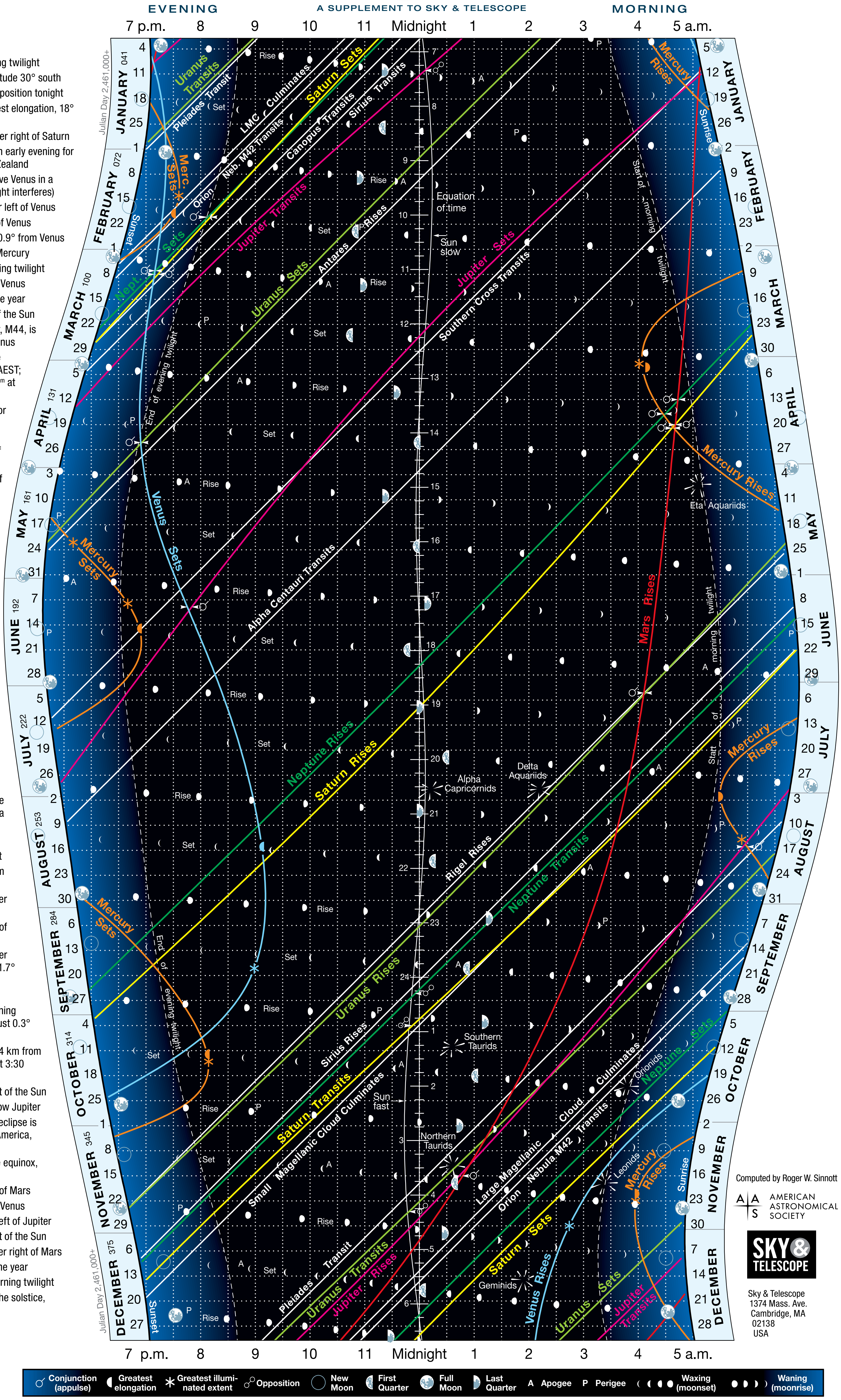
A SUPPLEMENT TO SKY & TELESCOPE

EVENING SKY

- Jan 4 Latest end of evening twilight
- Jan 9 Latest sunset at latitude 30° south
- Jan 10 Jupiter comes to opposition tonight
- Feb 19 Mercury is at greatest elongation, 18° east of the Sun
- Feb 20 Neptune is 0.8° lower right of Saturn
- Mar 3 Total lunar eclipse in early evening for Australia and New Zealand
- Mar 7 Neptune is 0.1° above Venus in a telescope (but twilight interferes)
- Mar 8 Saturn is 0.9° upper left of Venus
- Apr 24 Uranus is 0.9° left of Venus
- May 21 The cluster M35 is 0.9° from Venus
- Jun 3 M35 is 1.5° left of Mercury
- Jun 8 Earliest end of evening twilight
- Jun 9 Jupiter is 1.6° from Venus
- Jun 10 Earliest sunset of the year
- Jun 15 Mercury 25° east of the Sun
- Jun 20 The Beehive Cluster, M44, is 0.8° lower left of Venus
- Jun 21 Winter begins at the solstice, 6:25 p.m. AEST; shortest day, 10ʰ 13ᵐ at latitude 30° south
- Aug 12 Total solar eclipse for parts of Greenland, Iceland, and Spain
- Aug 15 Venus is 46° east of the Sun
- Sep 2 Spica is 1.5° right of Venus
- Sep 25 Neptune comes to opposition
- Sep 26 Spica is 0.9° left of Mercury
- Oct 4 Saturn is at opposition
- Oct 12 Mercury is 25° east of the Sun
- Nov 25 Uranus reaches opposition
- Dec 22 The longest day, 14ʰ 05ᵐ at latitude 30° south

MORNING SKY

- Jan 4 Earth is 147,099,894 km from the Sun (perihelion) at 3:16 a.m. AEST
- Feb 17 Annular solar eclipse for part of Antarctica
- Mar 21 Autumn begins at 12:46 a.m. AEST
- Apr 4 Mercury is 28° west
- Apr 13 Neptune is 0.5° from Mars in a telescope
- Apr 17 Neptune is 1.4° lower left of Mercury
- Apr 20 Saturn is 1.2° right of Mars
- Apr 21 Mercury is 0.7° lower right of Saturn and 1.7° right of Mars
- Jul 2 Latest sunrise
- Jul 4 Latest onset of morning twilight; Uranus is just 0.3° below Mars
- Jul 7 Earth is 152,087,774 km from the Sun (aphelion) at 3:30 a.m. AEST
- Aug 2 Mercury is 20° west of the Sun
- Aug 16 Mercury is 0.9° below Jupiter
- Aug 28 A nearly total lunar eclipse is visible from South America, darkest at 4:13 UT
- Sep 23 Spring begins at the equinox, 10:05 a.m. AEST
- Oct 12 Beehive is 0.3° left of Mars
- Nov 10 Spica is 1.2° below Venus
- Nov 16 Mars is 1.2° lower left of Jupiter
- Nov 21 Mercury is 20° west of the Sun
- Nov 27 Regulus is 1.7° upper right of Mars
- Dec 4 Earliest sunrise of the year
- Dec 9 Earliest onset of morning twilight
- Dec 22 Summer begins at the solstice, 6:50 a.m. AEST



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Skygazer's Almanac 30°S 2026

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 2026*, 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 11, 2026.

First find "January" and "11" 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 11–12 crosses many slanting *event lines*. Each event line tells when something happens.

The dotted line for January 11–12 begins at the black curve at left, which represents the time of sunset. Reading up to the top of the chart, we can estimate that sunset on January 11th 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 11th, we see that the dim outer planet Uranus transits the meridian at 8:18 p.m., its high point in the sky. The Pleiades star cluster transits seven minutes later. But these events occur in late twilight, which technically doesn't end until 8:40 (note the dashed line), when the Sun is 18° below the horizon.

At about 10:00 p.m. the Large Magellanic Cloud culminates (another way of saying it transits). The Orion Nebula, Messier 42, transits at 10:12. Then Saturn sets at 10:38, a sign it was better viewed earlier in the evening.

The two brightest nighttime stars, Canopus in Carina and Sirius in Canis Major, transit at 11:00 and 11:22, respectively. Transit times of such celestial landmarks help us follow the nightly march of constellations.

At 11:51 p.m., notice the tiny Moon symbol on the dotted line. The legend at the bottom of the chart tells us it is at its waning crescent phase, 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 11–12 this is $7^h\ 25^m$. 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.)

The brilliant planet Jupiter transits the meridian very nearly at midnight, so it is currently visible all night long.

Also 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 11th the Sun runs slow, transiting at 12:08 p.m. This deviation, useful in reading a sundial, is due to the tilt of the Earth's axis and the ellipticity of its orbit.

As the wee hours continue, Uranus sets at 1:33 a.m. Then Antares, a star we usually associate with later seasons of the year, climbs above the southeastern horizon at 1:56.

The first hint of dawn — the start of morning twilight — comes at 3:37. Elusive Mercury rises at 4:40. The Sun finally peeks above the southeastern horizon at 5:11 on Monday morning, January 12th.

Other Charted Information

Many of the year's most important astronomical events are listed in the chart's left-hand margin. Additional

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

events 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, Jupiter reaches opposition on the night of January 10–11 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 with surface features whether rising or setting; the circle for new Moon is open. *P* and *A* mark dates when the Moon is at perigee and apogee (nearest and farthest from Earth, respectively).

Mercury and *Venus* never stray far from the twilight bands. Their dates of greatest elongation from the Sun are shown by ◗ symbols on their rising or setting curves. Asterisks mark when their telescopic disks have the greatest illuminated extent in square arcseconds. For example, this occurs for Venus on the evening of September 18th this year.

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

Julian dates can be found from the numbers just after the month names on the chart's left. The Julian Day, a seven-digit number, is a count of days beginning with January 1, 4713 BC. Its first four digits this year are 2461, as indicated just off the chart's upper left margin. To find the last three digits for days in January, add 041 to the date. For instance, on January 11th we have 11 + 041 = 052, so the Julian Day is 2,461,052.

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 far left has the corrections, in minutes, for some of the world's major cities.

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

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

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

For reprints (item SGA26S) or to order a similar chart for latitude 40° north or 50° north, go to: shopatsky.com/collections/maps-globes/almanacs

Skygazer's Almanac 2026 is a supplement to *Sky & Telescope* Magazine, 1374 Massachusetts Avenue, Cambridge, MA 02138, USA, skyandtelescope.org.

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Skygazer's Almanac 40°N 2026

FOR LATITUDES NEAR 40° NORTH

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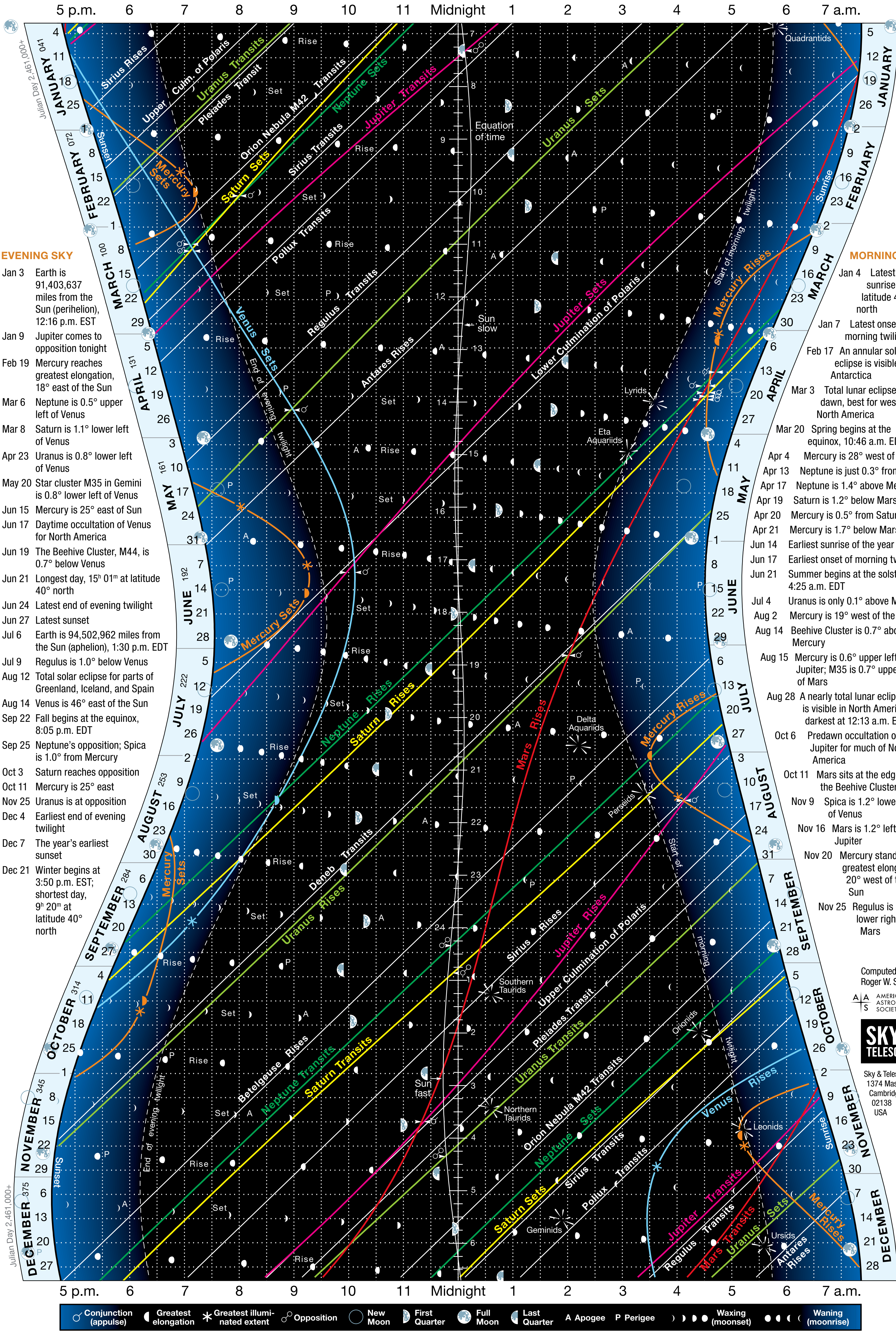

EVENING SKY

- Jan 3 Earth is 91,403,637 miles from the Sun (perihelion), 12:16 p.m. EST
- Jan 9 Jupiter comes to opposition tonight
- Feb 19 Mercury reaches greatest elongation, 18° east of the Sun
- Mar 6 Neptune is 0.5° upper left of Venus
- Mar 8 Saturn is 1.1° lower left of Venus
- Apr 23 Uranus is 0.8° lower left of Venus
- May 20 Star cluster M35 in Gemini is 0.8° lower left of Venus
- Jun 15 Mercury is 25° east of Sun
- Jun 17 Daytime occultation of Venus for North America
- Jun 19 The Beehive Cluster, M44, is 0.7° below Venus
- Jun 21 Longest day, 15h 01m at latitude 40° north
- Jun 24 Latest end of evening twilight
- Jun 27 Latest sunset
- Jul 6 Earth is 94,502,962 miles from the Sun (aphelion), 1:30 p.m. EDT
- Jul 9 Regulus is 1.0° below Venus
- Aug 12 Total solar eclipse for parts of Greenland, Iceland, and Spain
- Aug 14 Venus is 46° east of the Sun
- Sep 22 Fall begins at the equinox, 8:05 p.m. EDT
- Sep 25 Neptune's opposition; Spica is 1.0° from Mercury
- Oct 3 Saturn reaches opposition
- Oct 11 Mercury is 25° east
- Nov 25 Uranus is at opposition
- Dec 4 Earliest end of evening twilight
- Dec 7 The year's earliest sunset
- Dec 21 Winter begins at 3:50 p.m. EST; shortest day, 9h 20m at latitude 40° north

MORNING SKY

- Jan 4 Latest sunrise at latitude 40° north
- Jan 7 Latest onset of morning twilight
- Feb 17 An annular solar eclipse is visible from Antarctica
- Mar 3 Total lunar eclipse at dawn, best for western North America
- Mar 20 Spring begins at the equinox, 10:46 a.m. EDT
- Apr 4 Mercury is 28° west of Sun
- Apr 13 Neptune is just 0.3° from Mars
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- Apr 19 Saturn is 1.2° below Mars
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- Apr 21 Mercury is 1.7° below Mars
- Jun 14 Earliest sunrise of the year
- Jun 17 Earliest onset of morning twilight
- Jun 21 Summer begins at the solstice, 4:25 a.m. EDT
- Jul 4 Uranus is only 0.1° above Mars
- Aug 2 Mercury is 19° west of the Sun
- Aug 14 Beehive Cluster is 0.7° above Mercury
- Aug 15 Mercury is 0.6° upper left of Jupiter; M35 is 0.7° upper left of Mars
- Aug 28 A nearly total lunar eclipse is visible in North America, darkest at 12:13 a.m. EDT
- Oct 6 Predawn occultation of Jupiter for much of North America
- Oct 11 Mars sits at the edge of the Beehive Cluster
- Nov 9 Spica is 1.2° lower left of Venus
- Nov 16 Mars is 1.2° left of Jupiter
- Nov 20 Mercury stands at greatest elongation, 20° west of the Sun
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Computed by Roger W. Sinnott

American Astronomical Society

Sky & Telescope
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Cambridge, MA 02138
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Skygazer's Almanac 40°N 2026

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A sweep of the eye shows that the line for the night of January 11–12 crosses many slanting *event lines*. Each event line tells when something happens.

The dotted line for January 11–12 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 11th occurs at 4:55 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 11th rightward, we see that at 6:16 p.m. Sirius, the brightest nighttime star, rises. Then the dashed line at 6:31 p.m. tells when evening twilight technically ends. This is when the Sun is 18° below the horizon and the sky becomes fully dark.

At 7:40 Polaris, the North Star, reaches upper culmination. It then stands directly above the north celestial pole (by 38′ or r37′ this year), a good time to check the polar alignment of an equatorial telescope mount.

At 8:15 the dim planet Uranus transits the meridian, meaning it is due south and highest in the sky — well placed for spotting with binoculars. The famous Pleiades star cluster transits at 8:22, followed by the Orion Nebula (Messier 42) at 10:10, so we know they'll be fine targets to enjoy in a telescope all evening. But that's not true of the ringed planet Saturn, which sets at 10:17.

Having risen earlier this evening, Sirius reaches the meridian at 11:19 p.m. The brilliant planet Jupiter does so, too, at one minute before midnight.

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 11–12 this is $7^h\ 27^m$. 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 11th the Sun runs slow, transiting at 12:08 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.

Notice the tiny Moon symbol on the dotted line at 2:08 a.m. We can see from the legend at the bottom of the chart that the Moon is at waning crescent phase, rising. The wee hours continue, and at 4:38 Antares, a star we normally associate with a later season, also rises.

The first hint of dawn — start of morning twilight — comes at 5:45. The Sun finally peeks above the horizon at 7:21 a.m. on January 12th.

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* necessarily the line for midnight). Opposition is marked there by a ☍ symbol, as for Jupiter on the night of

January 9–10 and Neptune on the night of September 25–26.

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 with surface features 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 Mercury on the evening of February 13th and for Venus on the evening of September 18th 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 this year are 2461, as indicated just off the chart's upper left margin. To find the last three digits for evenings in January, add 041 to the date. For instance, on the evening of January 11th we have 11 + 041 = 052, so the Julian Day is 2,461,052. For North American observers this number applies all night, because the next Julian Day always begins at 12:00 Universal Time (6:00 a.m. Central Standard Time).

Time Corrections

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

Rising or Setting Corrections

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

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

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

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

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

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

Local Mean Time Corrections

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

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

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

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

For reprints (item SGA26W) or to order a similar chart for latitude 50° north or 30° south, go to: shopatsky.com/collections/maps-globes/almanacs

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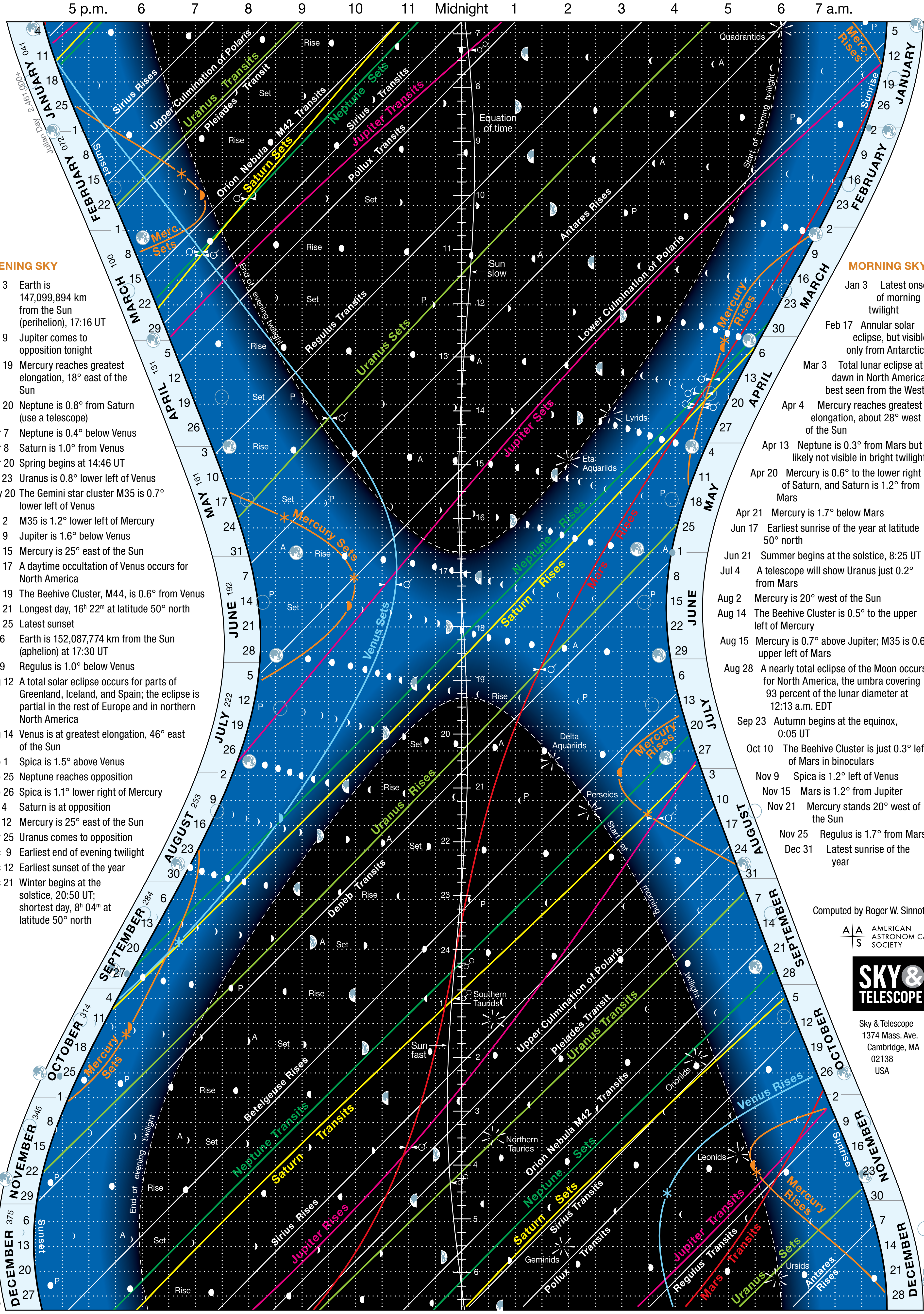
SKY & TELESCOPE

AMERICAN ASTRONOMICAL SOCIETY

Skygazer's Almanac 50°N 2026

FOR LATITUDES NEAR 50° NORTH

A SUPPLEMENT TO SKY & TELESCOPE



EVENING SKY

- Jan 3 Earth is 147,099,894 km from the Sun (perihelion), 17:16 UT
- Jan 9 Jupiter comes to opposition tonight
- Feb 19 Mercury reaches greatest elongation, 18° east of the Sun
- Feb 20 Neptune is 0.8° from Saturn (use a telescope)
- Mar 7 Neptune is 0.4° below Venus
- Mar 8 Saturn is 1.0° from Venus
- Mar 20 Spring begins at 14:46 UT
- Apr 23 Uranus is 0.8° lower left of Venus
- May 20 The Gemini star cluster M35 is 0.7° lower left of Venus
- Jun 2 M35 is 1.2° lower left of Mercury
- Jun 9 Jupiter is 1.6° below Venus
- Jun 15 Mercury is 25° east of the Sun
- Jun 17 A daytime occultation of Venus occurs for North America
- Jun 19 The Beehive Cluster, M44, is 0.6° from Venus
- Jun 21 Longest day, $16^h 22^m$ at latitude 50° north
- Jun 25 Latest sunset
- Jul 6 Earth is 152,087,774 km from the Sun (aphelion) at 17:30 UT
- Jul 9 Regulus is 1.0° below Venus
- Aug 12 A total solar eclipse occurs for parts of Greenland, Iceland, and Spain; the eclipse is partial in the rest of Europe and in northern North America
- Aug 14 Venus is at greatest elongation, 46° east of the Sun
- Sep 1 Spica is 1.5° above Venus
- Sep 25 Neptune reaches opposition
- Sep 26 Spica is 1.1° lower right of Mercury
- Oct 4 Saturn is at opposition
- Oct 12 Mercury is 25° east of the Sun
- Nov 25 Uranus comes to opposition
- Dec 9 Earliest end of evening twilight
- Dec 12 Earliest sunset of the year
- Dec 21 Winter begins at the solstice, 20:50 UT; shortest day, $8^h 04^m$ at latitude 50° north

MORNING SKY

- Jan 3 Latest onset of morning twilight
- Feb 17 Annular solar eclipse, but visible only from Antarctica
- Mar 3 Total lunar eclipse at dawn in North America, best seen from the West
- Apr 4 Mercury reaches greatest elongation, about 28° west of the Sun
- Apr 13 Neptune is 0.3° from Mars but likely not visible in bright twilight
- Apr 20 Mercury is 0.6° to the lower right of Saturn, and Saturn is 1.2° from Mars
- Apr 21 Mercury is 1.7° below Mars
- Jun 17 Earliest sunrise of the year at latitude 50° north
- Jun 21 Summer begins at the solstice, 8:25 UT
- Jul 4 A telescope will show Uranus just 0.2° from Mars
- Aug 2 Mercury is 20° west of the Sun
- Aug 14 The Beehive Cluster is 0.5° to the upper left of Mercury
- Aug 15 Mercury is 0.7° above Jupiter; M35 is 0.6° upper left of Mars
- Aug 28 A nearly total eclipse of the Moon occurs for North America, the umbra covering 93 percent of the lunar diameter at 12:13 a.m. EDT
- Sep 23 Autumn begins at the equinox, 0:05 UT
- Oct 10 The Beehive Cluster is just 0.3° left of Mars in binoculars
- Nov 9 Spica is 1.2° left of Venus
- Nov 15 Mars is 1.2° from Jupiter
- Nov 21 Mercury stands 20° west of the Sun
- Nov 25 Regulus is 1.7° from Mars
- Dec 31 Latest sunrise of the year

Computed by Roger W. Sinnott

American Astronomical Society

Sky & Telescope

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Skygazer's Almanac 50°N 2026

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 2026*, 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 11, 2026.

First find "January" and "11" 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 11–12 crosses many slanting *event lines*. Each event line tells when something happens.

The dotted line for January 11–12 begins at the black curve at left, which represents the time of sunset. Reading up to the top of the chart, we can estimate that sunset on January 11th occurs at 4:21 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 11th, we see that a dashed line at 6:18 marks the end of evening twilight, the time when the Sun is 18° below the horizon and the sky is fully dark. At 6:41 the brightest nighttime star, Sirius, rises in the southeast.

Polaris, the North Star, reaches upper culmination at 7:41 p.m. This is when Polaris stands directly above the north celestial pole (by 38′ or 37′ this year), a good opportunity to check the polar alignment of a telescope mount.

The dim outer planet Uranus transits the meridian at 8:16, meaning it is then due south and highest in the sky. It will be very well placed for telescopic viewing all evening.

At 8:23 the famous Pleiades star cluster in Taurus transits, followed at 10:11 by the Orion Nebula (Messier 42). Transits of such celestial landmarks help remind us where the constellations are during the night.

The ringed planet Saturn sets at 10:14 p.m., so it was well placed for viewing a few hours earlier this evening. But brilliant Jupiter now takes center stage, transiting at exactly midnight.

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 11–12 this is $7^h\ 26^m$. 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 11th the Sun runs slow, transiting at 12:08 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.

Notice the small Moon symbol on the dotted line at 2:22 a.m. The legend at the bottom of the chart tells us the Moon is at waning crescent phase, and rising. As the wee hours continue, Regulus transits at 2:43. Then at 5:25 Antares, a star we usually associate with later seasons of the year, rises in the southeast.

The first hint of dawn — the start of morning twilight — comes at 5:58. The

Local Mean Time Corrections

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

Sun finally peeks above the eastern horizon at 7:55 a.m. on Monday morning, January 12th.

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, Jupiter reaches opposition on the night of January 9–10 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 with surface features 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, this is true for Mercury on the evening of February 13th, and for Venus on the morning of November 29th.

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 this year are 2461, as indicated just off the chart's upper left margin. To find the last three digits for evenings in January, add 041 to the date. For instance, on the evening of January 11th we have 11 + 041 = 052, so the Julian Day is 2,461,052. For European observers this number applies all night long, because the next Julian Day always begins at 12:00 Universal Time (noon Greenwich Mean Time).

Rising or Setting Corrections

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

Time Corrections

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

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

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

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

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

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

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

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

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

For reprints (item SGA26E) or to order a similar chart for latitude 40° north or 30° south, go to: shopatsky.com/collections/maps-globes/almanacs

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