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THE ESSENTIAL GUIDE TO ASTRONOMY

MARCH 2024

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The Hubble Space Telescope after servicing, December 1999

PHOTO: NASA

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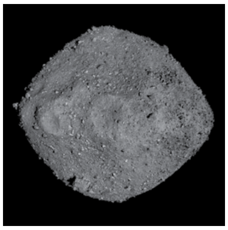
What's in a Name?

I'M PLEASED TO REPORT that Consulting Editor Gary Seronik recently had an asteroid named after him. It's a rock roughly 5.4 kilometers (3.4 miles) wide coursing through the main asteroid belt. Discovered at Chile's La Silla Observatory in 1993, it's now officially known as 20046 Seronik (1993 FE_{15}). See Ken Hewitt-White's full online report here: **https://is.gd/Seronikasteroid**.

What's in a name? Shakespeare reminds us that "That which we call a rose / By any other name would smell as sweet." An asteroid named "Seronik" would, if labeled with any another name, still be a rock. Yet to us Earthlings, naming things is important, for many reasons.

Among them, identification. Without Linnaeus' system of binomial nomenclature — *Homo sapiens* and the rest — how could we possibly keep all species straight? As Monica Young notes in her Beginner's Space on asteroid-naming (page 74), more than 600,000 discovered asteroids and other small solar system bodies remain unnamed. While the International Astronomical Union, which oversees such things, holds that appending a name is not strictly necessary for identification, the practice isn't really about that.



▲ The asteroid Bennu was named after an ancient Egyptian deity.

NASA / GODDARD / UNIVERSITY OF ARIZONA

Rather, it's often about honoring someone. That's true with 20046 Seronik and with the 30-plus asteroids that recognize *Sky & Telescope* editors, writers, and photographers. (More than 20 of those folks currently grace our masthead.) See Hewitt-White's post for the full list.

Not all asteroids are named after individuals. There's 3243 Skytel, for instance, and, as Young mentions, even more whimsical ones like 88705 Potato. Then there are "special objects" that the IAU insists receive mythological names. For instance, all Plutinos, or objects in a 3:2 mean-motion resonance with the planet Neptune, get ancient names connected to the underworld.

But commemorating a person remains a favorite, and the roughly 19,000 space rocks named thus far laud individuals ranging from planetary scientists to physicians, artists to sports figures — and, of course, those who've devoted their careers to celebrating amateur astronomy, like Gary Seronik.

Imagine having your "own" asteroid. That planetoid is out there right now, winging its way through the void. You can savor the fact that your name will cling to this primordial orb long after your own chemical elements have been recycled. In a way, you've slipped the surly bonds of Earth — you, or your flinty alter ego anyway, have become a solar system explorer.

That's what's in a name — at least of asteroids like 20046 Seronik.

Peter

Editor in Chief

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The Essential Guide to Astronomy

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The Bottle of Labeyrie

I'd like to react to Jerry Oltion's "The Darkness Before the Dawn" (*S&T:* Nov. 2023, p. 72) on the construction of a ball scope. He noted that Pierre Lemay had done it 10 years earlier. Both Jerry and Pierre were probably not aware that the famous French optical engineer and astronomer Antoine Labeyrie built two ball scopes from concrete for stellar interferometry at the CERGA (Center for the Research of Geodynamics and Astronomy) Observatory on the Plateau de Calern near the town of Grasse in Provence, France. Now the observatory is part of Côte d'Azur University in Nice. Labeyrie is known for introducing speckle interferometry in 1970. In 1977, I spent two weeks on the Plateau de Calern for my research and met Labeyrie. I found the above picture of what my French colleagues called the "bottle of Labeyrie" in my photo archives.

▲ This massive, concrete ball scope is one of a pair that sits on the Plateau de Calern in southeastern France.

Peter B. van der Wal
Stephanion Observatory
Stefani, Greece

Bringing the Sun Indoors

I enjoyed Jerry Oltion's article "Build a Solar Projector" (*S&T:* Dec. 2023, p. 72). This spring, I built a variation on that theme: a solar projector with a variable-focal-length lens system that projects a focusable image of the Sun into my house. The impetus was an old Gaertner Scientific coelostat that I had inherited, thinking "wouldn't it be fun to have a live solar image in the house."

The projector lens system consists of two simple lenses, one positive and the other negative. With the appropriate choice of focal lengths, the effective focal length of the system is a function of the lens spacing, so the system can project a solar image anywhere from a few feet all the way to infinity.

◀ Bernd Enders built a solar projector that projects an image of the Sun into a frame on his living-room wall from 40 feet away.

The trick turned out to be finding a suitable combination of commercial lenses. (I wasn't prepared to make my own lenses!) After numerous online purchases of inexpensive lenses (with focal lengths often very different from the advertised focal lengths) and some experimentation, I came up with a functioning solar projector with an image distance of about 40 feet, approximately f/430, projecting a 4-inch image onto a screen framed by a gold frame hanging on my living-room wall!

Bernd Enders
San Rafael, California

Three Cheers for M33

I thoroughly enjoyed Howard Banich's article "Messier 33: An Observer's Guide" (*S&T:* Nov. 2023, p. 58) and the sketches of the Triangulum Galaxy and its detailed nuances. We have a tendency, I think, to consider galaxies as single entities. Banich's description of M33's components was a delight.

It prompted me to look at my attempts at imaging the galaxy from 2020. Living with a suburban light-polluted sky means I don't bother trying to observe or image galaxies much. But occasionally I have a chance at darker skies, and then I do. So it made me happy that I could find some of the celestial bodies Banich describes in my photo taken from a Bortle 4/5 site, even with a small-aperture setup. The next time I get a chance at darker skies, I'll attempt longer exposures on M33 and visual observations as well.

Steve Altic
Columbus, Ohio

Howard Banich replies: *I'm delighted you enjoyed my article and sketches of M33, and your point about thinking of galaxies as single entities is excellent. I certainly do that at times, but when I remember to use my informed imagination to consider what makes up a galaxy that I can barely see, or one that's edge-on from our perspective, I often think of M33. Imagine what M31 must look like seen face-on!*

Anyway, good luck with imaging and observing when you get under a dark sky!

BALL SCOPE: PETER B. VAN DER WAL

I really enjoyed Howard Banich's detailed observer's guide to M33 in the November *S&T*. I'm hoping my Bortle 4 sky will allow me to try observing some of the details he pointed out in his wonderful article using my Celestron C11 Schmidt-Cassegrain. His sketches are incredible!

One thing I really appreciate is that many articles in *S&T* are regularly aimed at those of us who call visual astronomy our passion — I'm so glad for that! I'm out there with my always-growing observing list, various binoculars, wide-field 4.7-inch refractor, and 11-inch Schmidt-Cassegrain any chance I get.

It was such a great article, and for Banich's 33rd at *S&T*, it was extra fun. It has got me jonesing for a clear night for a close look with his sketches.

Nils Walter
Garrison, New York

Howard Banich replies: *Thank you, Nils! I think you have a good chance of seeing some of M33's details through your Schmidt-Cassegrain on a good night. I live in a Bortle 4 area, too, and have been surprised by what I can see, but the sky has to be very transparent. You may even get your best view of M33's spiral structure with your 4.7-inch refractor. I agree that* S&T *does a good job of presenting articles for visual observers — as wonderful as imaging is, it isn't for everyone. I'm looking forward to seeing M33 again this autumn, too.*

Thanks for Participating

Thanks to *S&T* for publishing my "Jupiter Deflection Project — Call for Observations" (*S&T:* Oct. 2023, p. 6) for last October's Jupiter conjunction. From within hours of the digital issue going live, up until the morning of the event, I had people signing up. Skill levels ranged from beginners to professionals, including programmers. I was hoping for a wide geographic coverage in case of bad weather, and it worked: Observing locations ranged from all across the U.S. to Europe and even included some remote telescopes. Some observers were clouded out, but others were very successful. It will take a while to process the data, but I'll send another note when the results are good enough to demonstrate once again that Einstein was right!

Here is a link to a video of the event: **skyandtelescope.org/jupiter-deflection-project-october-2023**.

Don Bruns
San Diego, California

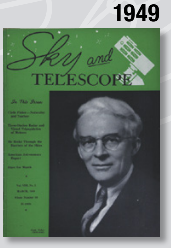
FOR THE RECORD

• In "Messier 33: An Observer's Guide" (*S&T:* Nov. 2023, p. 58), the locations of two targets, U62 and IC 134, are mislabeled. See **https://is.gd/Banich_M33** (at end) for their correct locations.

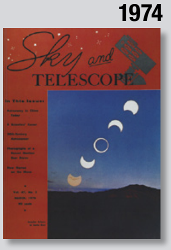
SUBMISSIONS: Write to *Sky & Telescope*, 1374 Massachusetts Ave., 4th Floor, Cambridge, MA 02138, USA, or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1949



1974



1999

◖ March 1949
Radar Echoes "Early in the summer of 1947 the Dominion Observatory and the National Research Council, both of Ottawa, commenced a co-operative program of meteor observation. . . . The basic purpose of this investigation is a detailed correlation of visual, photographic, and radar data. . . . The radar equipment has been operated in the band 30–36 megacycles per second (10.0–8.3 meters wave length). . . .

"To study the relation among heights determined by the three methods, detailed computations have been carried out for the night of August 10–11, 1948. [We found that] there is a tendency for the radar echo to occur near the end of the visual trail — for the Perseids at least."

Meteor experts Peter M. Millman and D. W. R. McKinley added that radar held promise for studying daytime showers.

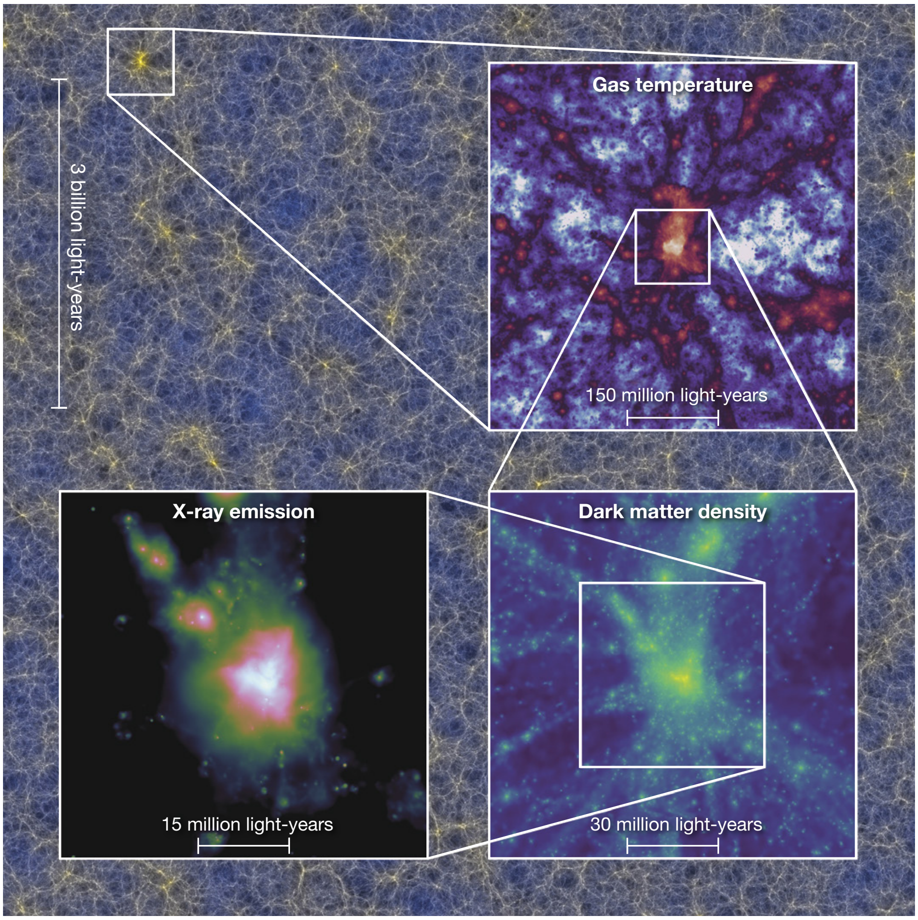
◖ March 1974
Cometary Dud "The impression made by Comet Kohoutek 1973f depends very much on with whom you talk. Professional astronomers are enthusiastic about observations they obtained that should tell much about the structure and origins of comets. . . . [Amateurs] were rewarded by a beautiful and delicate object in the evening sky . . . But the general public wondered what had happened to the spectacle promised by the news media. . . .

"[Their disappointment] was mainly due to overenthusiastic advance publicity. Last spring, if an astronomer were asked how bright Kohoutek would become, a careful answer would have been: 'Possibly magnitude –5 to –10, but that will be at a time when the comet is too close to the sun to be seen . . .'"

◖ March 1999
Killer Asteroid "Like finding a stray bullet at a crime scene, a researcher believes he has uncovered a long-sought chunk of the impactor thought to have snuffed out 70 percent of the species of life on Earth 65 million years ago. . . .

"Geochemist Frank T. Kyte (University of California, Los Angeles) has been studying a core sample from the bottom of the Pacific Ocean containing dark clay marking the boundary of the Cretaceous and Tertiary periods (the K-T boundary). [This] clay layer included a 4-millimeter-wide piece of lighter-colored clay. Upon splitting open the nugget, he discovered a fossil meteorite. . . .

"Because the ocean-floor sediments at the K-T boundary accumulated over perhaps as much as 500,000 years, there is no way to prove that this truly is a piece of the K-T impactor. [But Kyte] largely discounts the possibilities that the material is interplanetary dust or cometary debris. [He] thinks it quite conceivable that a piece of the asteroid that struck the Yucatán Peninsula survived the blast and landed 9,000 kilometers away."



◀ The background image shows the present-day distribution of dark matter (brightness) and neutrinos (color) in a slice through the largest Flamingo simulation. The insets show three consecutive zooms centered on a massive galaxy cluster, showing the gas temperature, dark matter density, and simulated X-rays.

COSMOLOGY

Largest-ever Computer Simulations of the Universe

ASTRONOMERS HAVE CARRIED out the largest-ever cosmological simulations using one of the most powerful supercomputers in the world. Known as Flamingo, this set of simulations traces the growth of the large-scale structure from just after the Big Bang to today. By comparing these simulations to observations, scientists hope to learn about fundamental properties of the universe, which govern its long-term behavior.

The current "cosmic web" of galaxy clusters and superclusters came together out of an almost-homogeneous soup that existed shortly after the Big Bang, made of atoms, dark matter particles, and almost massless neutrinos. Ever since the 1980s, astronomers have tried to reproduce this process in computer simulations. Thanks to rapid developments in computer technology, these simulations have become ever more detailed, growing both in size (how much space is being simulated) and in resolution (how many "particles" are being followed, and how much mass those particles represent). Flamingo, which is short for "Full-hydro Large-scale structure simulations with All-sky Mapping for the Interpretation of Next Generation Observations," is the largest and most complex project so far.

A team led by Joop Schaye (Leiden University, The Netherlands) traced the evolution of as many as 300 billion "particles" within an expanding cube of space 9.1 billion light-years on a side. Each of these particles has a baryonic mass of some 130 million solar masses, equivalent to an average dwarf galaxy.

The simulations required more than 50 million hours of computer time, distributed across the 30,000 processors of the DiRAC-COSMA8 supercomputer at Durham University in the UK. The results are published in three papers in the December *Monthly Notices of the Royal Astronomical Society*.

Apart from its size and resolution, Flamingo also sets itself apart from earlier simulations by incorporating more than gravity. "Up to now, most of the cosmological computational simulations of our universe focused on modeling dark matter only, as it is the main matter component," says Guadalupe Cañas Herrera (ESA), who was not involved in the new work.

Even though "normal" (that is, *baryonic*) matter makes up only 15% of all the universe's mass, it affects the distribution of cosmic matter over small distances. In addition to including the behavior of baryons, the Flamingo project also accounts for *neutrinos*, elementary particles with a very small but non-zero mass.

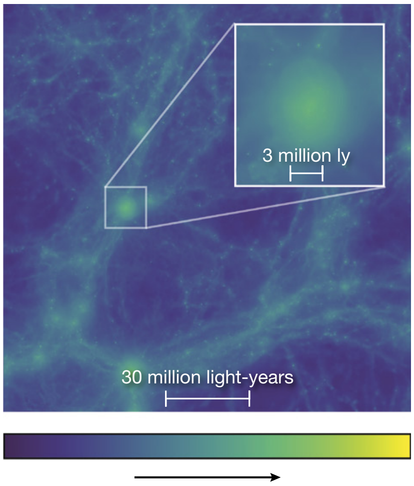
"On all fronts, these simulations are the state of the art," says Koen Kuijken (also at Leiden University), who was not involved in the studies.

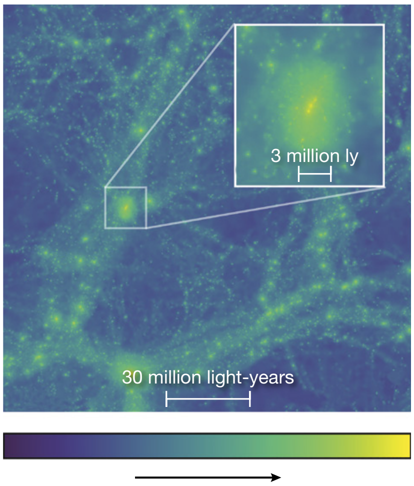
So far, the team has carried out 28 slightly different simulations, tweaking cosmic parameters such as the dark matter fraction, the neutrino mass, the influence of galaxies' central black holes, and the *stellar mass function*, that is, what percentage of stars fall in different mass ranges.

"Simulations are crucial for cosmologists," says Cañas Herrera. "They are a key player in understanding how well theoretical models predict the behavior of our universe."

One application of the Flamingo simulations is to look at a problem that has nagged cosmologists for decades: The universe appears to be a bit less clumpy than the standard cosmological model predicts (*S&T:* June 2023, p. 11).

Previously, astronomers have suggested that galactic winds and other





▲ These two simulation stills compare the surface density of gas (top) and dark matter particles (bottom) in the modern-day universe. The insets zoom in on a massive dark matter halo, which might hold many galaxies.

feedback delivered via ordinary, baryonic matter might explain this tension. However, the Flamingo team concluded that while feedback indeed affects the universe's large-scale structure, it's not enough to solve the clumpiness problem. If unknown systematic errors in the analysis can also be excluded, the researchers write, "then the exciting implication would appear to be that new physics [...] is required."

In other words, the new Flamingo simulations might indicate that something is wrong with our standard model of cosmology.

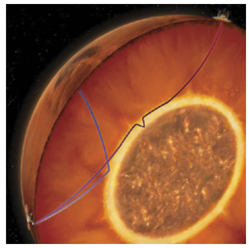
■ GOVERT SCHILLING

PLOTS: SCHAYE ET AL. / *MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY* 2023 (2); MARS INTERIOR: IPGP / CNES / N. STARTER

SOLAR SYSTEM

Marsquake Reveals Molten Layer Above Martian Core

ON SEPTEMBER 18, 2021, an impact triggered a marsquake on the planet's farside from the seismometer aboard NASA's Insight lander. For the first time in three years of operations, it detected vibrations that could enable scientists to probe the deep Martian interior. In the October 26th *Nature*, two separate groups used the impact to probe a layer of molten magma in the lower mantle.



◀ An artist's view of the internal structure of Mars shows the propagation of seismic waves from two events in 2021.

In 2021, scientists employed Insight to measure the size of the liquid Martian core (*S&T:* Nov. 2021, p. 8), estimating its diameter to be 3,660 km (2,270 miles), more than half the planet's width. The large volume implied a low average density, just 6 grams per cubic centimeter compared to at least 10 g/cm^3 in Earth's core.

That's problematic in light of Mars's formation, says Amir Khan (ETH Zürich), who led one of the *Nature* studies. "It would be very difficult to get all those light elements into the core."

Scientists needed more data, and just months before Insight lost power, the planet provided. The September impact and a second, closer event on December 24, 2021, generated slow seismic waves that indicated they'd traveled through a stratified mantle, explains Henri Samuel (University of Paris), who led the second *Nature* study. Both Khan's and Samuel's teams saw a layer of molten silicates at the bottom of the mantle; Samuel's team also found that a partially molten layer tops the fully molten region.

Accounting for the stratified mantle shrinks the measurement of the true core to 3,300 km in diameter, increasing the density to about 6.5 g/cm^3. While still not nearly as dense as Earth's core, the new value reduces the amount of light elements required.

The results have other implications, too, Samuel's team argues. A liquid lower mantle would have insulated the core, preventing it from cooling and thus inhibiting internal motions. So Mars's early magnetic field might have come not from within but from external sources, such as giant impacts.

"This shows the power of seismology," says Simon Stähler (also at ETH Zürich), who wasn't involved in the study. "It can sound the deep interior and give us otherwise unobtainable information."

■ JEFF HECHT

IN BRIEF

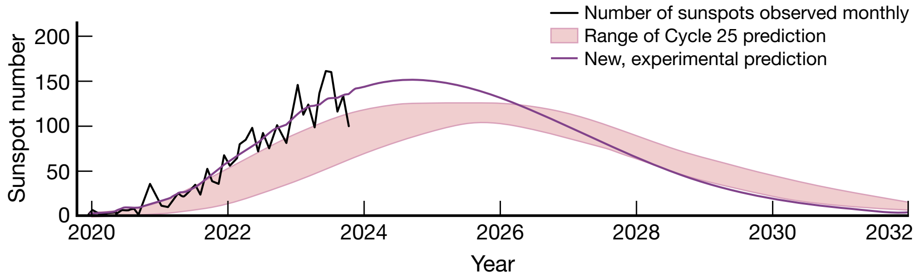
Planets Really Do Start with Pebbles

The James Webb Space Telescope turned up evidence that icy pebbles really do deliver vital building blocks to the inner regions of planet-forming disks. A team led by Andrea Banzatti (Texas State University) used Webb's mid-infrared instrument to explore four disks around young stars in Taurus. Two of them are compact (just 10 to 20 astronomical units, or a.u., across), while two are bigger (100 to 150 a.u.), with multiple gaps and rings. Under the pebble scenario, greater friction within more compact disks causes distant, icy pebbles to drift inward. The rings and gaps of larger disks, on the other hand, impede such pebble drift. If a pebble drifts across the *snow line*, the temperature rises enough to sublimate the veneer of ice into water vapor, leaving behind bare, rocky material for terrestrial planet formation. In the November 10th *Astrophysical Journal Letters*, Banzatti's team reports excess cool water vapor around the snow line, compared with only hot vapor for the larger ones. However, additional observations could complicate this picture, says Jane Greaves (Cardiff University, UK), who wasn't involved in the research.

■ COLIN STUART

THE SUN

New Forecast Resets Solar Cycle Expectations



▲ The plot shown here compares the number of sunspots predicted now (purple line) to the number predicted in 2019 (pink shaded area). The jagged black line shows the actual number of sunspots recorded each month, which is higher than the 2019 prediction.

A NEW FORECAST has sunspot numbers and other solar activity peaking sooner and at a higher level than expected. This new prediction has important consequences for space operations, including provisions for the safety of satellites and astronauts.

The Sun's 11-year cycle takes it from being relatively sunspot-less at minimum, to spot-filled at maximum, and back again. With more sunspots come more frequent solar flares, coronal mass ejections, and a stronger solar wind.

In 2019, a panel of researchers worked with the National Oceanic and Atmospheric Administration's Space Weather Prediction Center (SWPC) to forecast the current Solar Cycle 25 (*S&T:* Jan. 2021, p. 12). They originally predicted that solar maximum would occur between December 2024 and March 2026, with a monthly sunspot count around 105 to 125. That's low compared to the average peak number.

In the years since, the Sun surprised us to the upside, with more sunspots and greater solar activity than expected. Now, an updated prediction calls for Solar Cycle 25 to peak between January and October 2024, with a maximum sunspot number between 137 and 173.

The prediction marks the debut of SWPC's experimental prediction product, updated on a monthly basis on the Space Weather Prediction Testbed website. "We expect that our new experimental forecast will be much more accurate than the 2019 panel prediction," says Mark Miesch (University of Colorado, Boulder), solar cycle lead at SWPC. "It's a pretty significant change." In addition to more accurate space weather forecasts, the revised predictions will also help astronomers understand the solar interior.

"What jumped out at me from the prediction is its asymmetry, with a decay phase much longer than its rise phase," says Ryan French (National Solar Observatory), who was not involved in the prediction. "This means we can look forward to continuing high solar activity (including frequently enhanced aurorae) until at least 2027."

Another upside is that, according to the new forecast, the April 8th solar eclipse will occur around solar maximum, which could give us more impressive views of the corona during totality.

■ **COLIN STUART**

The European Space Agency has published the first color images from its Euclid space telescope, and they're gorgeous. One of the first galaxies Euclid observed is the Milky Way-like IC 342, 11 million light-years away in Camelopardalis. The image assigns 0.7, 1.1, and 1.7 microns to the blue, green, and red channels, respectively. Hot stars appear white, hot hydrogen gas appears blue, and regions rich in dust and cooler, molecular gas are red. Between the spiral arms, far more distant galaxies are visible.

Each image from the 1.2-meter Euclid telescope covers an area more than twice the size of the full Moon, with an angular resolution of 0.2 arcseconds. Euclid is now using its infrared instrument to map the 3D distribution of 1.5 billion galaxies out to distances of 10 billion light-years. This map will reveal the evolution of the large-scale structure of the universe, governed by dark matter and dark energy. Meanwhile, precision measurements of galaxy shapes, which are affected by the gravitational distortions of intervening matter, will yield information on dark matter's distribution. "Everything suggests that Euclid will perform even better than expected," says science team member Henk Hoekstra (Leiden University, The Netherlands), "and that the mission will reach its scientific goals."

■ **GOVERT SCHILLING**

PLOT OF SUNSPOT NUMBERS: NOAA SWPC; IC 342: ESA / EUCLID / EUCLID CONSORTIUM / NASA, IMAGE PROCESSING BY J.-C. CUILLANDRE (CEA PARIS-SACLAY), G. ANSELMI; CC BY-SA 3.0 IGO

SOLAR SYSTEM

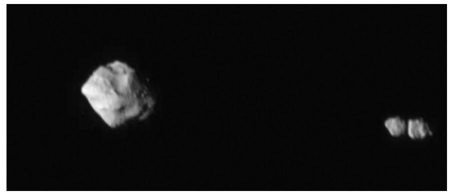
Lucy Flies By Asteroid Dinkinesh, Finds a Snowman-Moon

ON NOVEMBER 1ST, NASA's Lucy spacecraft zipped past the small main-belt asteroid 152830 Dinkinesh and discovered that it has a moon — and an oddly shaped one at that.

Lucy's first flyby image revealed the moon emerging from behind the asteroid. The spacecraft then turned during the flyby, so another image taken six minutes later showed the asteroid and its moon from a different angle (see image at right). The new perspective revealed that the moon is actually a *contact binary*, meaning two objects in contact with each other. This is the first discovery of a contact-binary asteroid moon. The International Astronomical Union has named it Selam (see page 74 for how asteroids are named).

Binaries are common among asteroids, though they likely didn't start out that way. A set of phenomena referred to as the *YORP effect* can spin up asteroids until they begin to shed mass at the waist. The breakaway material initially forms a ring but eventually coalesces into a companion. Such an effect might have created the moon.

Dinkinesh and Selam are the smallest main-belt asteroids seen up close. They resemble the recently visited near-Earth asteroids 101955 Bennu and 162173 Ryugu, with boulders perched on their surfaces, soft dents of craters, and bulging midlines. So the Dinkinesh pair are likely also rubble piles, agglomerations of rocks and dust loosely held together by gravity. The main asteroid's diameter, 790 meters, matches a prior estimate made using archival data from the Wide-field Infrared Survey Explorer (WISE). The moon is 220 meters across.



▲ This image, taken as Lucy turned around post-flyby, revealed the contact-binary nature of the asteroid moon.

Lucy is now headed for another main-belt asteroid, 52246 Donaldjohanson, for an April 2025 visit, before moving on to explore seven Trojan asteroids that share Jupiter's orbit.

■ EMILY LAKDAWALLA

GALAXIES

Ghost-like Galaxy Defies Dark Matter Model

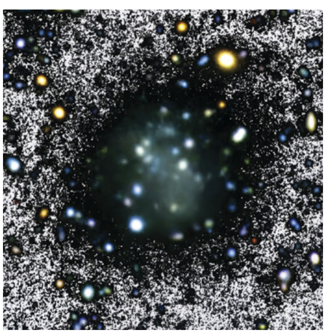
ASTRONOMERS HAVE DISCOVERED a large but dim galaxy whose very existence challenges our notions of dark matter. The galaxy is about half as large as our Milky Way but no more massive than the puny Small Magellanic Cloud, our galaxy's dwarf satellite.

This galaxy, nicknamed Nube (Spanish for "cloud"), is even more extreme than most *ultra-diffuse galaxies*, all of which exhibit an unusually low surface brightness.

"I was excited when I saw it presented at a conference," says Pieter van Dokkum (Yale University), who wasn't involved in the discovery. "We keep finding larger and fainter systems; we don't really know where the limits are!"

A team led by Mireia Montes (Institute of Astrophysics of the Canaries, Spain) found the faint blob in a deep survey of a strip of sky within Cetus, the Whale. Follow-up observations show it's an isolated galaxy at a distance of some 350 million light-years and is 10 billion years old, with some 400 million solar masses' worth of stars. The results will appear in *Astronomy & Astrophysics*.

The observations also show that Nube contains a few dozen times more total mass than in stars and gas alone. The galaxy's large size and dark matter abundance pose a challenge for cosmological simulations. If dark matter is made of massive, slow-moving particles, dark matter-rich galaxies never become as big as Nube in simulations. However, if dark matter instead consists of extremely low-mass, axion-like particles (also known as "fuzzy" dark matter), then simulations can reproduce both Nube's size and its dark matter abundance. Montes' team cautions, however, that more work is needed to assess this model.



▶ The composite image shown here covers 100×100 arcseconds around the newly discovered galaxy dubbed Nube.

■ GOVERT SCHILLING

IN BRIEF

A Puffy Planet with Clouds of Sand

It's a strange world: a planet only twice as dense as Styrofoam, enveloped in high-altitude clouds of sand. Yet it exists, 200 light-years away in Virgo. Known as WASP-107b, the low-density planet was discovered in 2017, orbiting its parent star once every 5.7 days at a distance of 0.06 astronomical unit. Previous observations revealed the planet to be almost as large as Jupiter but only about as massive as Neptune. Now, an international team publishing in *Nature* has used Webb's mid-infrared instrument to reveal abundant sulfur dioxide in its atmosphere as well as the presence of silicate clouds — but no methane. Interaction with starlight creates the sulfur dioxide, so it might be more abundant because starlight can penetrate deeper into the puffy atmosphere. Meanwhile, the absence of methane indicates that atmospheric temperature rises steeply with depth. The strong radiation and/or the hot interior might explain the presence of the sand clouds. Sand particles should "rain down" over time, so some kind of atmospheric cycle must replenish their presence at high altitudes.

■ GOVERT SCHILLING

DINKINESH BINARY: NASA / GODDARD / SWRI / JOHNS HOPKINS APL; NUBE GALAXY: MONTES ET AL. / ARXIV 2023

What's *Next* for

EYE IN THE SKY Launched by the Space Shuttle *Discovery* on April 24, 1990, the Hubble Space Telescope remains a mainstay of astronomical research.

NASA

Webb may be receiving the attention, but its predecessor still fills crucial roles in astronomy.

The Hubble Space Telescope has been carrying out awe-inspiring work for a third of a century, but lately the breathless headlines and dazzling photos we keep seeing are mostly coming from its new big brother, the James Webb Space Telescope. In the age of Webb, how much of a role does Hubble still have to play — and after more than three decades in space, how much longer can it last anyway?

The aging scope has temporarily shut down science operations at least a half-dozen times in the last two years, due to issues with a data-handling unit, the gyroscopes, and the solar panels' pointing system. Each of these *safe modes* took the observatory offline — sometimes for weeks — and caused operators to reshuffle observing schedules. Some planned observations were lost.

Hubble?

And yet, according to those managing Hubble's operations and dealing with its litany of glitches and ornery components, the telescope probably has a decade of very useful life ahead of it, and possibly even more if NASA approves a mission to boost it to a higher orbit. And the aging scope still provides a range of capabilities and wavelength coverage unrivaled by any existing or planned instrument, including Webb, for at least the coming decade.

"Hubble is actually more scientifically powerful now than ever before," says Jennifer Wiseman (NASA Goddard Space Flight Center), the telescope's senior project scientist. Thanks to both the successful fifth servicing mission in 2009, when astronauts installed new gyros and two instruments, as well as innovative techniques developed by astronomers since then, "we are at the peak of scientific capability," she says.

> **"Hubble is actually more scientifically powerful now than ever before."**

Competition to use the facility remains high, with about 1,000 new observing proposals received every year, only about 200 of which can be accepted. And increasingly, these proposals involve synergistic projects that combine the capabilities of multiple instruments, such as Hubble and Webb, to provide the broadest possible wavelength and resolution coverage.

"We have flagship missions now in space that can cover wavelength ranges from mid-infrared through visible into ultraviolet, and then with Chandra into X-rays," Wiseman says. "So, Hubble is as powerful as ever and is as popular as ever now, in fact — especially with Webb in play."

UV Is Key

One unique capability the telescope has is its ability to observe an extended ultraviolet range, down to 100 nanometers. Because Earth's atmosphere largely blocks UV radiation, only space telescopes can effectively observe it. "A lot of the diagnostics for temperature and chemistry for astrophysical phenomena are down at those wavelengths," says mission head Tom Brown (Space Telescope Science Institute).

This broad spectral coverage makes a big difference in determining the makeup and conditions of the atmospheres of planets orbiting nearby stars. "Hubble was the pioneer in understanding how to do transit absorption spectroscopy with exoplanets to discern their composition," Wiseman says. This involves taking spectroscopic observations as a planet crosses in front of its star and then subtracting out the star's data to see the chemical fingerprints left by the planet's atmosphere on the starlight.

For example, in 2022 Hubble's UV observations provided evidence for magnesium and silicon monoxide in the atmosphere of the hot Jupiter WASP-178b. These chemical species weren't condensed into clouds, though, suggesting that worlds have to be cooler than WASP-178b in order to have silicate rain.

Hubble is, "without a doubt, a unique workhorse for exoplanet science," says research scientist Néstor Espinoza (Space Telescope Science Institute). Its precision and accuracy are difficult for any other current observatory to reach in the ultraviolet through visible range.

The telescope's wavelength coverage also comes in handy for observing rapidly changing events, Brown says. "That's a lot of Hubble's bread and butter — anything with explosive phenomena, transients, and the chemistry and temperature of such events. People do a lot of work in that area, in the time domain."

Time-domain astronomy is the study of sources that measurably change with time. It has taken off with the advent of large-scale sky surveys, enabling observers to spot changes they wouldn't have before. Among the scientific panels that allocate Hubble time based on different research areas, the one on stellar physics is seeing more and more submissions for observing fleeting phenomena. "People are looking at exploding stars, merging stars, gravitational waves, and so on," Brown explains. "We're really expecting an avalanche of time-domain astronomy to hit us."

An important and growing area of Hubble's research consists of following up on transient phenomena detected by other instruments. Such follow-ups are "something that's really going to be a big deal in this decade," he says.

These discoveries will come primarily from future all-sky surveys, which astronomers will carry out with upcoming facilities such as the Vera Rubin Observatory in Chile and the Nancy Grace Roman Space Telescope in orbit. "When people are looking at these explosive phenomena, supernovas, gravitational-wave events, and so on, they always want to follow up in the ultraviolet, because that's where things happen most rapidly," Brown says. For example, when the LIGO gravitational-wave observatory detected the merger of two neutron stars in 2017, Hubble's follow-up observations provided crucial measurements of the way the UV light faded with time, he says.

No other facility comes close to Hubble's abilities, and none now planned will equal it until at least the 2040s. That's when NASA might launch a new space telescope, equal to Webb in size and provisionally called the Habitable Worlds

Observatory. Astronomers recommended HWO as a top priority in their 2020 decadal survey, and the space agency is investigating options for its construction. But even if HWO comes to fruition and has the same (or greater) UV coverage that Hubble has, there likely will be a gap between the end of Hubble's effective lifetime and the launch of the new facility.

"If Hubble ends its mission, the whole field is going to be without a UV-optical telescope in space with these kinds of capabilities for years," Brown says. By keeping Hubble alive and healthy as long as possible, "we'd like to close that gap," he says. "People depend on these capabilities in UV-optical, and once they go away, it's going to be shocking."

What Are the Worries?

What's likely to make Hubble go away? There's always the possibility of individual system failures, such as gyroscopes, batteries, or computer chips.

Each of Hubble's gyroscopes contains a rapidly spinning wheel that enables precise measurements of changes in orientation. The gyros allow the huge telescope to turn from one target to another and then maintain its position with rock-steady stability. The instrument was designed to use three gyros — one for each direction of motion (*x*, *y*, and *z*) — to provide this pointing and stability. It launched with six of them to provide redundancy, in case of failures.

Four of them did indeed fail within a few years. Astronauts replaced all six gyros in 1999 and again during the 2009 servicing mission, this time including three that had an updated design. These have exceeded expectations, lasting at least five times as long as the earlier type. Meanwhile, the three remaining "old-type" gyros have since failed.

Glitches with one of the gyros have triggered multiple safe modes, twice in August 2023 alone. Once Hubble enters safe mode, and after the underlying problem has been identified and corrected, it takes at least 24 to 30 hours to get all systems back online, says project manager Patrick Crouse (NASA Goddard), who oversees the telescope's operations and management.

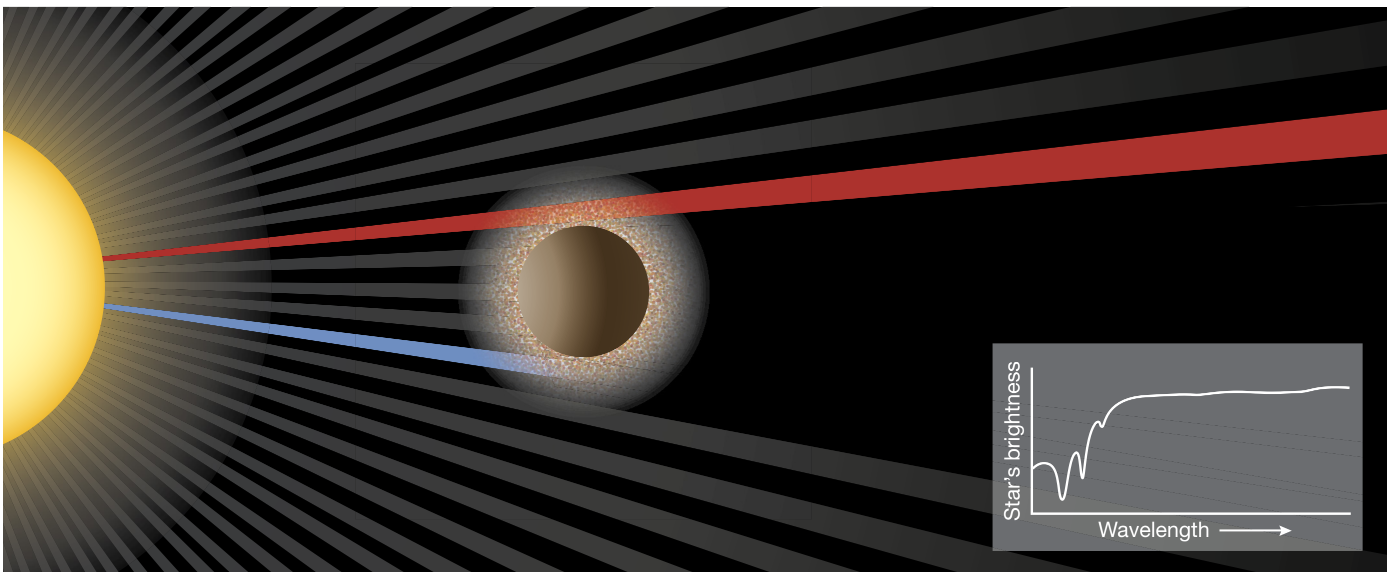
The team is working on ways of reducing that downtime. Meanwhile, a new operating process seems to have eliminated the glitches, at least for the time being, he says.

"We're confident we will have at least some subset of the three for some years to come," says Wiseman. And even if one or two of the new gyros do fail, the telescope can continue to carry out good science. "We already have a technique that we've tested and tried, that uses only one gyroscope in combination with Hubble's fine guidance sensors to continue to be able to point the telescope and keep stability."

There would be a significant limitation imposed by the loss of a gyro, however. "When we lose another gyroscope, we no longer have what we call the *field of regard*, covering the whole sky outside of the Sun," Brown says. "We'll only have about half the sky available at any one time, which is still good. Over the course of a year, the whole sky comes into view, but it's not on any one day." Neither the Webb nor Roman telescopes have that all-sky capability, he says, "so that will be a loss in some science efficiency for following up events."

If two gyros fail, productivity will drop by 25%, Crouse says. Some planned observations would simply become impossible because of the greater limitations on the telescope's sky coverage.

Other equipment onboard also continues to soldier on, more than a decade after the last servicing mission. Repairs to the Advanced Camera for Surveys and the Space Telescope



ATMOSPHERIC SPECTRUM When a planet with an atmosphere passes in front of its star, different wavelengths of starlight are blocked to varying degrees by the atmosphere, depending on the atmosphere's composition. (In this illustration, shorter, bluer wavelengths are absorbed.) Astronomers can use the absorption pattern to infer which elements and compounds are present.

LEAH TISCIONE / *S&T*, SPECTRUM SOURCE: J. D. LOTHRINGER ET AL. / *NATURE* 2022

Imaging Spectrograph, carried out during the 2009 mission, were more successful than expected, Wiseman says. "We were hoping to get maybe five more years out of them after the repair, and now it's been 14, and they're still going strong."

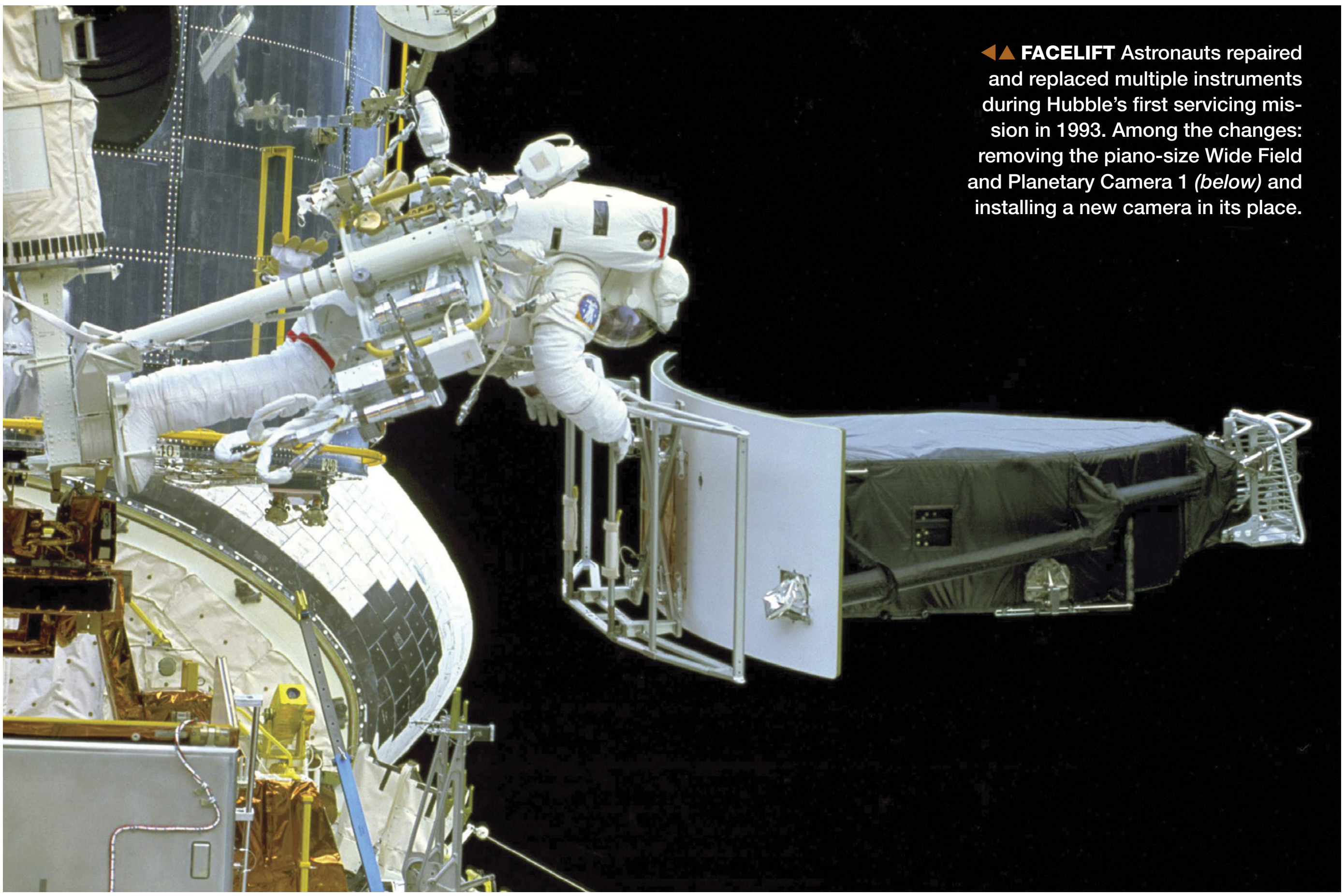
Meanwhile, two new instruments installed at that time, the Wide Field Camera 3 and the Cosmic Origins Spectrograph, continue to perform well, and the camera "will be providing terrific imaging for as long as Hubble is operating." The COS instrument is slowly losing sensitivity, "but this was expected," she says, and new observations are planned accordingly.

"We have every expectation that the telescope will keep doing excellent science through this decade," says Brown. "We're still going strong."

Command and Communications

Another possible failure point is the onboard computer, which serves as the science-instrument command and data handler. Hubble has two of these computers, for redundancy. One failed in 2021, and the operations team transferred to using the backup. Meanwhile, they've been working to try to restore the functionality of the primary computer, just in case they need it later.

Crouse says the computer restoration is progressing well, but it's a long process to evaluate and test the needed



FACELIFT Astronauts repaired and replaced multiple instruments during Hubble's first servicing mission in 1993. Among the changes: removing the piano-size Wide Field and Planetary Camera 1 *(below)* and installing a new camera in its place.

NASA (2)

▲ **PLANET HUGGER** Hubble orbits roughly 530 km above Earth's surface, as shown in this illustration. Our planet's atmosphere drags on the space telescope, inexorably robbing the craft of orbital energy. As the telescope drops lower, an uncontrolled reentry becomes more likely.

changes. Hopefully they'll have completed the critical design reviews by the end of 2023.

"I think it's going to be a year-and-a-half to two-year effort to implement this as a fully functional, highly efficient mode," he says. "But it's something that we're working on as a risk mitigator, so that if we experience a failure on the current side of the system, we still have a recourse to fall back on to continue operations."

"That's really one of the great things about Hubble," Brown says. "It's got enough hardware redundancy up there, and a lot of smart engineers working on the operations staff, so when we do have a failure, most of the time you can figure out a way around it."

Inevitable Orbital Decay

But the big looming issue is the telescope's orbit. Launched in 1990 into a 615-kilometer-high orbit (380 miles high), Hubble has sunk back toward Earth over time due to our planet's tenuous upper atmosphere, which drags on the craft and forces its orbit to decay. The telescope now sits about 530 km up. Once it drops below about 500 km, the risk of uncontrolled reentry rises. At that point, it would need to either be propelled into a controlled reentry and burn up in the atmosphere or be boosted to a higher orbit to preserve it.

In December 2022, NASA issued a request for information from companies to suggest plans for boosting Hubble by about 2025. These aren't formal mission proposals; rather, they're a way for the agency to consider its next steps. Eight teams responded to the request. NASA is currently evaluating the submissions and may decide to issue a formal request for proposals as a follow-up. Should the agency proceed with a mission, the selected partner would fund the effort, with no cost to NASA or the public.

One submission came from a collaboration between two companies, Astroscale and Momentus. Their proposal is an uncrewed mission, using a robotic arm to grasp the telescope and carry it to a higher orbit.

Such a mission "would buy another five or 10 years of lifetime, maybe even longer, depending on how active the present solar cycle is," says Rob Schwarz, chief technology officer of Momentus. The level of solar activity matters because it increases the turbulence of the tenuous upper atmosphere and thus increases the drag on the spacecraft.

Momentus, which builds what are essentially space tugboats for relocating satellites, has previously demonstrated its abilities by propelling a variety of small satellites into their intended orbits. Meanwhile, its partner Astroscale, which would provide a rendezvous vehicle, has successfully rendezvoused and docked with a satellite already in orbit.

"So the pieces of [a Hubble boost mission] have all been demonstrated on orbit, just not all together as one integrated system," Schwarz says. Momentus itself plans a mission in February 2024 that would demonstrate its ability to capture a satellite in space using a robotic arm, he says.

In addition to the eight proposals is one from SpaceX. SpaceX's initial study, which led to NASA's wider request for information, would use its crewed Dragon capsule launched aboard a Falcon 9 booster. The company would fund the mission, perhaps in combination with a tourist mission or other paying customer. Since astronauts would be aboard, they might be able to do some repairs, too, such as replacing the three failed gyros.

There might be some risk, however, since the mission would involve actually having Dragon dock with the telescope, using a docking port installed during the last servicing mission. The telescope was not designed to withstand the impact and vibrations caused by such docking.

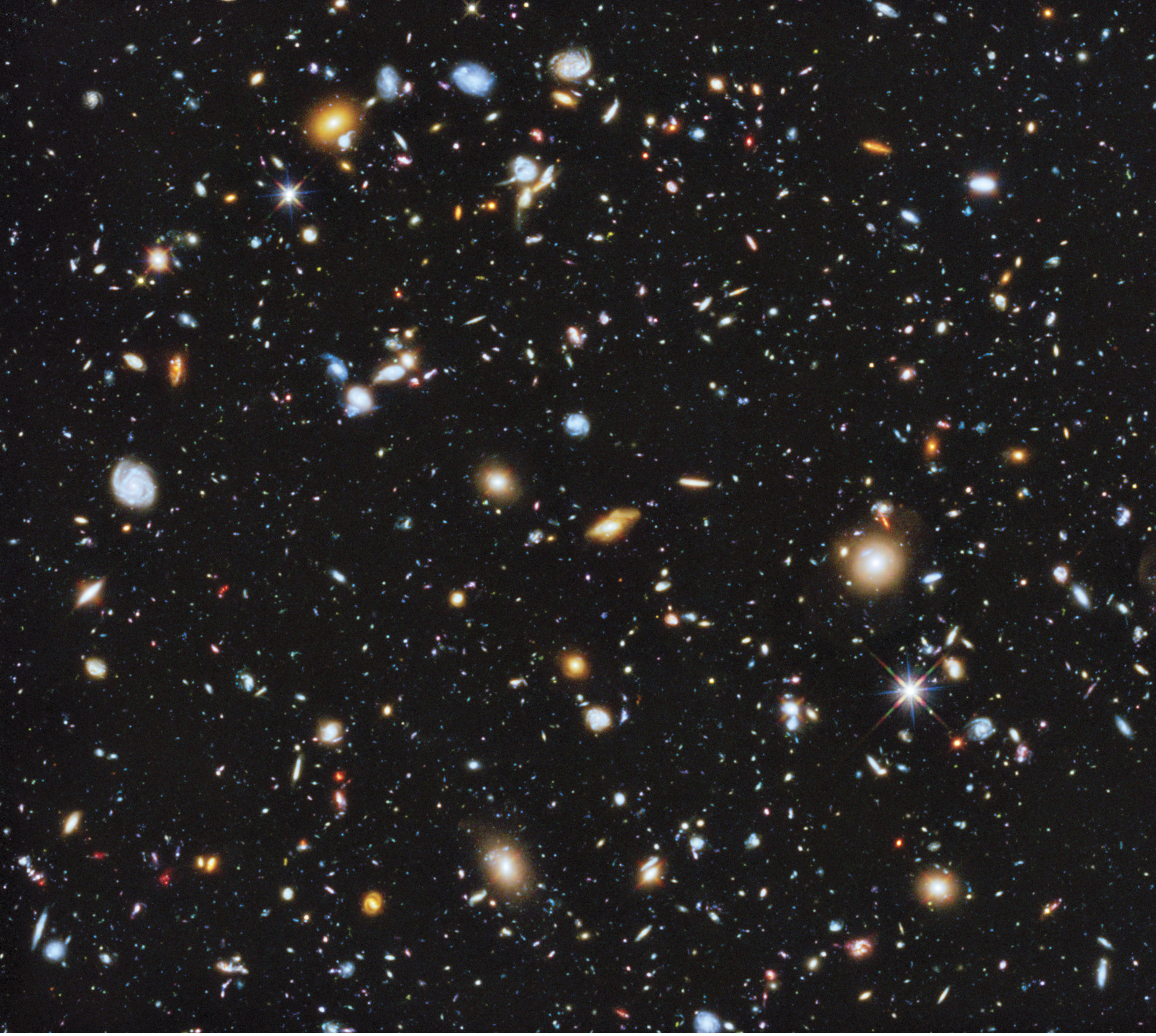
If such a mission does get approved and carried out, "we think even just a modest boost could get us into the 2040s, and maybe even into the 2050s," Crouse says. "I think it's a tradeoff that'll have to be identified between the risk and complexity of executing a mission like that, versus the expected lifetime of all the aging systems on Hubble, and if it makes sense to do that."

An Ongoing Role to Play

For users of the telescope, any extension of its life would be a very welcome possibility.

"Hubble's exquisite spatial resolution and ultraviolet-optical-near-infrared sensitivity have been critical in localizing and characterizing transient phenomena," says Suvi Gezari (Space Telescope Science Institute). Its ability to obtain ultraviolet spectroscopy of supernovae within days of their explosions is unparalleled, she explains, and it also gives astronomers key insight into the deaths of stars shredded by supermassive black holes.

NASA & ESA



▲ **GOING DEEP IN UV** This image of the Hubble Ultra Deep Field combines all the wavelengths HST can detect, from ultraviolet (bluer colors) to near-infrared. The UV wavelengths come from unobscured regions of star formation, enabling astronomers to spot not only galaxies that are actively making stars but also where in the galaxy stars are being born.

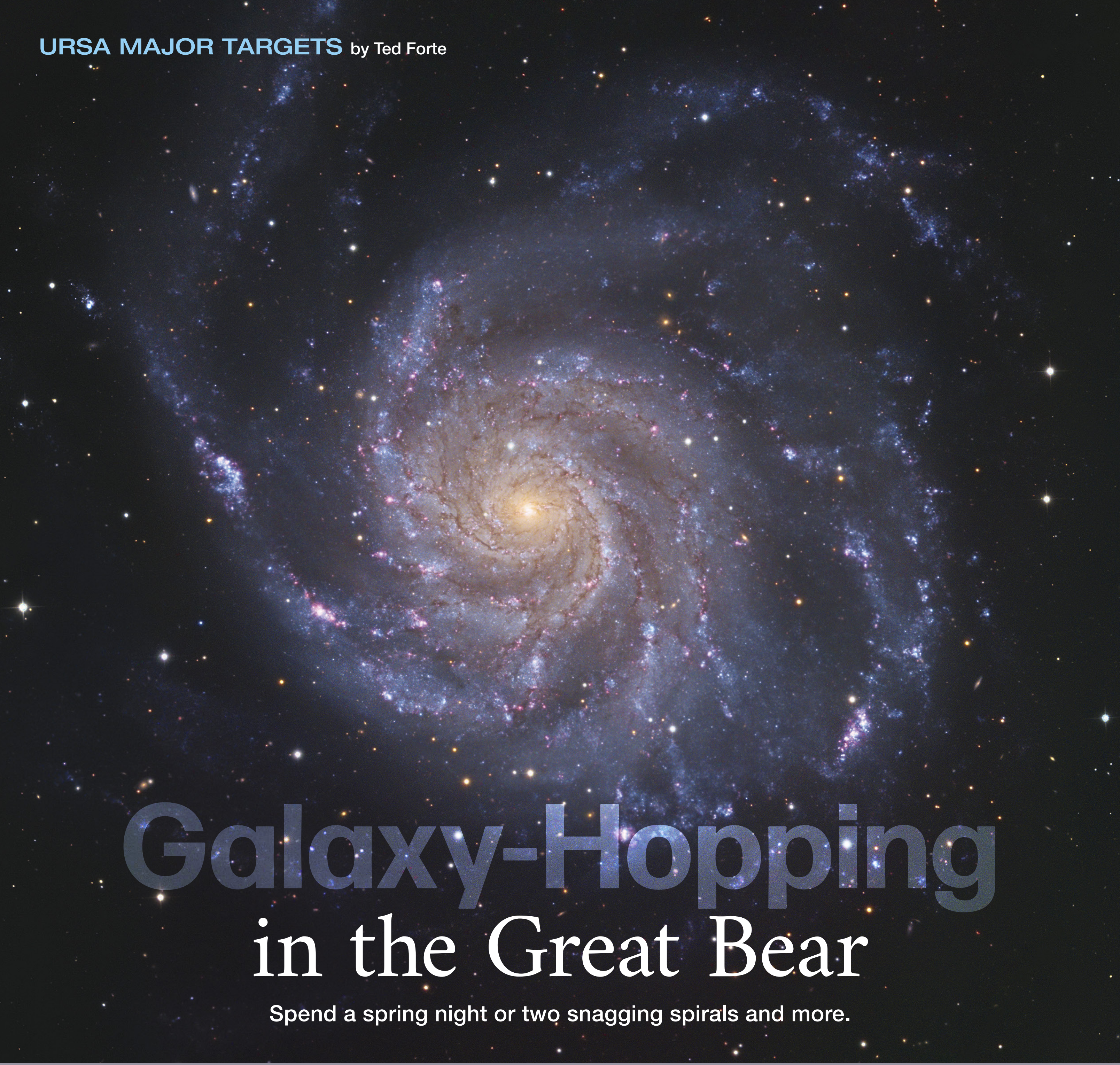
NASA / ESA / H. TEPLITZ & M. RAFELSKI (IPAC / CALTECH) / A. KOEKEMOER (STSCI) / R. WINDHORST (ARIZONA STATE UNIVERSITY) / Z. LEVAY (STSCI)

Recently, Hubble has shed light on distant explosions by detecting supernova images bent and magnified by the gravity of intervening matter. These images have enabled astronomers to see details of a supernova's evolution that would be otherwise inaccessible, because the lensing produced multiple images of the same event but at different stages of the explosion process.

Another decade of operations would give astronomers a chance to explore new kinds of research, including the rapidly growing field of time-domain astronomy, she says. Hubble might be aging, but it's still an agile instrument when it comes to innovation. "Who said an old dog can't learn new tricks?"

We live in a unique era in which we can study the universe using two fantastic observatories, both Hubble and Webb, Espinoza says. "What a time to be alive!"

■ **DAVID L. CHANDLER** is a science writer who has written for *Nature*, *New Scientist*, *The Atlantic*, *Wired*, and many other publications. He is the author of *Life on Mars* (Dutton, 1979).



Galaxy-Hopping in the Great Bear

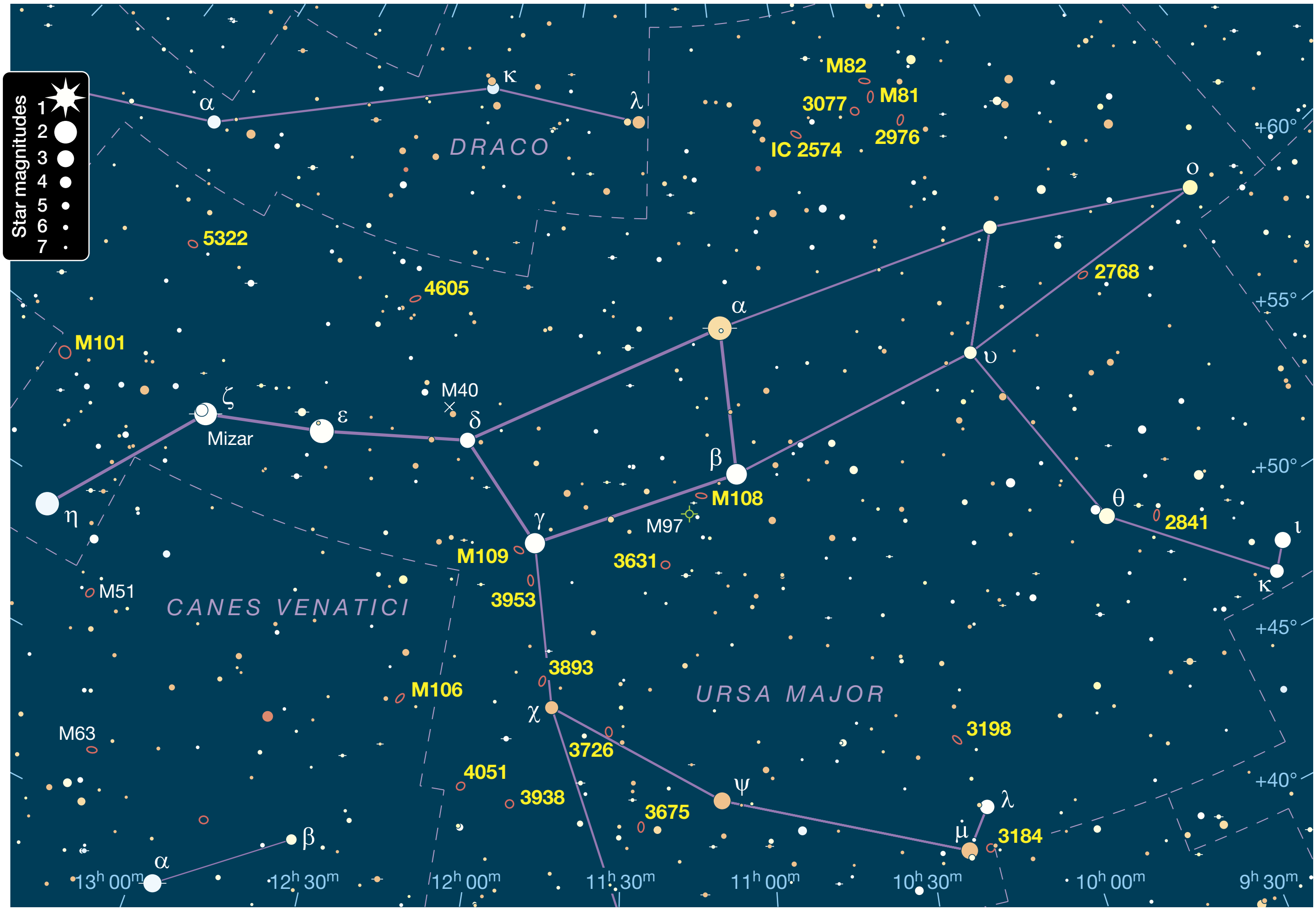
Spend a spring night or two snagging spirals and more.

Ursa Major is a bountiful hunting ground for deep-sky observers. More than 100 galaxies brighter than 13th magnitude lurk within its boundaries. Many of them are within reach of an 8-inch telescope. Several of the brightest galaxies are members of the Ursa Major Cluster — a rather ill-defined group of at least 79, mostly late-type galaxies. The Ursa Major Cluster includes many spirals but lacks the central concentration we see in the Virgo and Fornax clusters, which is probably why it isn't broadly recognized by most observers. However, the region sports an abundance of beautiful galaxies, enough to rival any area of the sky.

Galaxy-hopping is one of my favorite pastimes (see, e.g., *S&T:* May 2020, p. 22; *S&T:* Mar. 2022, p. 22; *S&T:* Apr. 2023, p. 20). I've observed nearly 500 galaxies in Ursa Major alone. I am fortunate to live in an astronomy-friendly area in southeastern Arizona, where I enjoy Bortle 4 skies and a

▲ **MARVELOUS MESSIER** Ursa Major has its fair share of splendid Messier galaxies, of which M101 is a prime example. The image above was captured with a 24-inch f/8 telescope.

MAKIS PALAIOLOGOU / STEFAN BINNEWIES / JOSEF PÖPSEL / CAPELLA OBSERVATORY



▲ **HOP ALONG IN THE BIG BEAR** Spring evenings are a great time to view Ursa Major, high in the evening sky, replete with a selection of galaxies you can hop your way through.

backyard observatory that houses a 30-inch f/4.5 computer-controlled StarSplitter Dobsonian. Even so, my favorite telescope remains my 18-inch f/4.5 Obsession Dob, and I observed most of the galaxies we'll visit on this tour with that instrument. However, I've limited the objects I cover to those that can be reliably detected in a 10-inch scope under good skies at about 120×, with one exception (IC 2574).

On the Western Side

As darkness falls on March evenings, the Great Bear stands on its mythological tail and stretches high into the northeastern sky. Omicron (ο) Ursae Majoris, or Muscida, represents the Bear's muzzle and marks the western end of the constellation figure. Our first target for this tour, **NGC 2768**, lies 5.1° east of 3.4-magnitude Muscida and halfway on a line extending to 3.8-magnitude Upsilon (υ) Ursae Majoris.

NGC 2768 is a 9.9-magnitude elliptical galaxy that, in my 18-inch at 197×, appears as a bright oval elongated east-west, with an almost stellar nucleus. Based on the galaxy's kinematics, astronomers propose that its interesting structure — a knotty ring of dust surrounding the center of the galaxy — hints at a past merger event, and that it likely harbors a pair of supermassive black holes as well as an embedded spiral disk. That monster duo may account for SN 2000ds — a Type Ib supernova detected in NGC 2768's outer halo. Not only are core-collapse supernovae quite rare in early-type galaxies such as NGC 2768, but the supernova's location so far from the nucleus is also unusual: After a too-close passage, the binary black hole likely expelled the progenitor star.

Moving 9.2° southward from NGC 2768 toward the Bear's front paws, we jump to **NGC 2841**, a 9.2-magnitude spiral galaxy located 1.8° west-southwest of Theta (θ) Ursae Majoris. I easily saw this galaxy in my 4-inch refractor at 100×, while my 10-inch Dob showed a bright core, elongated southeast-northwest with an 11th-magnitude star that sits just beyond its extended halo to the northwest. I noted that the eastern side of the halo is noticeably brighter than the western side.

Let's swing back to the northern reaches of the constellation to visit a few conspicuous members of the M81 Group, a clustering of some 35 galaxies. **M81** (also known as Bode's Galaxy) is not only the brightest galaxy in the

▲ **MAJESTIC DUO** The striking pair of M81 and M82 anchor an attractive quintet of galaxies in the northern reaches of Ursa Major. Besides several Messier targets, the constellation also offers a great variety of more challenging galaxies at which you can point your telescope. You might be able to fit some in the same field of view (as with M81, M82, and NGC 3077 shown above), while for others you'll need to do a bit of star-hopping. This image was acquired with a 4-inch telescope.

FRANZ KLAUSER / MANFRED WASSHUBER / CCD GUIDE

group, but it's also the brightest in the constellation. The elegant spiral forms one of the best-known galaxy pairs in the heavens with its neighbor, **M82** (fondly called the Cigar Galaxy). Separated by just 37′, the duo makes a remarkable sight in a wide-field eyepiece and is obvious in binoculars. While M81 is large and bright at magnitude 6.9, I find its fainter 8.4-magnitude companion to be far more interesting. A starburst galaxy, M82 is particularly prone to supernovae — several have been observed since 2004 alone, and radio observations have revealed a further number of supernova remnants. You'll easily spot the pair a bit more than 10° northwest of 2nd-magnitude Alpha (α) Ursae Majoris, familiarly known as Dubhe.

German astronomer Johann Elert Bode discovered both objects on December 31, 1774. Pierre Méchain, Charles Messier's younger colleague, independently discovered the pair in August 1779. William Herschel observed them on several occasions, and during one session an error in position led his astronomer sister, Caroline Herschel, to confuse M81 with M82. This may have influenced John Herschel, William's son, for he listed M82 as a new object in his catalog that he published in 1847 based on observations from his observatory at the Cape of Good Hope. John Louis Emil Dreyer finally righted this confusion when he published the *New General Catalogue of Nebulae and Clusters of Stars* in 1888, in which he assigned each object its current NGC designation.

NGC 3077 fits in the same low-power field of view as M81. Astronomers sometimes refer to this 10th-magnitude irregular galaxy as the Garland, a name that perhaps more properly applies to a string of knots that extends toward the southeast from the southern edge of the galaxy. These structures comprise groups of blue stars that were probably drawn out of NGC 3077 during an interaction with M81 and are only detectable in large-scale photographs. In the eyepiece, NGC 3077 appears as a large irregular oval with a conspicuous core, which itself brightens to a small, obvious nucleus. There's no sign of the namesake garland of stellar knots even in my 30-inch Dob.

From M81, scan 1.4° southwest to arrive at another 10th-magnitude galaxy, **NGC 2976**. It's an irregular dwarf spiral that has no central condensation or apparent core. In my 18-inch at 197× it has a very mottled appearance, and I can see at least three brighter patches presumably marking star-forming regions. A study published in 2010 of the star-formation history of NGC 2976 using the Hubble Space Telescope determined that active star formation is shutting down in the outer halo — likely due to an interaction with the core of the M81 group about a billion years ago that stripped away the gas from NGC 2976's outer reaches.

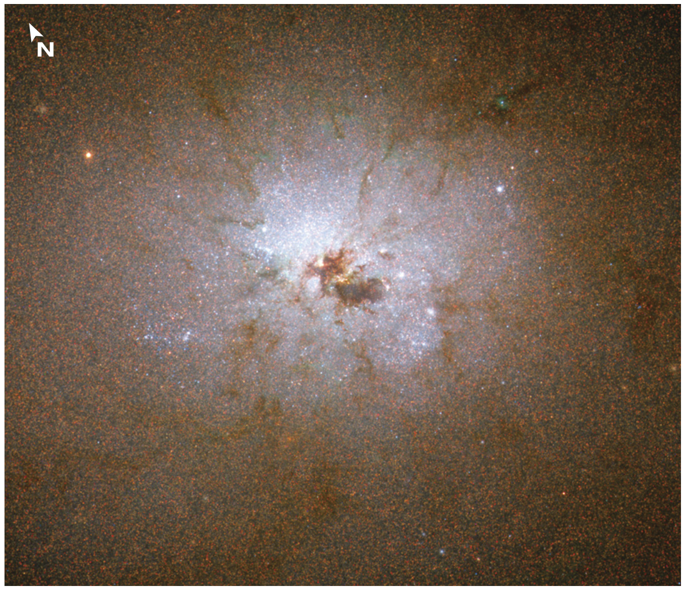
And now we come to our final target of this northerly quintet and the most challenging of the lot. American astronomer Edwin Coddington discovered **IC 2574** on a photographic plate captured at Lick Observatory in April 1898, and in fact today the galaxy is known popularly as Coddington's Nebula. This 10.4-magnitude dwarf spiral is an elongated oval with low surface brightness located 3° east of M81. I find lower magnification works best on this object; for a 10-inch scope, about 25× should be optimum. Amateur astrophotographer Stephen Leshin's remarkable image of IC 2574 on page 23 clearly shows several bright star-forming regions in the northeastern end of the galaxy. The brightest of these stellar nurseries appears as a nebulous knot among a group of several stars in my 18-inch at 200×. The galaxy is otherwise uniform in brightness with no central condensation.

Now let's swing back south to the Bear's hind paws. Looking 0.8° west of 3rd-magnitude Mu (μ) Ursae Majoris we find **NGC 3184**. I first turned my 18-inch Dob to this lovely open-faced spiral in December 1999 while seeking the Type II supernova SN 1999gi, discovered earlier that month. In that scope, at first glance the 9.8-magnitude galaxy appears large, round, and of low surface brightness, sporting a rather tiny core and a 12th-magnitude star on its northern edge. With longer study, however, two faint spiral arms become detectable. Revisiting this galaxy with the 30-inch at 300×, the arms display several branches and a mottled appearance. Two knots within NGC 3184 have earned their own NGC designations: NGC 3180 and NGC 3181. The *Morphological Catalogue of Galaxies* misidentifies the galaxy as NGC 3180.

NGC 3198 lies 4° north of NGC 3184 and about 2½° north of 3.5-magnitude Lambda (λ) Ursae Majoris. This 10.3-magnitude, nearly edge-on barred spiral presents a blotchy, elongated core and a barely discernible nucleus in my 18-inch at 138×. A 12th-magnitude star is perched about 4′ north of the core. William Parsons, the Third Earl of Rosse, described several "remarkable Nebulae" in a seminal paper he published in 1850, in which he reported on the "spiral or curvilinear" features of 14 objects, including NGC 3198. The nature of nebulae was the subject of significant debate in the late 19th and early 20th centuries, and Lord Rosse's observations of M51, the Whirlpool Galaxy, provided the first evidence of spiral structure — in fact, his 1845 sketch of M51 is iconic.

Below the Bear's Hindquarters

Shifting to targets below the Big Dipper's bowl, we'll start near Ursa's hind legs with 10.2-magnitude **NGC 3675**, which is about 3° east-southeast of 3rd-magnitude Psi (ψ) Ursae Majoris. In my 18-inch at 197× I note this elongated spiral is of uneven brightness — the mottled eastern side has a dark dust lane that sharply cuts off the elongated core. The core is bright but without a central condensation, and a 13th-magnitude star resides off the southwestern tip of the galaxy.



▲ **GALACTIC WRECKAGE** Right next to the glorious pair of M81 and M82 is NGC 3077, which — with the power of the Hubble Space Telescope — displays signs of past interactions between its two behemoth neighbors as in the image above.

NASA / ESA / J. DALCANTON AND B. WILLIAMS (UNIVERSITY OF WASHINGTON)

Scanning 3.7° north-northeast of NGC 3675 and 2.2° west-southwest of Chi (χ) Ursae Majoris, we come to **NGC 3726**. The 10.4-magnitude, nearly open-faced spiral presents a dappled oval with a small, obvious nucleus, and a 12th-magnitude star lies off its northern end. In my 30-inch Dob, I noted the hint of a spiral arm wrapping around the southern edge of the galaxy toward the east, but that structure isn't apparent in smaller apertures.

Slewing some 6.4° north-northwest of NGC 3726 we find **NGC 3631**. It's about 2° south of the bottom of the Big Dipper's bowl and nearly equidistant from the bowl stars Gamma (γ) and Beta (β) Ursae Majoris (Phecda and Merak, respectively). The 10th-magnitude open-faced spiral is rather remarkable in larger apertures, displaying at least two arms outlined by several bright knots. I see only the faintest hint of its spiral structure in the 10-inch, but it comes alive in the 18-inch; with the 30-inch, I note that the primary arms branch into multiple smaller arms.

M108 is 2.8° north-northwest of NGC 3631 — you can also look for it 1.5° east-southeast of Merak. At magnitude 10.0, it's a bright, elongated cigar-shaped glow with a stellar nucleus that appears speckled and dusty with several superimposed stars. I've detected M108 in a 60-mm refractor at 35×, but it's only just discernible at that aperture. My 10-inch Dob at 120× reveals an irregular central area flanked by brighter nodules. Pierre Méchain discovered M108 and five other objects that were added to the Messier catalog as M104 through M109 long after Messier's death. Messier had apparently measured an accurate position for M108 — along with M109, these entries appear in a handwritten annotation to Messier's own copy of his catalog, but he never published them.

▲ **DELIGHTFUL FACE-ON SPIRAL** Use 3rd-magnitude Mu Ursae Majoris (at left) to navigate less than 1° westward to land on NGC 3184. The H II knots discussed in the text, cataloged as NGC 3180 and NGC 3181, are northwest and southwest of the nucleus of the galaxy, respectively.

BERNHARD HUBL

To get to **M109**, look 38′ east-southeast of Phecda. In my 10-inch Dob, 9.8-magnitude M109 appears a bit smaller and fainter than M108. Using a photo (similar to the one on page 24) as an aid, I was able to pick out its spiral structure using my 18-inch at 197×. I also note that the galaxy has faint spiral extensions emanating from a short, stubby bar, and two 14th-magnitude stars are superimposed on its halo.

NGC 3953 lies 1.3° south of Phecda and is part of the M109 Group, yet another clustering of galaxies in Ursa Major. Dutch amateur astronomer and astronomy historian Henk Bril argues that this galaxy, and not NGC 3992, is actually the object that Pierre Méchain discovered and that was later listed as M109. Bril bases this theory on the object's placement on a map prepared by the French instrument-maker Jean Nicolas Fortin for his 1795 reissue of John Flamsteed's *Atlas Coelestis*. He also suggests that Messier himself may have actually discovered NGC 3992 when he attempted to retrace Méchain's observation a dozen days later and arrived at a different object.

Whether it's the real M109 or not, NGC 3953 is a worthy target. In my 18-inch at 197×, the 10.1-magnitude galaxy presents a large, bright oval with a hint of spiral structure and a conspicuous, nearly stellar core.

Moving 3.7° south-southwest of NGC 3953 we come to **NGC 3893**. This remarkable 10.5-magnitude, face-on spiral is part of the M109 Group. It's large and round, and its spiral structure is quite apparent in my 30-inch and strongly suspected in the 18-inch. NGC 3893 forms a pair with a much smaller companion, 13.6-magnitude NGC 3896. Astronomers consider the pair to be an interacting system similar to M51 and NGC 5195. Based on simulations, research published in 2014 suggests that a single, close passage by the smaller gal-

STEPHEN LESHIN

▲ **CODDINGTON'S NEBULA** Dwarf, irregular galaxies such as IC 2574 also display signs of star-forming activity, which are traced in pink in the image above. NASA's Astronomy Picture of the Day featured this photo on its webpage in June 2012.

axy is actually responsible for NGC 3893 evolving its "grand design spiral" in as little as a billion years.

Another grand-design spiral, **NGC 3938**, lies 4.7° southward of NGC 3893. The 10.4-magnitude galaxy's spiral structure doesn't show at all in my smaller scopes, but it's just hinted at in my 30-inch, where it appears round, bright, and a bit mottled, with only a slightly brighter core and a stellar nucleus. As with most celestial objects, distance estimates can vary wildly. In fact, many references give a distance of about 43 million light-years for NGC 3938, but more recent measurements using newer techniques derive an estimate of about 73 million light-years.

NGC 4051 is one of the six galaxies that Carl Seyfert studied and reported in his seminal 1943 paper, "Nuclear Emission in Spiral Nebulae." Seyfert galaxies are similar to quasars in that they have active cores, but unlike quasars the hosts are visible. Today, at least 10% of galaxies are classified as Seyfert galaxies. You'll find NGC 4051 by slewing 1.9° east-northeast of NGC 3938. In my larger scopes, I see this 10.2-magnitude galaxy as a bright oval with a stellar core that displays some spiral structure. I also detect a prominent spiral arm to the south that curves northward on the galaxy's eastern side. My 10-inch Dob at 120× easily shows the galaxy, which displays a spotty texture toward its center.

Above the Tail

To conclude our Great Bear galaxy tour, let's next swing to the northern side of the Dipper's handle. **NGC 4605** is located 5.5° north-northeast of Delta (δ) Ursae Majoris (Megrez). This 10.3-magnitude, nearly edge-on barred spiral is rather interesting-looking, with a very clumpy texture that hints at its dust and knots. Having a high surface brightness, it's easy to hold NGC 4605 with direct vision in my 10-inch Dob.

Our next stop is **NGC 5322**, 8.5° east of NGC 4605 and about 4½° south-southwest of 3.7-magnitude Alpha Draconis. In my 30-inch at 229× I see the 10.2-magnitude elliptical galaxy as a bright, oval glow that's very much brighter in the middle. A star of 14th magnitude sits on its southern edge. NGC 5322 is also classified as a radio galaxy — astronomers have detected relativistic jets likely powered by a supermassive black hole in the galaxy's core.

◀ **HYDROGEN AND MORE** *Top:* NGC 3631, nestled below the Big Dipper's bowl, is brimming with H II regions — astronomers have identified more than 220 in this dainty, grand-design spiral. Astrophotographer Gary Imm used an 11-inch telescope to acquire this image and the one of NGC 3893 below.

◀ **CLUSTER ANCHOR** *Middle:* M109 is the brightest and largest in a group of galaxies that may hold as many as 50 members, if not more. The two 14th-magnitude stars described in the text are about 1′ north-northwest of the core and 5′ west of it.

◀ **BIG AND SMALL** *Bottom:* NGC 3893, a face-on spiral in the Great Bear's hind legs, is accompanied by smaller NGC 3896 to its southeast, classified as a barred spiral. A 14th-magnitude star adorns the larger galaxy's northwestern edge.

NGC 3631 AND NGC 3893: GARY IMM (2); M109: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

We'll end our tour with **M101**, which is a fitting finale indeed. M101 is perhaps the archetype of the grand-design spiral with its majestic, sweeping arms. Look for the 7.9-magnitude galaxy at the apex of a nearly 4.5°-tall equilateral triangle pointing northeast from a base defined by Zeta (ζ) Ursae Majoris, or Mizar, and Eta (η) Ursae Majoris, or Alkaid. M101 can be difficult to snag in light-polluted skies due to its rather low surface brightness, but under good conditions a 4-inch telescope will readily show the bright core surrounded by a large, faint glow. An 8-inch telescope should reveal some definition in the spiral arms, which can be traced as a series of bright knots. Ten of these H II regions have individual NGC designations.

In August 2011, an automated survey detected a Type Ia supernova (SN 2011fe) in M101, which quickly brightened to almost 10th magnitude. The supernova was the highlight of star parties for most of September that year, including for me. I first observed it through a friend's 25-inch Dob in Coinjock, North Carolina, on September 3rd. Later that month, I shared views of it at a couple of public outreach events at Northwest River Park in Chesapeake, Virginia, through my 18-inch. My final look came on the 29th at the No Frills Star Party at Tuckahoe State Park on Maryland's Eastern Shore. By then it was low in the west at the end of twilight, making for a suitable farewell.

It's galvanizing to consider that, besides IC 2574, all of the objects we've visited were discovered visually. Even more rousing is the fact that William Herschel discovered 15 of the 21 objects discussed. For me, following in the footsteps of Herschel and the other great observers of the past is what spurs me on to seek out these faint fuzzies. Perhaps you find the same sort of inspiration. Whatever motivates you to observe, I hope this tour provides you a bit more of it.

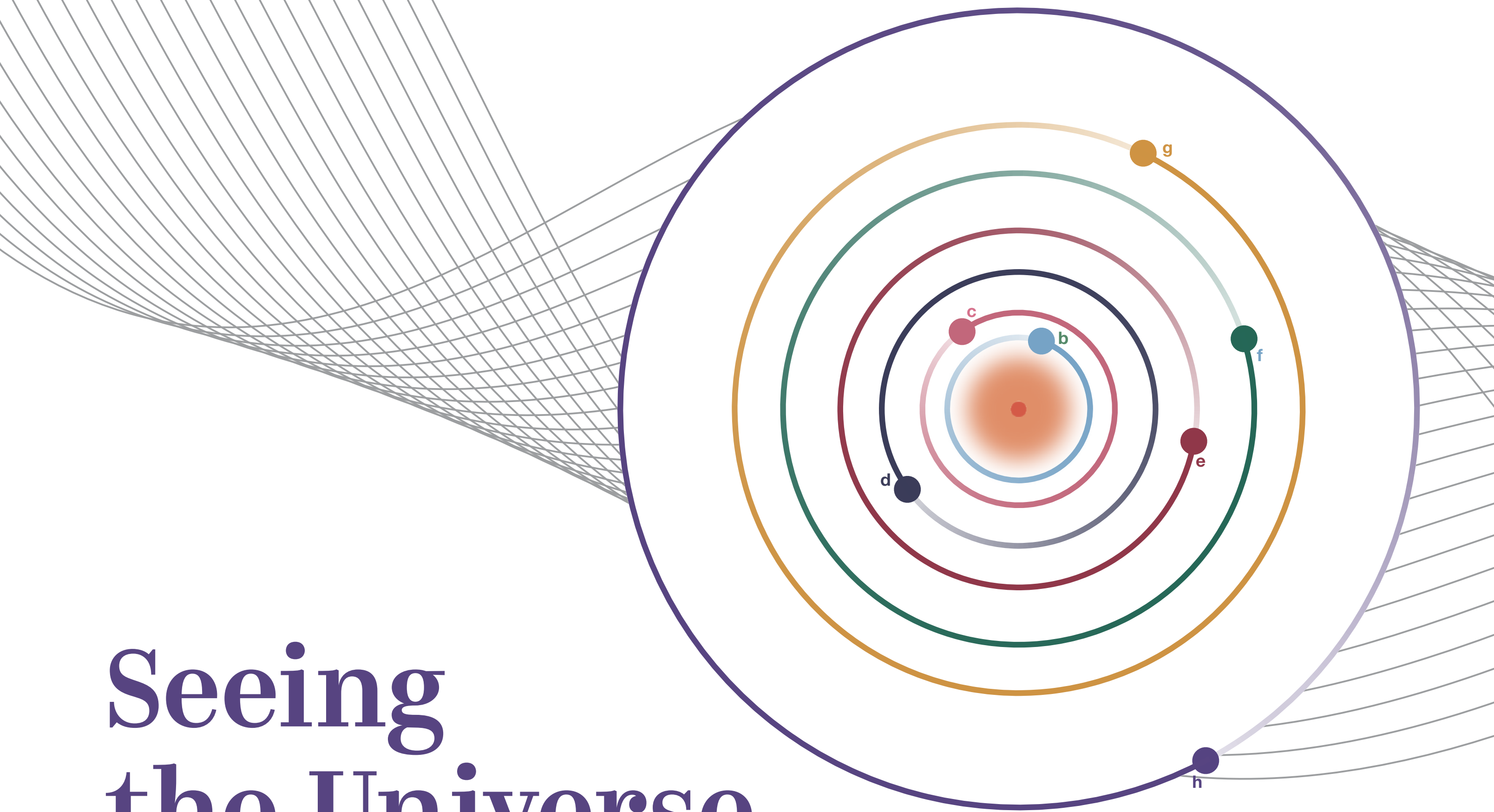
■ Contributing Editor **TED FORTE** enjoys observing the deep sky from his home observatory near Sierra Vista, Arizona.

FURTHER READING: If you want to learn more about the history of the discoveries — and misidentifications — of the targets discussed here, head to Steve Gottlieb's and Harold Corwin's websites, **https://is.gd/astronomy_mall** and **haroldcorwin.net/ngcic**, respectively.

Great Bear Galaxies

Object	Alternate ID	Type	Surface Brightness	Mag(v)	Size/Sep	RA	Dec.
NGC 2768		Elliptical	13.1	9.9	6.4′ × 3.0′	$09^h\ 11.6^m$	+60° 02′
NGC 2841		Spiral	12.7	9.2	8.1′ × 3.5′	$09^h\ 22.0^m$	+50° 59′
M81	NGC 3031	Spiral	13.2	6.9	26.9′ × 14.1′	$09^h\ 55.6^m$	+69° 04′
M82	NGC 3034	Irregular	12.5	8.4	11.2′ × 4.3′	$09^h\ 55.9^m$	+69° 41′
NGC 3077	The Garland	Irregular	13.2	9.8	5.4′ × 4.5′	$10^h\ 03.4^m$	+68 44′
NGC 2976		Spiral	13.0	10.2	5.9′ × 2.7′	$09^h\ 47.3^m$	+67° 55′
IC 2574	Coddington's Nebula	Dwarf spiral	14.8	10.4	13.2′ × 5.4′	$10^h\ 28.4^m$	+68° 25′
NGC 3184		Spiral	13.9	9.8	7.4′ × 6.9′	$10^h\ 18.3^m$	+41° 25′
NGC 3198		Barred spiral	13.8	10.3	8.5′ × 3.3′	$10^h\ 19.9^m$	+45° 33′
NGC 3675		Spiral	13.2	10.2	5.9′ × 3.1′	$11^h\ 26.1^m$	+43° 35′
NGC 3726		Spiral	13.8	10.4	6.2′ × 4.3′	$11^h\ 33.4^m$	+47° 02′
NGC 3631	Arp 27	Spiral	13.4	10.4	5.0′ × 3.7′	$11^h\ 21.0^m$	+53° 10′
M108	NGC 3556	Barred spiral	13.1	10.0	8.7′ × 2.2′	$11^h\ 11.5^m$	+55° 40′
M109	NGC 3992	Barred spiral	13.5	9.8	7.6′ × 4.6′	$11^h\ 57.6^m$	+53° 22′
NGC 3953		Barred spiral	13.4	10.1	6.9′ × 3.5′	$11^h\ 53.8^m$	+52° 19′
NGC 3893		Spiral	13.1	10.5	4.5′ × 2.8′	$11^h\ 48.6^m$	+48° 43′
NGC 3938		Spiral	13.8	10.4	5.4′ × 4.9′	$11^h\ 52.8^m$	+44° 07′
NGC 4051		Spiral	13.3	10.2	5.2′ × 3.9′	$12^h\ 03.2^m$	+44° 32′
NGC 4605		Barred spiral	12.9	10.3	5.8′ × 2.2′	$12^h\ 40.0^m$	+61° 37′
NGC 5322		Elliptical	13.6	10.2	5.9′ × 3.9′	$13^h\ 49.3^m$	+60° 11′
M101	NGC 5457	Spiral	14.9	7.9	28.8′ × 26.9′	$14^h\ 03.2^m$	+54° 21′

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.



Seeing the Universe Without Sight

Creative minds are finding ways to explore and share the wonders of the cosmos without visual aids.

Look up at the night sky and then close your eyes. The twinkling stars and distant worlds disappear.

Now imagine you hear a repeating piano note. Rhythmic and regular, it tolls like a bell.

A new note interrupts the drone, adding itself to the noise. Higher in pitch, it comes in at a slightly faster tempo. A few beats later more notes chime in, each higher in pitch and speed. Finally, the last note arrives as staccato pings, beeping like a metal detector over hidden treasure.

The instruments making this cacophony are the Trappist-1 exoplanets, a system of seven alien planets orbiting a red dwarf star 40 light-years away from us.

Scientists created the beeps and boops of Trappist-1 through *data sonification*, a process that mathematically translates data into sound. They used the exoplanets' orbital periods to choose each pitch: They assigned the longest orbit to a low note — specifically C3, one octave below middle C — and then scaled the other orbits to higher pitches based on their frequency relationship with one another.

The resulting sonification is more than an engaging educational tool. It's a door that opens up the whole universe like never before.

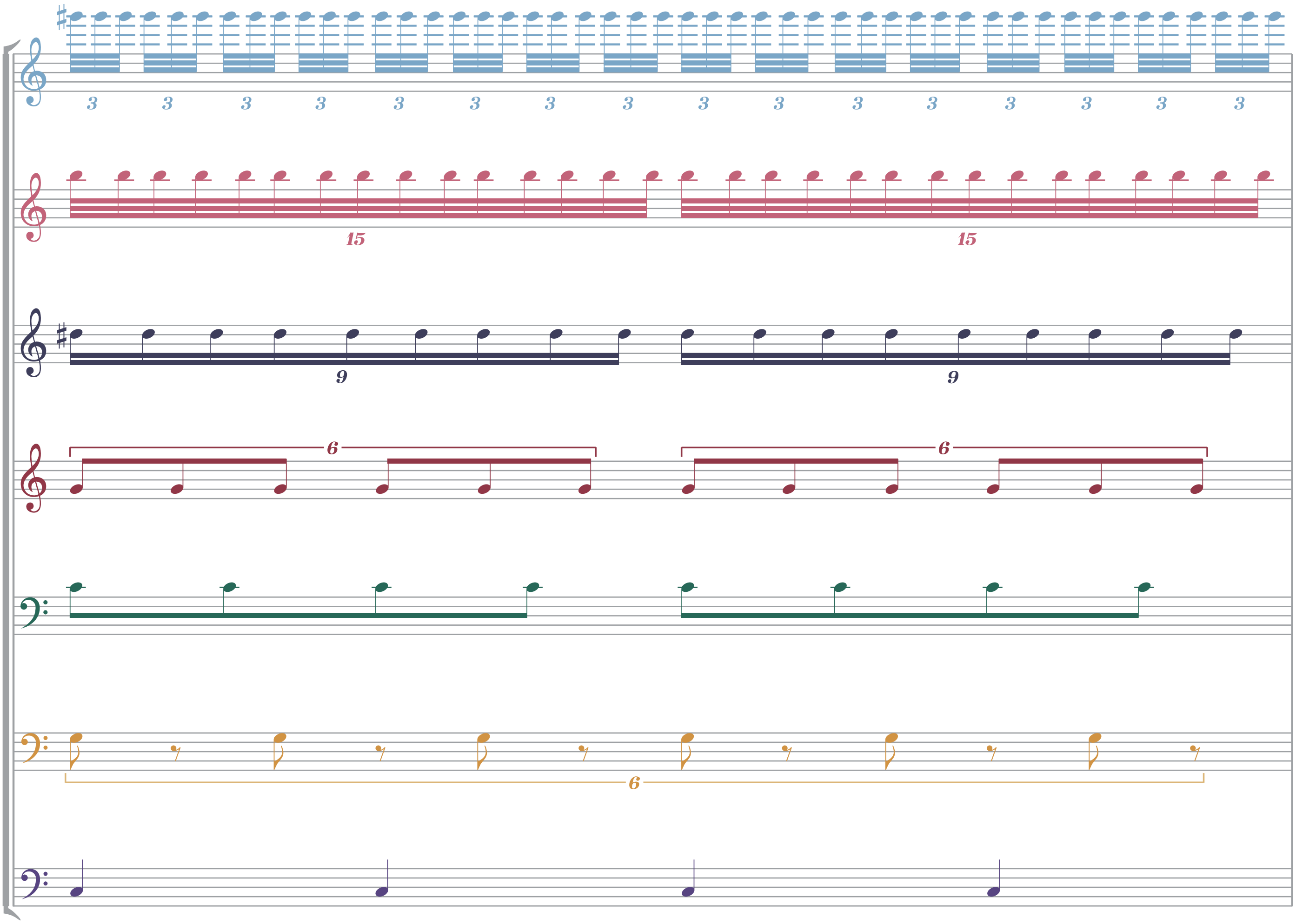
Astronomy as we know it has been built upon a visual language. From scientific charts and complicated graphs to planetarium shows and 20-million-pixel images, the mainstream way to do astronomy is with our eyes.

But for audiences who are blind or have low vision, expressing the beauty of the cosmos in this way renders it inaccessible.

Although humans began astronomy by looking at the heavens, our experience of the universe doesn't necessarily have to be communicated in visual ways. And since much of the light in the universe is beyond what humans can see, astronomers are already cosmic translators when they present what they've detected. Every day, they methodically combine telescope observations from across the spectrum, from radio waves to X-rays, to visualize the universe.

A growing number of astronomers, educators, and advocates are working to expand those translation efforts to new

ORBITS: BEATRIZ INGLESSIS / S&T, TRAPPIST-1 MUSIC: MATT RUSSO & ANDREW SANTAGUIDA; ABSTRACT WAVE BACKGROUND: VECTORSTUFF / SHUTTERSTOCK.COM



◀▲ **TRAPPIST-1** The seven worlds in the Trappist-1 system are locked in a resonant chain, with each planet's orbital period making simple ratios with those of its neighbors. This pattern can be translated into sound *(above)*. Shifting the periods to frequencies that are in the human hearing range assigns each planet a pitch, and the resonances among the periods determine the rhythmic subdivisions — for example, there are three notes of Trappist-1g for every two of Trappist-1h. (Here, each planet's notes have been shifted from the audio version so that the patterns start at the beginning of a bar.)

Listen to the Trappist-1 system and learn more about the physics and music theory behind the sonification: https://is.gd/trappist1_music.

languages, making the wonders of the cosmos accessible by using sound and tactile, 3D models. These efforts are of interest to general audiences, but they go beyond outreach: Scientists themselves are using these tools in their own work, finding novel ways to interact with data that may bring insights unreachable through visual means.

The Sound of Space

The creators of the Trappist-1 symphony didn't set out to make sonifications.

Matt Russo, an astrophysicist and musician, and Andrew Santaguida, a musician, have been friends since high school and played in a band together for 15 years. Shortly after Russo completed his PhD, astronomers discovered the seven rocky planets of the Trappist-1 system (*S&T:* June 2017, p. 12).

The planets orbit so close together that they gravitationally tug on one another as they pass by their neighbors, causing their orbits to be locked in a pattern, or *resonance*. The resonance is what inspired Russo and Santaguida to turn the information into sound.

"We didn't even know really what sonification was at that time," says Santaguida. "Matt just saw that the resonances of the planets made music."

In 2020, visualization scientist and science communicator Kimberly Arcand (Center for Astrophysics, Harvard & Smithsonian) reached out to Russo and Santaguida after meeting them at a conference. "We started a project on Chandra sonifications that really tried to bring all that high-energy,

PERSEUS SONG This composite image reveals the X-ray glow of the superheated gas that suffuses the Perseus Cluster, a collection of thousands of galaxies. Bluer colors are more energetic X-rays. The dark blue filaments in the center are likely due to a galaxy that has been torn apart and is falling into NGC 1275, the giant galaxy that lies at the center of the cluster.

X-ray information to life in a different way through sound, through that mathematical mapping," says Arcand.

One particular X-ray energy source, a supermassive black hole at the center of the galaxy NGC 1275, stuck out to Arcand because it "sings." At a frequency about 57 octaves below middle C, the cosmic diva releases waves of energy that travel through the hot gas of the surrounding Perseus Cluster as pressure waves, much as sound waves move through air.

Even if the black hole sang its note for us here on Earth, it would be too low for our ears to hear. Through sonification, Arcand transposed the sound into an eerie hum. Accompanying an image of the black hole, the sonification tracks the X-ray data like a radar scanner, with a line sweeping clockwise around the image.

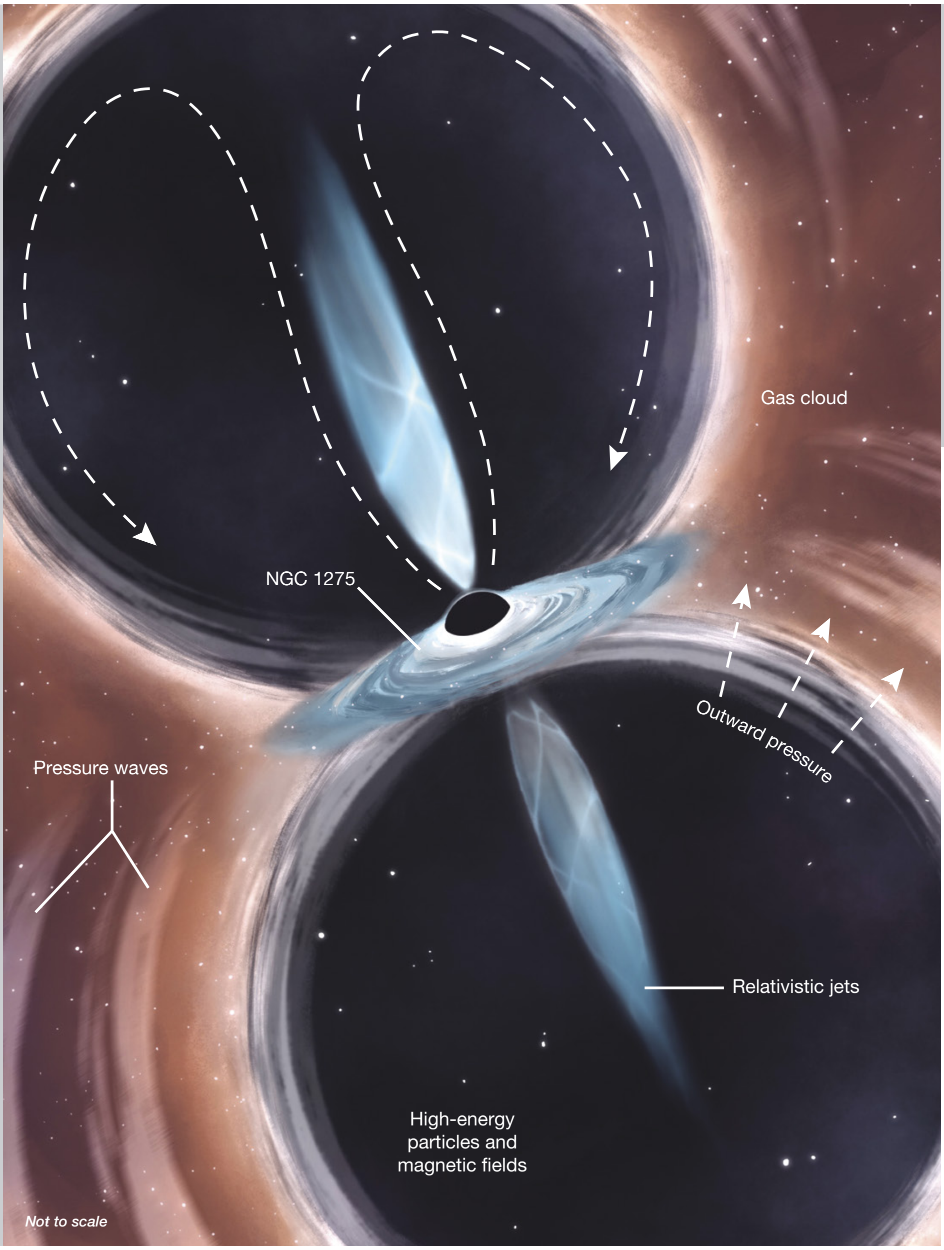
On August 21, 2022, a NASA Twitter account posted Arcand's sonification. The tweet quickly went viral, garnering thousands of likes and international news coverage.

"I felt like I was on a merry-go-round," says Arcand, who was "totally gobsmacked" by the attention.

Wanda Díaz-Merced (AstroParticle and Cosmology Laboratory, France), an astronomer who is blind and uses sonification in her research, describes Arcand's work as groundbreaking. Before Arcand, she says, no one was integrating multiple sensory methods at the same time for public outreach in astronomy. "She is a pipeline that brings more people to the field."

Conducting a Gravitational-wave Orchestra

Sonifications are not new to astronomy research, Díaz-Merced says. Karl Jansky was investigating sources of radio noise at Bell Labs in 1931 when he discovered interference coming



DIVA IN ACTION An artist's concept illustrates how the jet-firing black hole deep within NGC 1275 creates pressure waves that ring through the cluster's gas. These waves' frequency would need to be more than one thousand trillion times higher in order to be audible to the human ear.

Listen to the sound waves in the Perseus Cluster: https://is.gd/perseus_soundwaves.

from the direction of the constellation Sagittarius, where the center of the Milky Way lies. Other astronomers later confirmed that radio waves emanate from there. By listening to radio signals, Jansky started the field of radio astronomy.

Today, sonifications are picking up momentum. In April 2023, the United Nations Office for Outer Space Affairs released a special report highlighting the important role sonification can play in both outreach and research. Human hearing covers a broader frequency range than sight does, for example, and it's better for identifying quick changes or patterns in time than vision is. It's also easier to pick events out of background noise using sound, like homing in on someone's voice in a crowded room.

For Díaz-Merced, one of the report's contributors, the universe is teeming with sound. In her work, she turns data from Europe's Virgo gravitational-wave detector into sonifications.

"It's very hard for me to describe, because it's actually like going into the forest," she says. "You listen to all the wonders in the forest, and you know how magnificent it is, you know all the information is given to you. But if you're going to describe it . . . there are no words to do it justice."

Although beautiful, these sonifications are less melodic than those used for public outreach. Díaz-Merced uses the sound of a timpani for her sonifications and slows down the million data points that make up a gravitational-wave signal in order to listen to each and every note. The result is somewhat akin to an erratic telephone ringtone or a randomized musical scale. Higher pitches are underscored by slower, deeper notes, varying in speed and volume.

The sounds convey the many characteristics of the collected data, including the frequency and amplitude of a signal. Díaz-Merced listens for significant changes in the sounds, such as shifts in pitch or speed, and dives into these moments searching for waves that are stretching and squeezing spacetime as they pass the Virgo detector.

For now, Díaz-Merced says she is "calibrating" her ear to detect known gravitational-wave events in the noisy data from Virgo, in order to validate and support new detections down the line.

"What makes [the data] beautiful is that it's like trying to find a grain of gold in a whole pile of sand — a Mount Everest of sand," says Díaz-Merced. "It takes time, it takes dedication, it takes patience."

But this is not a problem for Díaz-Merced; it's simply a tool for her to do her research, just like any other astronomer

ADARA KOIVULA

uses. When she started listening to sonifications in 2003, they "opened a big realm of hope" and "a sense of possibility" for her, giving her the ability to perform data analysis as a sighted person does.

Astronomy sonification also provided hope to Garry Foran, who recently completed his second PhD at Swinburne University of Technology in Melbourne, Australia. Foran, however, is not your typical academic.

Before studying astronomy, Foran worked in the field of X-ray physics and synchrotron radiation. He traveled the world visiting particle accelerators and doing spectroscopy research, all while living with a degenerative eye disease.

Once his vision had deteriorated enough for it to no longer be useful, Foran was forced into early retirement.

"I looked around for what I really, really wanted to do without giving a whole lot of thought to whether it would be possible or not," he says.

Pursuing his lifetime fascination with astronomy, Foran reached out to the Centre for Astrophysics and Supercomputing at Swinburne. "It was clear to them right from the start, I wasn't the typical young person coming into a PhD in astrophysics. And of course, I said, 'Well, also, by the way, I'm blind,'" says Foran. "It wasn't clear to me at all if it was even going to be physically possible. I just had this dream."

After listening to a TED talk by Díaz-Merced, Foran reached out to her. She encouraged him to use sound as a tool in his research.

"Wanda was . . . the proof of concept that someone with low or poor vision could meaningfully and at a high level do research using sound to analyze and interpret data — and, in fact, use the advantages of sound over visual input to analyze data and to make discoveries," says Foran.

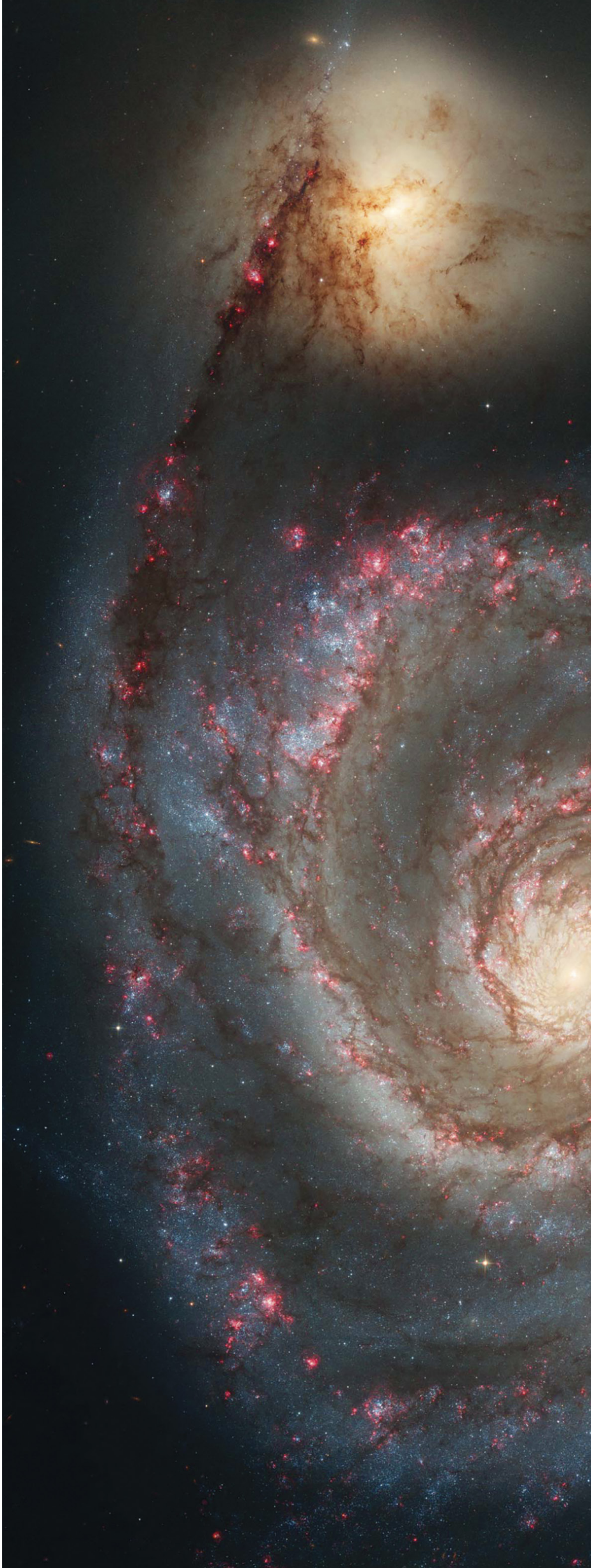
Foran studies the spectra of distant, star-forming galaxies. These spectra can show us the chemical makeup and internal motions of galaxies, and are typically plotted as a jagged line on a graph. Foran instead transposes the frequencies of light into frequencies of sound.

"I never really got a true feeling for what the spectra looked like" before working with sound, says Foran — even though he had been a spectroscopist for nearly 20 years. "All of these things that were really just words and segregated mental pictures in my mind coalesced into a spectrum the first time I heard it."

Foran listens for variations in tone that correspond to peaks and troughs in the spectra and for patterns of repeated or unusual features. These spectral details are clues to the composition and structure of the galaxies he studies.

Both Díaz-Merced and Foran point out that our ear's sensory abilities are faster than our eyes at detecting changes, a vital skill in data analysis.

"The reason why we have two ears, in addition to two eyes, is because sound adds to our sensory perception," says Foran. "If we add that same sensory perception to our interaction with data, there's no reason why we can't enhance discovery and complement the discovery process with sound."



◀▲ **PALM-SIZE GALAXY** To convey the magnificent, star-studded spiral arms of M51 and the compact glow of its companion, NGC 5195, outreach astronomers in the UK turned to raised-relief representations *(above)*. The bumps convey brightness.

Multi-sensory Astronomy

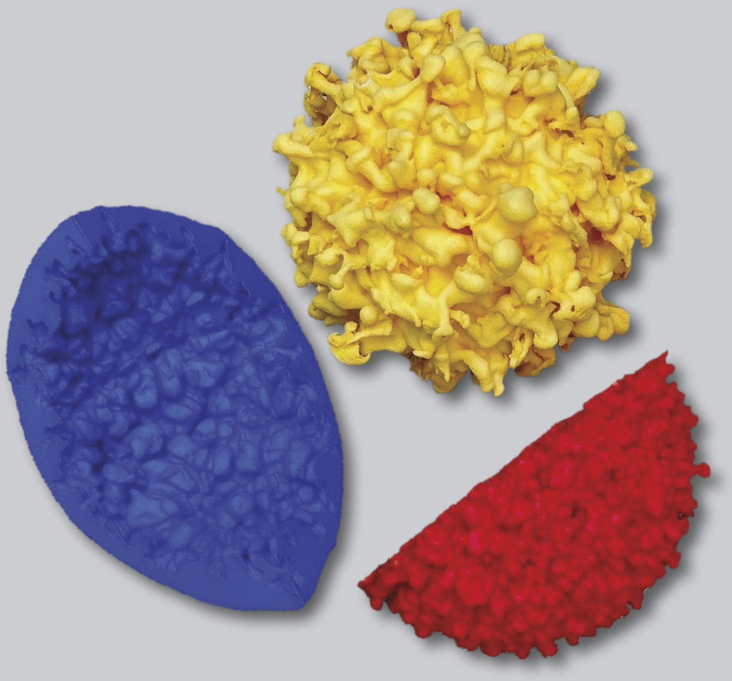
Astronomer Chris Harrison (Newcastle University, UK) also uses sonifications in his research, but he uses them in addition to visualizations. Like Foran, Harrison studies the spectra of galaxies. Astronomers normally represent spectra with plots and figures — an intuitive choice for those who can see a spectrum as a rainbow of wavelengths. As a sighted person, Harrison can look at these charts and analyze them visually, as he was trained to do during his entire career.

But after meeting with a colleague who has low vision, Harrison dove into creating his own sonifications. The first time he heard one, he was hooked.

"I loved it," says Harrison. Even though he knew what was in the datasets, experiencing them through sound was completely different. "I can hear the fact that that bit is moving away, and that bit is moving towards me. I can hear the wind in the center of this galaxy."

Sonifications have made it easier for him to parse impossibly large amounts of data, because his ears are more sensitive and don't tire as quickly as his eyes. They also draw him into the observations.

M51 IMAGE: NASA / ESA / S. BECKWITH (STSCI) / HUBBLE HERITAGE TEAM (STSCI / AURA); 3D PRINT: NICOLAS BONNE



▲**SUPERNOVA 1006** *Top:* This X-ray composite of 10 different Chandra observations shows the debris created when a white dwarf exploded as SN 1006. The optical image shows the surrounding star field. *Above:* To enable people to explore the remnant without using sight, a Chandra team created different 3D models. One presents the whole, knobbly remnant (yellow), while the other comes in concentric pieces: The inner piece (red) is the stellar ejecta, and the other piece (blue) is the blast wave.

Download the 3D-printer files for these and other objects: **http://chandra.si.edu/3dprint.**

"I find that that's one of the beauties of the sound, actually," he says. Engaging with visuals can be a passive experience, he explains. "They're only there on the screen, you can look away, you can be distracted. But with the sound, especially if you put headphones on, you really feel more immersed in it."

A Galaxy in the Palm of Your Hand

A spiral galaxy is probably the most quintessential galaxy shape. Our own Milky Way is a spiral galaxy, as is the iconic Whirlpool Galaxy (M51) located next to the handle of the Big Dipper, with the arms of its grand spiral wound around its bright center.

But how do you explain a spiral galaxy to a student who has never seen one?

Nicolas Bonne decided to 3D-print it.

As someone with a vision impairment, Bonne (University of Portsmouth, UK) had found completing his PhD in astronomy difficult. "If I could have made my images tactile, if I could have felt those shapes instead of trying to look at them and not being able to see them very well, that would have actually made things way, way easier for me," says Bonne.

This inspired him and his colleagues to create 3D-printed educational materials for blind and visually impaired students in the United Kingdom. Their first print was of the Whirlpool Galaxy. It was a small, postcard-size plate with raised dots, tracing hills and valleys that form the shape of M51. Much like how a relief map demonstrates elevation on Earth, these 3D prints demonstrate brightness: Brighter spots create taller peaks, and dimmer areas are flatter.

"To actually feel that image was a real turning point for me," says Bonne. "It made me realize that yeah, this was actually a legitimate way for me to access the kinds of stuff that I'd really struggled with during my PhD — but also that we probably had something really interesting that we were going to be able to share with the public."

Bonne and his team create written descriptions to go along with their 3D-printed images to teach students about astronomy. They visit classrooms all across the UK and, in turn, learn from the students about how they interact with the 3D images, making the process one of co-creation.

Touching Stellar Deathbeds

Co-creation efforts like these transform astronomy into a more inclusive community. In 1984, Noreen Grice was working at the Museum of Science in Boston as a planetarium show director. One day, a group of blind students came into the planetarium. Curious to see what their experience was like, she asked the students what they thought of the show.

"They said it stunk. They didn't like the show and they walked away, and I felt horrible. I felt like someone had just thrown a brick at me," says Grice. "If I hadn't been working that day, it would have never occurred to me that the planetarium was not accessible."

In collaboration with scientists and NASA astronomers,

SUPERNOVA REMNANT: X-RAY: NASA / CXC / MIDDLEBURY COLLEGE / F. WINKLER, OPTICAL: DSS; 3D MODEL: NASA / CXC / SAO / K. & C. ARCAND

Grice has since written and developed numerous books and tactile images for the blind and low-vision community. Conveying information in three dimensions — like with Braille, for example — has long been a vital way to communicate with audiences who are blind or have low vision. But for the majority of astronomy education, the communication stopped at Braille text, with no images to be found.

Grice's books, like *Touch the Stars* and *Touch the Universe*, however, include embossed images of planets, constellations, and galaxies, which allow readers to feel an image with their fingers. Different textures represent different elements of an image, like dots for stars and lines for constellations.

With this experience in creating tactile astronomy images, Grice has also collaborated with Arcand to design tactile and Braille posters of comets, planets, and galaxies. And Arcand's team has worked on other tactile initiatives, developing 3D-printed models of supernovae and nebulae.

Some stars don't go quietly; they go supernova. A supernova occurs either when a massive star explodes or a white dwarf does. With the latter, the dwarf detonates when it gains too much mass from a companion star. These explosions can eject matter at speeds that exceed 10,000 kilometers per second, or over 20 million miles per hour.

The explosions look like lumpy bubbles, with various protrusions and dimples pockmarking the outer shell. Astronomers color-code images by wavelength range or by composition, denoting the different parts of the remnant.

These unique shapes led Arcand and her team to 3D-print scientifically accurate models of these stellar deathbeds.

In 2017, Arcand's team brought their prints to a group of students with the National Federation of the Blind to get their feedback. As each student felt through the models, Arcand was amazed by their unique perceptions of the prints.

"They were really creating these incredible mental maps inside their heads as they were exploring tactically through the object," she says. "That absolutely blew my mind."

The workshops helped the team figure out that things like size, print quality, and texture were very important as someone explored the objects. The students also asked to feel the inside of the 3D prints. Much like how images struggle to convey a supernova remnant's inner geometry, a solid model is opaque to someone touching it.

This led Arcand to create prints that could be chopped in half and peeled back like an onion. For the model of Supernova 1006, the fatal explosion of a white dwarf, the inner layer is a messy conglomerate of little stone-like spheres connected by short pillars and small pockets. This smooshed-together ball of bubbles fits like a puzzle piece into the outer shell, which represents the high-energy blast wave of the supernova. The shell is smooth on the outside and dimpled on the inside to match the inner ball of bubbles.

▲ **CASSIOPEIA A** Based on multiple telescopes' observations, this 3D model shows the tempestuous conditions of the hot gas inside the supernova remnant Cas A.

NASA / CXC

Universal Design

This phenomenon of creating experiential mental maps is a common way that people in the blind and low-vision community interpret the world. When a person cannot rely on vision, other senses like sound and touch, and their presence in their own body, become the primary ways to interact with their surroundings.

"When I have a three-dimensional representation of a space in my mind, there's an association of my body being in that space," says Christine Malec, an accessibility consultant and member of the blind community. For her, engaging with these astronomy materials is like remembering the route to her local bus stop or the path she takes through the grocery store.

"Sonifications were life-changing," says Malec. "They were a visceral way for me to process some of the really abstract ideas that I had only been able to read about before that time."

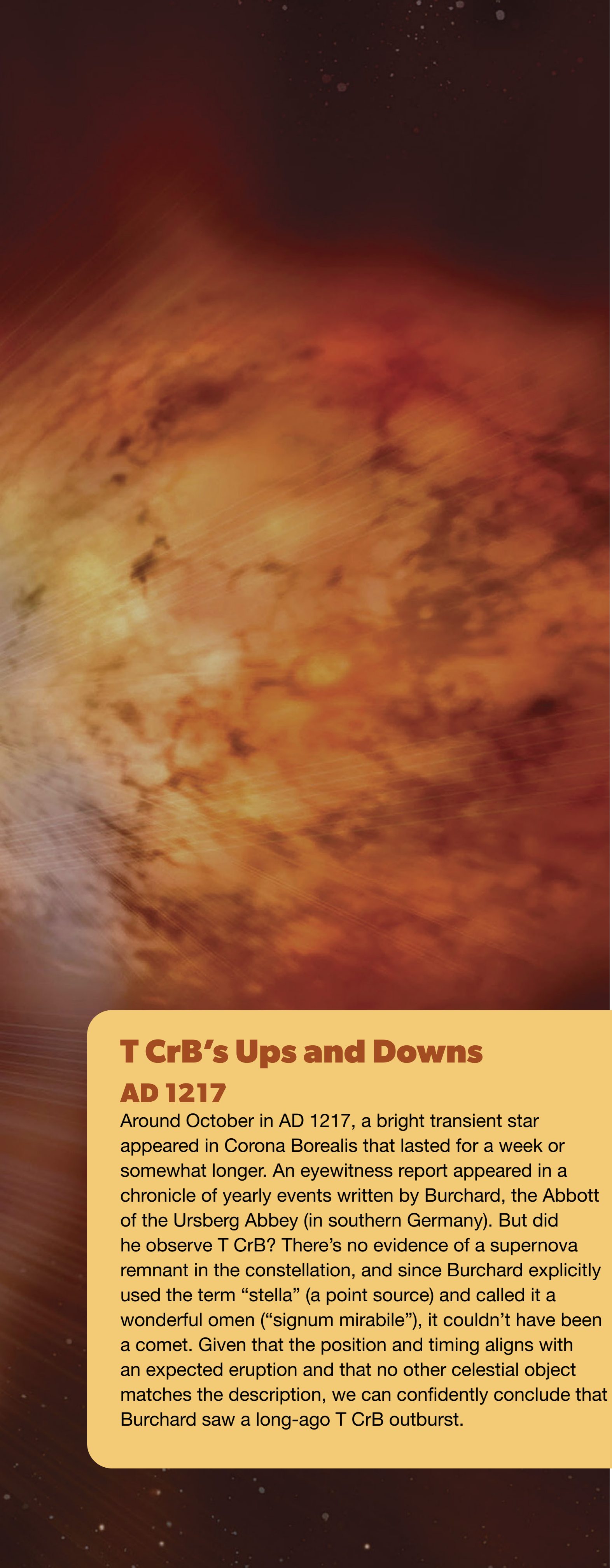
A black hole sonification or a 3D-printed galaxy appeals to senses that many of us share — a concept central to universal design. "Universal design means that we're making something that the widest range of learners can access," says STEM teacher Kris Bayne (Perkins School for the Blind). "Everyone, regardless of ability, can benefit from accessible astronomy."

"We have a universe of data, so we might as well universally design it," says Arcand.

■ **ISABEL SWAFFORD** was once an astronomer. Now she writes about them (and the universe they study).

Get Ready for a Nova's Bright Return

Recurrent nova T Coronae Borealis last erupted in 1946. It's due to erupt again this year.



What could be the brightest nova of your lifetime will flare within the next few months. The star in question is T Coronae Borealis (T CrB). Its most recent eruption was in 1946, and if predictions prove correct, the so-called Blaze Star will soon add a spectacular temporary jewel to the Northern Crown.

Novae appear in the sky when very dim stars suddenly rise to peak brightness, then slowly fade to near their pre-eruption faintness. Rise times typically range from hours to days, and the stars stay near maximum for as little as one day to as long as a few months. Although something like 50 novae occur annually in the Milky Way, the modern discovery rate averages only nine per year. Most of these max out at magnitude 9 or fainter, and in the past 20 years only five have been somewhat brighter than magnitude 5.0.

Strange Behavior

No one is going to confuse the celestial Blaze Star with Blaze Starr, the famous American striptease artist, whose stage name was coined at the time of the 1946 eruption. However, the true nature of novae was completely unknown before the 1960s. The breakthrough came in the late 1950s, when Merle Walker and Robert Kraft (both at Mount Wilson and Palomar Observatories) discovered that novae are close binary systems consisting of an ordinary star in a tight orbit around a white dwarf. Gas from the companion star accretes onto the surface of the white dwarf, and when the accumulated matter has piled deep enough, the temperature at the base of the accreted layer rises sufficiently to reach the

◀ **SPACESHIP VIEW** Novae arise from tightly orbiting binary stars in which a normal star orbits a white dwarf star. Gas falling onto the white dwarf forms a flat accretion disk. Recurrent nova T Coronae Borealis is the rare case in which the white dwarf is near the Chandrasekhar limit and the gas is being transferred at a high rate, resulting in a very short recurrence time between eruptive episodes. If calculations are correct, the star will soon brighten dramatically.

T CrB's Ups and Downs

AD 1217

Around October in AD 1217, a bright transient star appeared in Corona Borealis that lasted for a week or somewhat longer. An eyewitness report appeared in a chronicle of yearly events written by Burchard, the Abbott of the Ursberg Abbey (in southern Germany). But did he observe T CrB? There's no evidence of a supernova remnant in the constellation, and since Burchard explicitly used the term "stella" (a point source) and called it a wonderful omen ("signum mirabile"), it couldn't have been a comet. Given that the position and timing aligns with an expected eruption and that no other celestial object matches the description, we can confidently conclude that Burchard saw a long-ago T CrB outburst.

1787

In Christmastime 1787, the Reverend Francis Wollaston recorded the position of a star that was exactly where T CrB lies. He made four visits to the star, with both a large and a small telescope, while the limiting magnitude for his targets was around magnitude 7.8. Gaia and other all-sky surveys prove that no variable star is near the same line of sight to very deep limits. Wollaston's star cannot be a comet or asteroid, as he would have detected its movement across the sky. The star could not have been a background supernova because such a recent explosion would leave behind a bright remnant. An erupting T CrB is the only star in the specific location that's bright enough. Thus, Wollaston is an eyewitness to a T CrB event.

DAVID A. HARDY / SCIENCE PHOTO LIBRARY

kindling temperature for hydrogen. This triggers a runaway thermonuclear reaction (basically, a huge H-bomb) that blows up the surface layer, resulting in the star's sudden brightening. As the ejecta expand outward and the white dwarf cools, the star slowly fades to its pre-eruption state over months or even years.

Once the white dwarf returns to its quiescent state, the whole process begins again, creating a new eruption cycle. For most novae, a complete cycle takes up to a million years. But for a small fraction of these systems, the recurrence time is much shorter — from one year to one century. Those with recurrence times of less than 100 years are classed as *recurrent novae* (RNe). Only a handful of RNe have two or more known eruptions, and of those only 10 are known to exist in the Milky Way.

1866

Late on the evening of May 12, 1866, Julius Schmidt, director of the National Observatory of Athens in Greece, scanned the skies around the Northern Crown but saw no new star down to 5th magnitude. Less than three hours later, observing from western Ireland, John Birmingham spotted a new 2nd-magnitude star in Corona Borealis and knew that he'd found something remarkable. News of Birmingham's discovery travelled fast, so many astronomers were able to contribute observations, including British astronomer William Huggins, who became the first person to examine a nova's light spectroscopically. Before T CrB, there was no recognition of the phenomenon that today we call a "nova." After T CrB, the existence of novae became well known, though no one had any idea about the forces at play.

T CrB is the prototype RNe and consists of a red giant star and a 1.35-solar-mass white dwarf with an unusually long orbital period of 227 days. Most novae have orbital periods of only 3 to 8 hours! T CrB famously erupted in 1866 and 1946 — data from those observations tell us something about its behavior. Its *light curve* (a plot of brightness against time) has a rise and fall that is fast — *very* fast: Its rise time is only a few hours long, and it remains near its peak brightness of magnitude 2.0 only for half a day or so. In total, the star remains naked-eye visible for only one week.

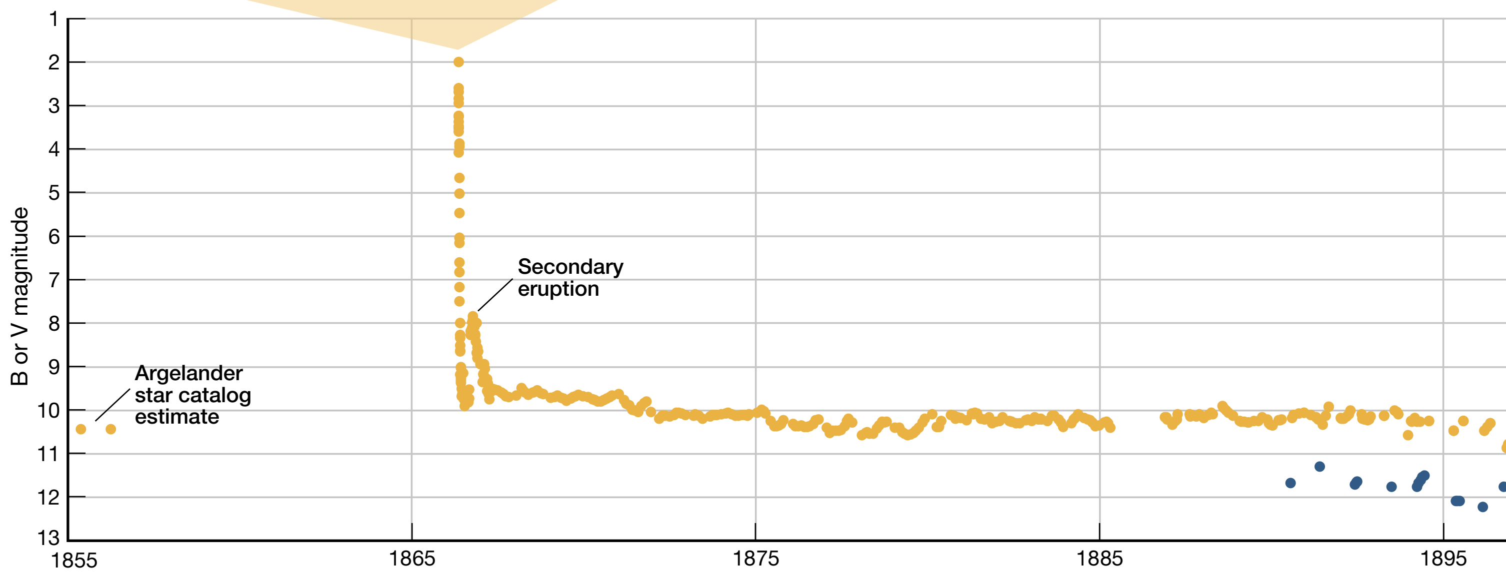
Time to Blow?

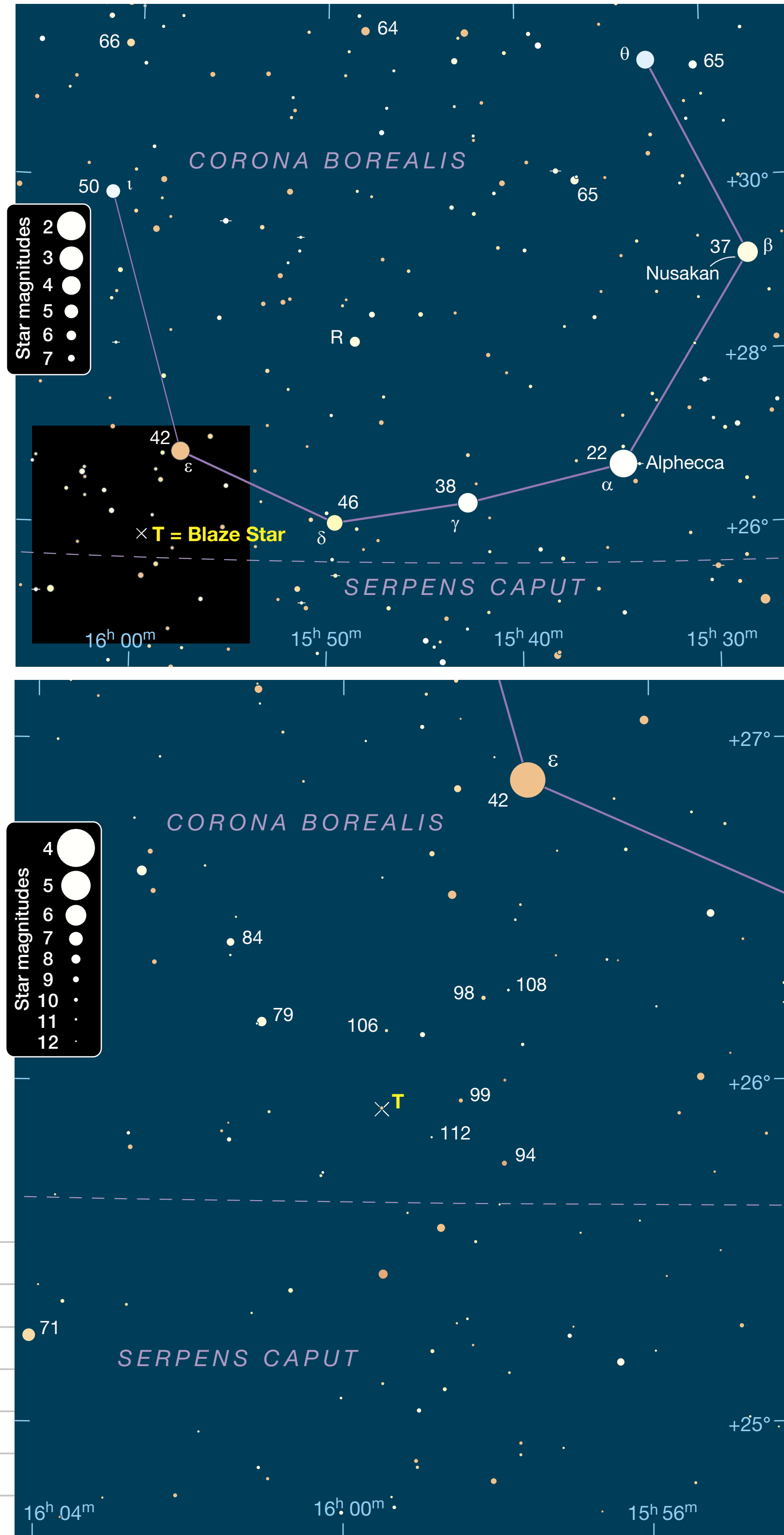
When I was a teenager, I noted that 80 years had elapsed between the T CrB eruptions of 1866 and 1946 and figured the next eruption should occur some time around 2026. Of course, many others made that same calculation. But were there additional eruption episodes predating the one in 1866? A few months ago, I found a long-lost, eyewitness report of one that occurred around Christmastime in 1787. Taking this episode into account, the average recurrence time turns out to be closer to 79 years, indicating the next eruption is due sooner — perhaps in 2025.

In addition, over the last few years I compiled detailed light curves for T CrB's two most recent eruptions and found them to closely match. I also examined the light curves for the other nine Milky Way RNe, finding that they always reach the same peak each time. I now feel confident that the upcoming T CrB eruption will once again reach a peak magnitude of 2.0. But were there additional clues that would allow me to further refine the timeframe for this event?

▼ **A LONG HISTORY** The light curve of T Coronae Borealis stretches along the bottom of this page and the next three. The vertical axis is the same on each page, giving the visual (V) magnitude in orange and the blue (B) magnitude in blue. The horizontal axis provides the date. In total, 124,935 magnitude estimates were used to create this plot.

BEATRIZ INGLESSIS / S&T, SOURCE: BRADLEY E. SCHAEFER / AAVSO



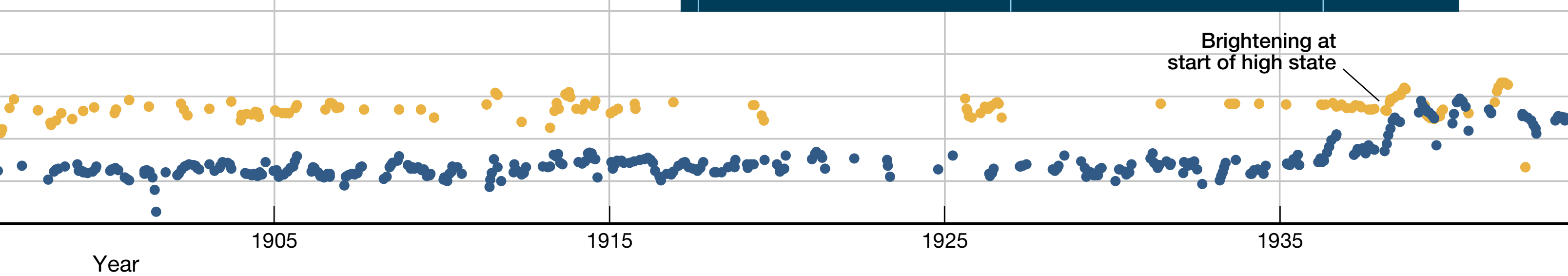


▶ **COMPARISON STARS** Use this pair of charts to locate and estimate the brightness of the Blaze Star, T Coronae Borealis. The chart at top is suitable for naked-eye and binocular use, while the one at bottom is better suited for making estimates with a telescope when the star is at the faint end of its brightness range. Note that comparison star magnitudes are given with their decimal points omitted (e.g., a 11.2-magnitude star is labeled "112").

I carefully analyzed the T CrB light curves from 1866 and 1946 and noted three distinct phases. First, after it erupted and had returned to quiescence for more than two months, it underwent a second outburst, rising to magnitude 8.0, that lasted for about 100 days. Second, in the year leading up to the main eruption, T CrB exhibited a dip of up to two magnitudes. Third, for the 20 years centered on the main outburst, T CrB's brightness plateaued at nearly one magnitude brighter than in its quiescent state. The light curves for both the 1866 and 1946 eruptions are identical and exhibit all three phases. These features are unique to T CrB and so far astrophysicists don't know the causes.

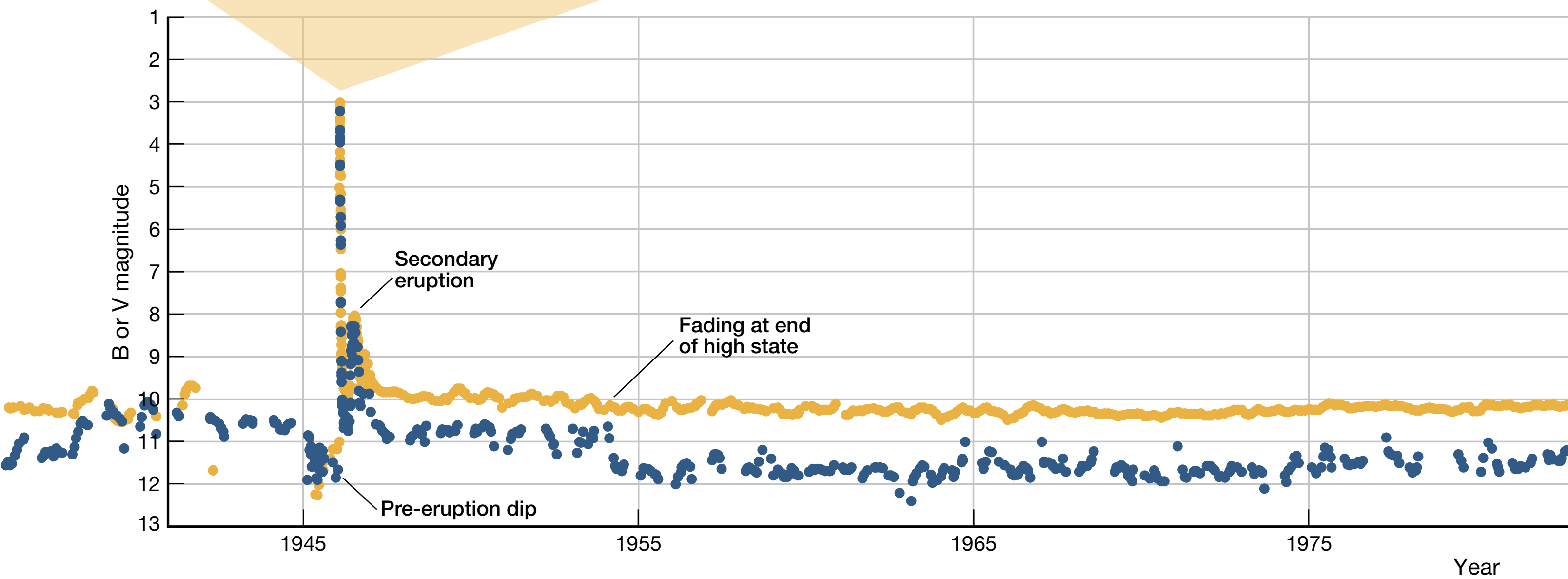
From 1955 to 2015, T CrB flickered away in its dimmer state, when it's at a visual magnitude near 10.3. Then suddenly, in 2015, it brightened to the plateau level of magnitude 9.8. This is the same behavior it displayed in 1935 — some 11 years before the 1946 eruption. (It was Italian astronomer Ulisse Munari who first realized that this brightening was the harbinger of an upcoming eruption.) Comparing the most recent light curve with the 1930's curve predicts an outburst occurring in 2025.5±1.3, assuming T CrB follows

BEATRIZ INGLESSIS / S&T, DATA: AAVSO (2)



1946

For decades after the 1866 eruption, T CrB was observed to glow at around 10th magnitude, yet with chaotic variability of around 0.5 magnitude or so. The most persistent of the star's observers was Leslie Peltier. He started monitoring T CrB in 1920 from his home in Delphos, Ohio, convinced that the star would erupt again. This was insightful, as the concept of a recurrent nova was unknown at the time. In his book *Starlight Nights*, Peltier says, "For more than twenty-five years I looked in on it from night to night as it tossed and turned in fitful slumber." In 1945, Peltier observed that the star was suddenly fading fast (what we now call the pre-eruption dip) and had the insight that this activity marked an imminent outburst. "Then, one night in February 1946 it stirred, slowly opened its eyes, then quickly threw aside the draperies of its couch and rose! And where was I, its self-appointed guardian on that once-in-a-lifetime night when it awoke? I was asleep! Self-pity comes easy at 2:30 on a cold February morning so I went back to my warm bed with the comforting thought that I owed it to my family, at least, to take care of my health." The pride of discovery instead went to N. F. H. Knight, a veteran English variable-star observer. Peltier continued, "I still have the feeling that T could have shown me more consideration. We had been friends for many years; on thousands of nights I had watched over it as it slept and then, it arose in my hour of weakness as I nodded at my post. I am still watching it [up to 1973] but now it is with a wary eye. There is no warmth between us anymore."



the same script it did last time. And if it does, we should also see a pre-eruption brightness dip — something astronomers are anxiously watching for. Amateurs around the world are reporting magnitude estimates on the website of the American Association of Variable Star Observers (AAVSO), **aavso.org**.

Sure enough, the star finally began to fade in March 2023. For the 1945–46 event, the pre-eruption dip started 1.1±0.3 years before the nova. If the current cycle follows the same pattern, the timing of the 2023 dip implies an eruption date of 2024.4±0.3! That means the star should brighten to prominence again some time between January and September 2024. In any case, we can be confident that T CrB will go into outburst soon and that it's likely to happen sometime in 2024.

Mysteries and Big Questions

The upcoming eruption will provide a wonderful opportunity to solve some of T CrB's deep mysteries, including the causes of the high-state, pre-eruption dip, and the secondary eruption. What powers those events, and where in the system do they happen? Why is the timing the same each eruption cycle? Why are these phenomena apparently unique to T CrB?

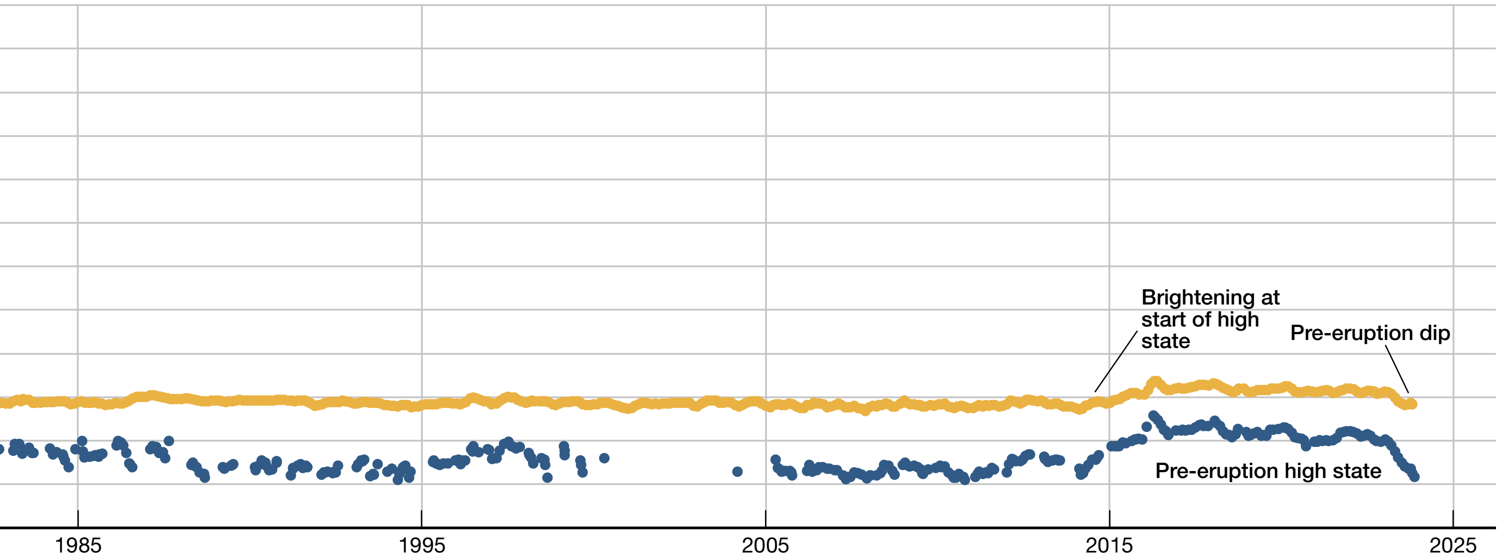
Also mysterious is the evolution of the T CrB system. A fundamental problem is that we don't even know what powers its very high accretion rate. Initially I expected that the red giant was expanding normally and pushing more and more gas in its upper atmosphere "over the edge" to fall onto the white dwarf. But this mechanism is orders-of-magnitude too small. So, what drives the T CrB system?

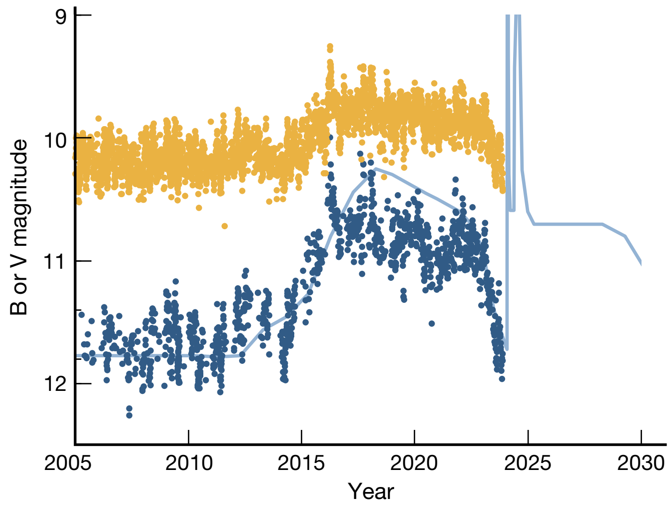
Another set of questions relates to whether T CrB will eventually explode as a Type Ia supernova. This is a prominent part of the supernova progenitor problem, a long-running conundrum regarding the nature of the systems that produce Type Ia supernovae — the variety used as standard candles to measure cosmological distances. The underlying binary pair consists of at least one white dwarf that's pushed to near the *Chandrasekhar limit* — the maximum mass a stable white dwarf can possess. But the companion can be either another white dwarf or a normal star. In the double-degenerate case (DD), both components are white dwarfs, and therefore the binary is made up of two *degenerate stars* — stars composed of very dense "degenerate matter." In the single-degenerate case (SD), one of the stars is a white dwarf while its companion is a normal star. Since T CrB has only one white dwarf, it's a SD system. If we can demonstrate that T CrB will become a Type Ia supernova, then we have a strong argument in favor of the SD solution. However, if we can establish that it will not become a Type Ia supernova, then the SD option is probably off the table, and we have a strong argument for the DD case.

But the path to becoming a supernova is not certain. One roadblock would be if T CrB were a *neon nova*. Roughly 20% of novae are of this variety, in which the white dwarf is composed mainly of oxygen and neon. Such stars cannot explode as a supernova. The nature of the T CrB white dwarf could be revealed from spectroscopy that measures the strength of the neon lines late in the eruption. Another roadblock is if the white dwarf ejects more mass during the eruption than it accretes between eruptions. If the white dwarf is losing mass across each eruption cycle, then it's not approaching the Chandrasekhar mass and will not go supernova. We have a pretty good measure of the total mass accumulating on the surface of the white dwarf over its 80-year cycle, but it's difficult to measure how much material it ejects. Previous attempts to measure this have produced results with great uncertainty, so some new method is needed. If T CrB hits

AKIRA FUJII (WITH MODIFICATIONS)

▶ **EXTRA JEWEL IN THE CROWN** Corona Borealis, the Northern Crown, is a half-circle of modestly bright stars tucked between the constellations Hercules and Boötes. This photo has been modified to show T CrB as it will appear at the peak of its brightness, likely some time in the coming months. (Use the charts on page 37 to identify T CrB here.)





▲ **LEAD-UP TO 2024** This closeup shows T CrB's brightness in visual (V, in orange) and blue light (B, in blue) from 2005 to 2023. The rise from the low state to the high state (starting around 2015) and the decline in the pre-eruption dip (starting around March 2023) are both more prominent in blue light. The 1927-to-1952 blue light curve is shown as the faint blue line. Assuming the nova follows the same pattern it did in the 1930s and 1940s, it should erupt soon.

either of these roadblocks, then the SD case takes a strong hit. But if it avoids both roadblocks, then we have living proof in favor of the SD solution for one of the premier controversies in modern astrophysics.

Moving Forward

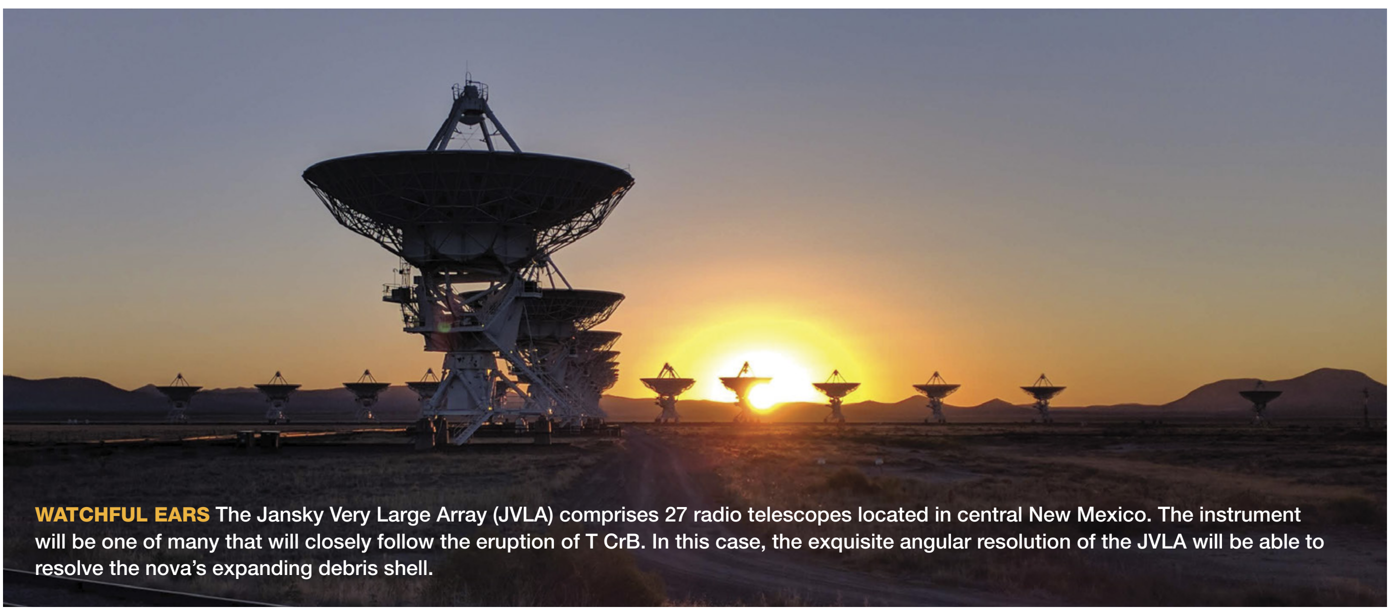
The upcoming T CrB eruption has excited much preparation among both amateurs and professionals. For example, many groups are monitoring T CrB to ensure that the start of its rise is detected as early as possible. This is critical because the star remains at peak brightness only for a short time. The largest such program is ongoing with the AAVSO, where hundreds of observers around the globe check T CrB on average once every 12 minutes every hour of every day. Perhaps a reader of this magazine will be the first to detect T CrB's rapid brightness increase!

Another type of preparation involves proposals for "target-of-opportunity" programs. In these cases, the telescope used will go into a "stop-everything" mode when the start of the eruption phase is detected. The first few days are likely to be busy and confused, so a well-thought-out plan is necessary for the best science return. For example, the team operating the orbiting Neil Gehrels Swift Observatory have worked out a detailed observing plan for the satellite's X-ray and ultraviolet instruments. Similarly, neutrino detectors will lower their event threshold for neutrinos coming from the direction of T CrB, pushing to the lowest possible detection limits. With T CrB being only 3,000 light-years away, it represents the best chance for detecting nova neutrinos. In the first week of the eruption, it's likely that the majority of professional telescopes and space telescopes will be turned toward T CrB.

Observations will also continue long after the peak has passed. For example, the Center for High Angular Resolution Astronomy array for optical interferometry (on Mount Wilson) and the Jansky Very Large Array radio telescope (in central New Mexico) should both be able to see the expanding nova shell. The Hubble Space Telescope will also watch for the *light echo*, which will appear as an apparently expanding ring or shell around the star and can be used to map the distribution and quantity of mass in the prior ejecta.

As exciting as all this activity is, perhaps the most important part of this T CrB eruption is that we can all look up, see the Blaze Star, and ponder its titanic energies.

■ **BRAD SCHAEFER** is a professor of astronomy and astrophysics at Louisiana State University. He first estimated the magnitude of T CrB back in high school.



WATCHFUL EARS The Jansky Very Large Array (JVLA) comprises 27 radio telescopes located in central New Mexico. The instrument will be one of many that will closely follow the eruption of T CrB. In this case, the exquisite angular resolution of the JVLA will be able to resolve the nova's expanding debris shell.

GRAPH: BEATRIZ INGLESSIS / S&T, SOURCE: BRADLEY E. SCHAEFER / AAVSO; VLA: NRAO / AUI / NSF

OBSERVING
March 2024

3 MORNING: The last-quarter Moon and Antares rise in tandem in the southeast. The Moon eclipses the star for parts of the southern U.S. (turn to page 50 for full details). As the pair climbs higher, the distance between them increases — before sunrise, the Moon is a bit less than 2° lower left of the red supergiant. (See page 46 for more information on events listed here.)

6 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:17 p.m. PST (go to page 50).

9 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:07 p.m. EST (7:07 p.m. PST).

10 DAYLIGHT-SAVING TIME starts at 2 a.m. for most of the U.S. and Canada.

13 DUSK: High in the west, the waxing crescent Moon gleams about 3° above right of Jupiter.

14 EVENING: Face west to see the Moon in Taurus, two days shy of first quarter, around 1½° below the Pleiades.

18 DUSK: The waxing gibbous Moon is in Gemini, less than 3° lower right of Pollux. Look nearly overhead to take in this sight.

19 SPRING BEGINS IN THE NORTHERN HEMISPHERE at the equinox, 11:06 p.m. EDT (8:06 p.m. PDT).

21 EVENING: The waxing Moon adorns the southeastern sky where it shines 3½° above Regulus, Leo's brightest star.

25 FULL MOON (03:00 AM EDT): A penumbral lunar eclipse will be visible across most of the Americas, western Europe and Africa, northeastern Asia, and Oceania (see page 49).

26 EVENING: Look toward the east-southeast to see the Moon, one day past full, following Spica as they climb above the horizon. Some 3° separates the pair.

27 EVENING: The soft glow of the zodiacal light should be visible above the western horizon from dark locations after sunset. Look for a tall, hazy pyramid of light stretching through Taurus into Gemini and beyond. The sight will improve over the next fortnight as the Moon wanes.

29 EVENING: Algol shines at minimum brightness for roughly two hours centered at 9:52 p.m. PDT.

30 MORNING: The waning gibbous Moon leads Antares by about 4° as they rise above the southeastern horizon.
—DIANA HANNIKAINEN

▲ NGC 4051 is a magnificent spiral galaxy in Ursa Major. The article on page 20 has more on galaxies in the Great Bear.
ESA / HUBBLE / NASA / D. CRENSHAW AND O. FOX

MARCH 2024 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						

LAST QUARTER
March 3
15:23 UT

NEW MOON
March 10
9:00 UT

FIRST QUARTER
March 17
4:11 UT

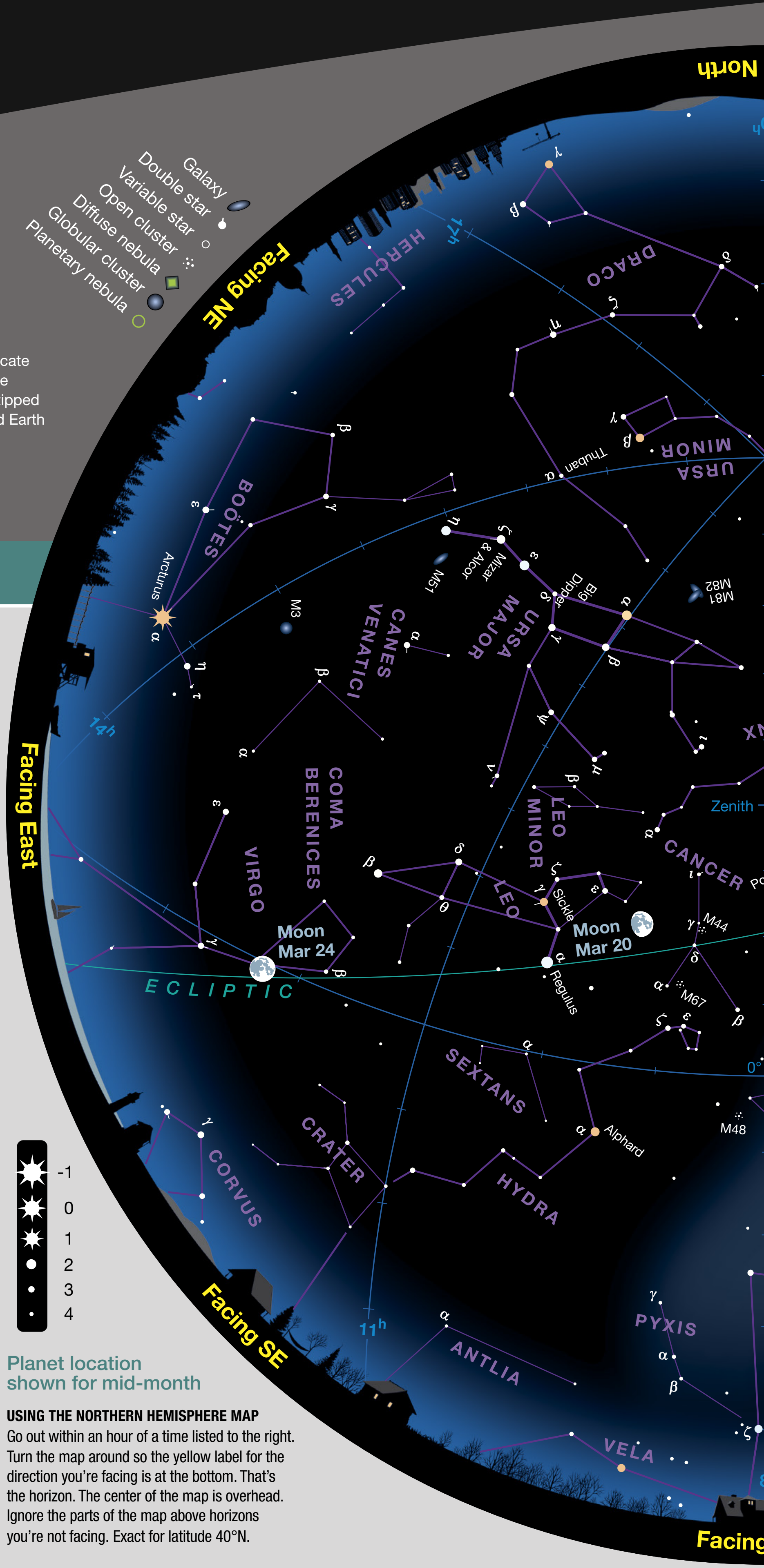
FULL MOON
March 25
7:00 UT

DISTANCES

Perigee	March 10, 7ʰ UT
356,895 km	Diameter 33′ 29″
Apogee	March 23, 16ʰ UT
406,294 km	Diameter 29′ 25″

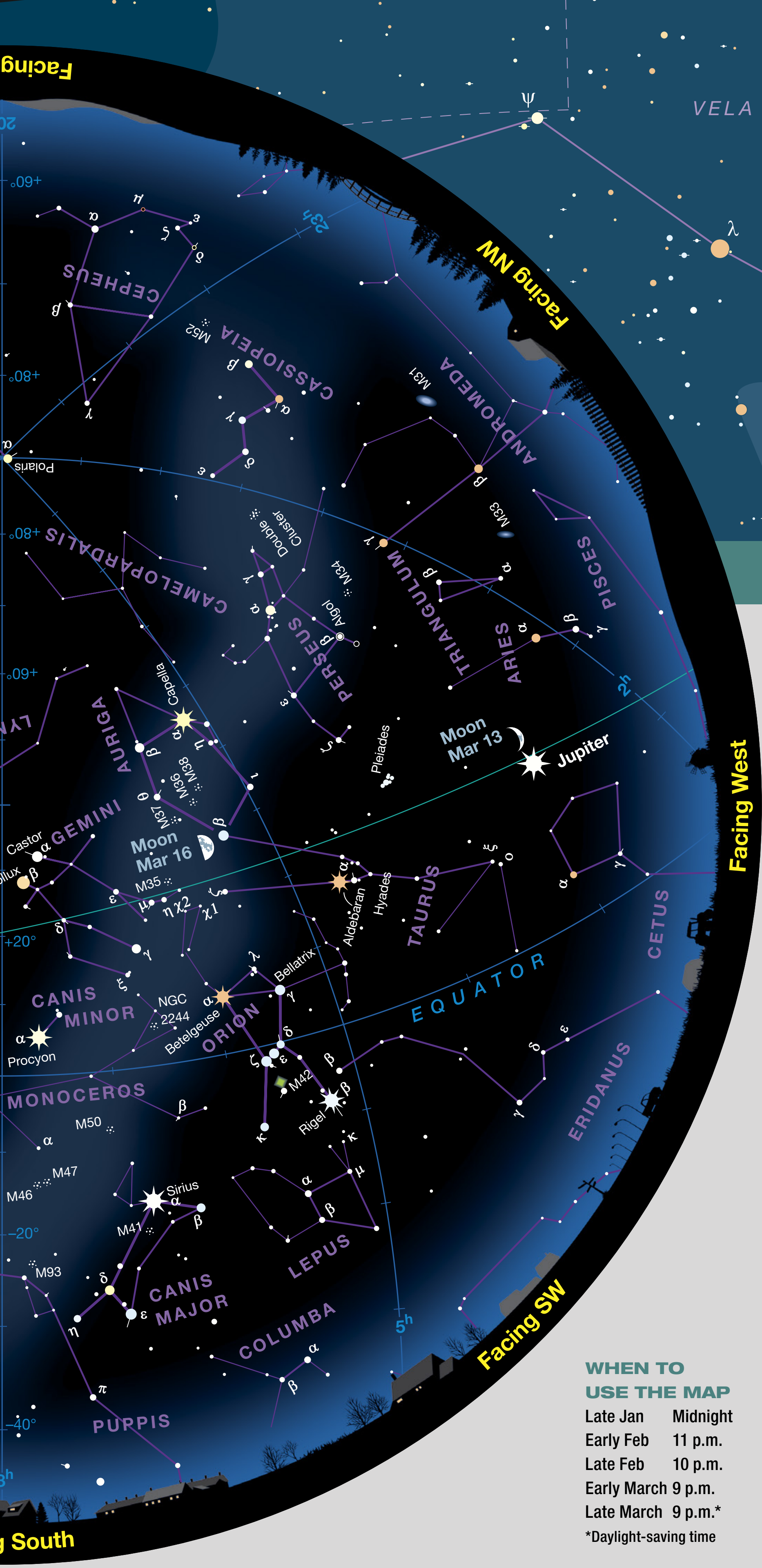
FAVORABLE LIBRATIONS

• Harding Crater	March 6
• Behaim Crater	March 13
• Oken Crater	March 18
• Lavoisier Crater	March 31



Planet location shown for mid-month

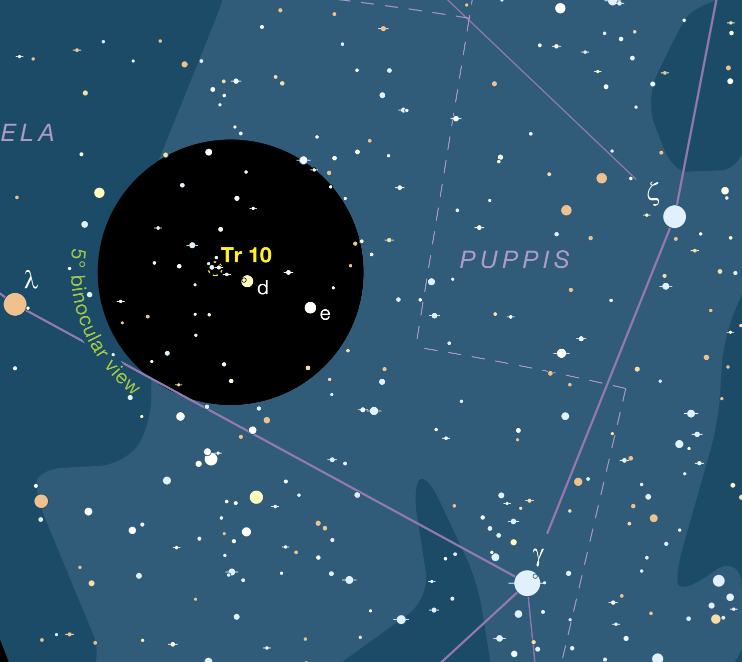
USING THE NORTHERN HEMISPHERE MAP
Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing. Exact for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



WHEN TO USE THE MAP

Late Jan	Midnight
Early Feb	11 p.m.
Late Feb	10 p.m.
Early March	9 p.m.
Late March	9 p.m.*

*Daylight-saving time



Binocular Highlight by Mathew Wedel

Southerly Challenge

Confession time: I don't explore enough low in the southern sky. I fall into the trap of thinking of the southern end of Canis Major, the Great Dog, as "pretty far down there." It's not! The southern border of Canis Major is at –33°, but the great globular cluster Omega Centauri (which can be seen from most of the contiguous U.S. and Hawai'i) lies a full 14° farther south. And in winter and early spring, those southerly latitudes of the Milky Way are just jam-packed with celestial wonders.

An overlooked gem in this area is the open cluster **Trumpler 10** in Vela, the Sails of the defunct constellation Argo Navis. Look 3¾° west-northwest of 2nd-magnitude Lambda (λ) Velorum to find the stars d and e Velorum making a straight line with the bright, compact cluster. At 5th magnitude it should be visible even in 7×50 binos — provided you have a clear southern horizon.

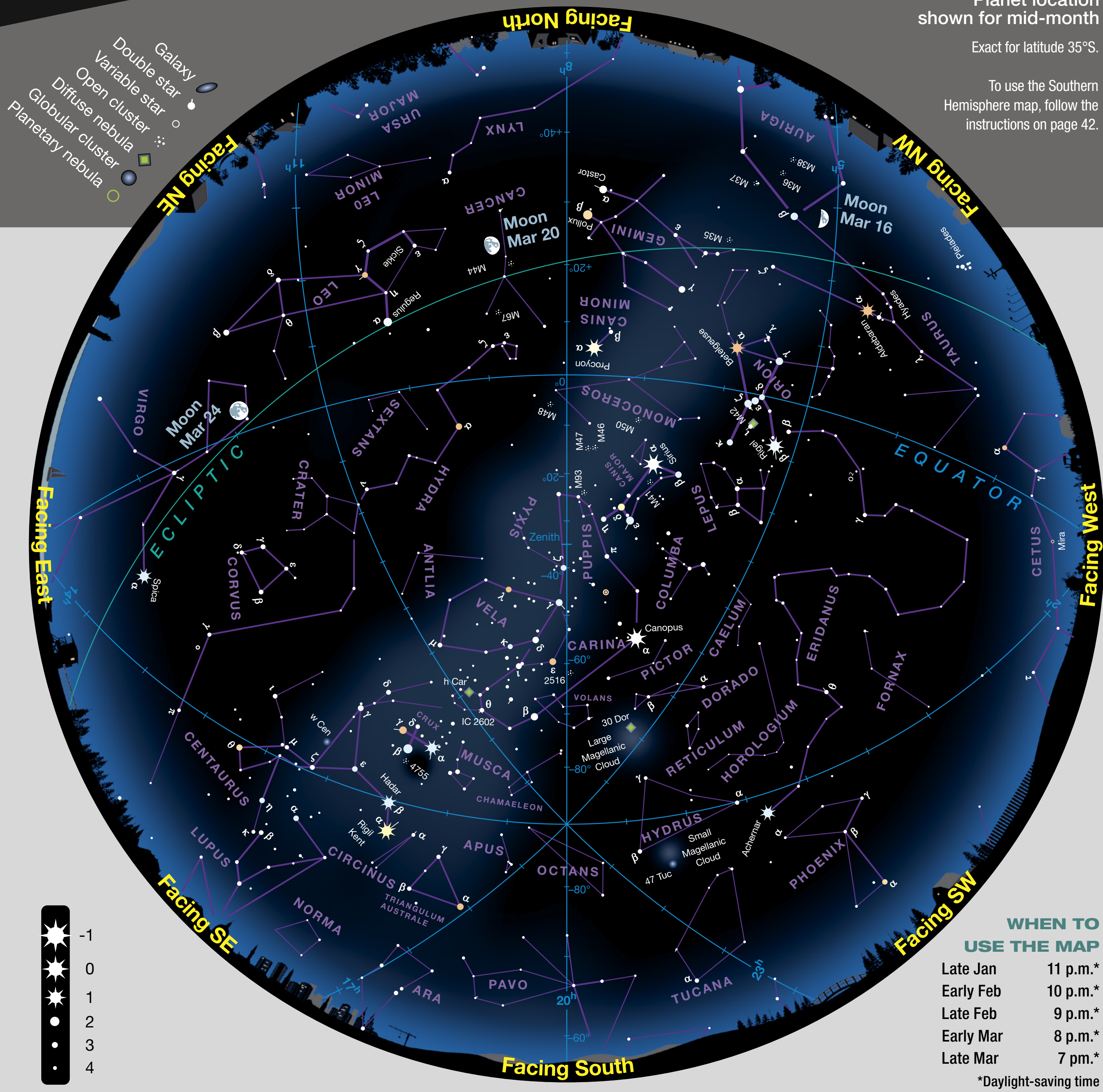
My 15×70 binoculars start to reveal Trumpler 10's true nature, with a dark center surrounded by a ring of stars, like a necklace of jewels hanging in space. The brightest stars in the ring are all 7th- and 8th-magnitude, and many of them are spectroscopically blue or blue-white, a clue to the cluster's relatively young age of 30 million years or so. I've never been able to make out any of those colors in binoculars — perhaps because Trumpler 10 is so close to my horizon — but it never hurts to try.

Here's a neat exercise if you get down to Vela as infrequently as I do: After you've found Trumpler 10, set aside your star atlas and just explore. When you find something interesting, record its position and make a note or a sketch. I suspect you'll have vibrant memories of your finds and a lot of fun to boot.

■ **MATT WEDEL** admits his SoCal stomping grounds give him an advantage on low-declination targets.

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 Jan	11 p.m.*
Early Feb	10 p.m.*
Late Feb	9 p.m.*
Early Mar	8 p.m.*
Late Mar	7 pm.*

*Daylight-saving time

THE CONSTELLATION Carina is a wonderland of nebulae and star clusters, with the open cluster **IC 2602** (shown on the chart above) being a prime example. Visible to the unaided eye, this fine grouping is led by 2.8-magnitude Theta (θ) Carinae and comprises about six dozen stars, though binoculars or a small telescope are needed to see most of them.

A combined apparent magnitude of 1.6 makes IC 2602 one of the brightest open clusters in the sky, inviting favorable comparison with the Pleiades, in Taurus. In fact, French astronomer Nicolas-Louis de Lacaille, having spotted IC 2602 from the Cape of Good Hope in the early 1750s, noted its resemblance to the Pleiades, which is why it's widely known as the Southern Pleiades. And both clusters are somewhat less than 500 light-years distant. ■

Betelgeuse "Inflamed by Wine"

Is an ancient Greek myth linked to the variability of one of the night sky's most prominent stars?

▲ **ROSÉ LIGHT** The recovery of Betelgeuse (the bright, reddish star at upper left) from its record slumber is captured in this pair of images. The one at left was obtained on February 12, 2020, when the author estimated the star's magnitude at 1.7. The right-hand image captured on April 24, 2020, shows the red giant's return to average brightness, estimated to be magnitude +0.5.

STEPHEN JAMES O'MEARA (2)

No naked-eye star in the heavens has drawn so much attention of late as Betelgeuse, the rosé-colored alpha star of Orion. Astronomers are debating whether this aged red supergiant will erupt as a supernova in the near future or continue to wax and wane in brilliance as it has done for centuries. Now is as good a time as any for you to start monitoring Betelgeuse's changes. But first, let's look back in time.

Our story begins with English astronomer John Herschel, who is often credited with discovering the star's variability. Usually Betelgeuse shines around magnitude +0.5, nearly as bright as yellow Procyon, Alpha (α) Canis Minoris. Herschel's observations of the star from 1836 to 1839 from the Cape of Good Hope, however, show that Betelgeuse rivalled Rigel (magnitude +0.2) in November 1836. In January 1839, it dropped to a low of 1st magnitude, when it was fainter than Aldebaran but brighter than Pollux. By November 1839, Betelgeuse had rebounded — this time exceeding Rigel.

Herschel thought it "a little extraordinary" that a periodic variation of such great extent in a "so very important and remarkable star" should have previously gone completely unobserved. But is that true? Support is growing for the claim that Indigenous Australians long ago registered the variability of Betelgeuse. And one myth hints that the ancient Greeks had noticed Betelgeuse's brightness variations.

That myth (which might predate the 8th century BC) tells us that when the handsome giant Orion travelled from Egypt to the Greek island of Chios, he fell in love with Merope, the only daughter of the island's legendary king Oenopion. All was well until one night, when, "inflamed by wine," Orion insulted Merope. Unable to control his anger, Oenopion asked Dionysus (god of wine) to put Orion into a deep sleep. Merope's father then blinded the giant and cast him off to sea in a boat. Following the sound of a Cyclops's hammer, Orion landed on the island of Lemnos, where Hephaestus (god of fire) provided Orion with a guide who led him eastward to be healed by Sol (the Sun). Upon facing Sol's rays, Orion's sight returned.

The loss and recovery of Orion's sight could parallel the fading and recovery of Betelgeuse, whose wine-infused hue may have helped inspire the myth. "Many of the first recorded wines [in ancient Greece] were rosé, light libations made by watering down field blends of combined white and red grapes," writes Victoria James in *A Brief History of Rosé*, an online article for GuildSomm International. The link is at least an alluring possibility.

Just as Orion was a giant among humans in myth, Betelgeuse is a giant among stars in reality. This red supergiant star is 1,500 times larger than our Sun. And though it lies some 500 light-years distant, it generally shines as the ninth-brightest star in the night sky. The star's redness, however, makes estimating its magnitude a challenge, as our dark-adapted eyes are sensitive to red light — the longer we stare at Betelgeuse, the brighter it seems. One way to combat this problem is to use quick glances when gauging its brightness.

To make an estimate, start by selecting two comparison stars that appear closest to it in brightness (one brighter, one fainter). The best comparison stars near Betelgeuse are Capella (magnitude +0.1) in Auriga; Procyon (+0.4) in Canis Minoris; Aldebaran (+0.9) in Taurus; Pollux (1.1) in Gemini; and Bellatrix (1.6), also in Orion.

Although Betelgeuse was born only 10 million years ago, it may have already used up its energy supply and gone supernova. We don't know for sure, because we see the star as it was 500 years in the past. If Betelgeuse has already exploded, we might be lucky enough to see it brighten magnificently!

■ 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.

More Lunar Highs and Lows

The Moon dips into the Sagittarius Teapot, and Mercury pops up at dusk.

SUNDAY, MARCH 3

This morning, depending on where you're located, you'll either get to see something dramatic or something merely interesting. As described on page 50, the **Moon** occults **Antares** for observers in the southeastern U.S., Central America, the Caribbean, and northern parts of South America.

The rest of us get to see the last-quarter Moon very close to a first-magnitude star — not a bad consolation prize. You don't need optics to observe this conjunction, but I'd encourage you to try a pair of binoculars or a small telescope anyway. The extra photons such instruments gather will make the red supergiant's golden-orange hue contrast vividly with the silvery gray of the lunar surface. And if the weather isn't favorable on this date, you'll have another chance to view the pair together on the morning of the 30th, when they'll be just a little more than 2° apart.

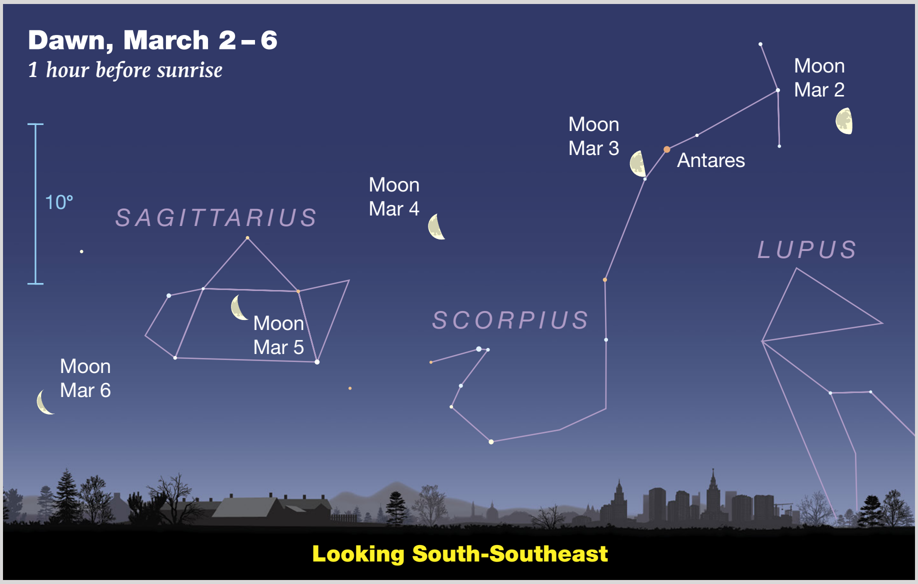
If you happen to be up as twilight brightens the sky this morning, cast your gaze to the east-southeast to catch **Venus** and **Mars** rising together, separated by less than 5°. The planetary duo clears the horizon roughly one hour before the Sun. They were closest on February 22nd and have been drifting apart ever since as Venus sinks sunward and Mars gradually gains elevation.

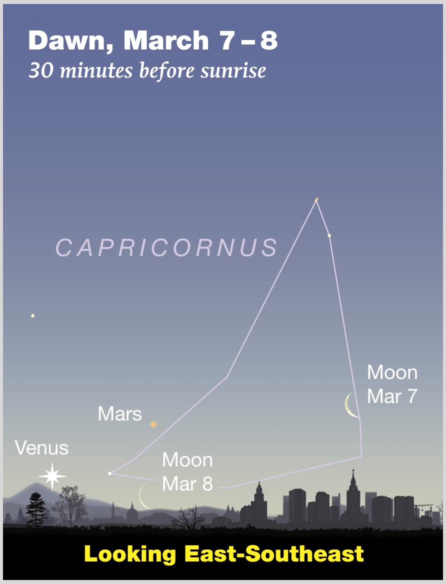
TUESDAY, MARCH 5

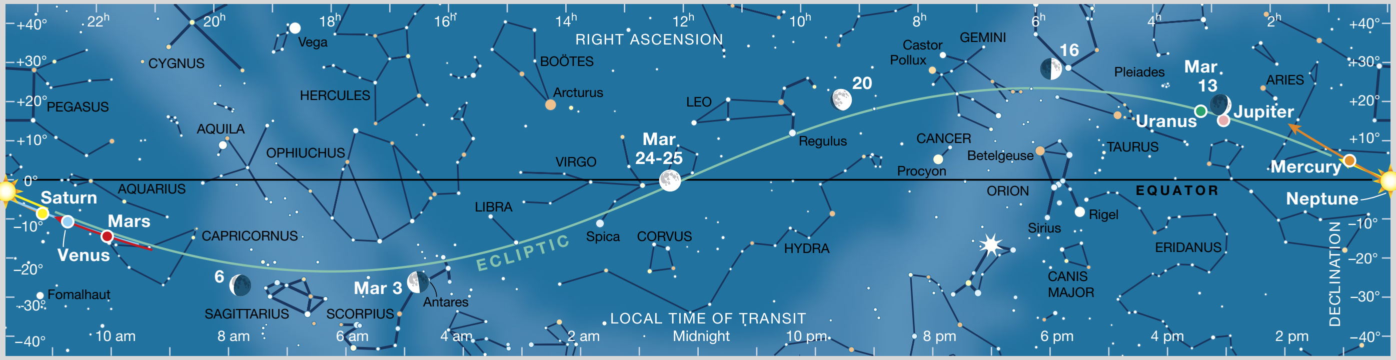
So, here's something you don't see every night. Get up before dawn and have a look at the waning crescent **Moon**. Notice anything odd? How about the fact that it's smack dab in the middle of the **Sagittarius Teapot**? Usually when the Moon passes through the constellation it does so much farther north, but (as described in this column in the February issue) the Moon's path is currently taking it unusually far south and (in two weeks' time) unusually far north.

This morning, the lunar crescent has a declination of roughly –29°. That's some 6° south of the *ecliptic* — the plane defined by Earth's orbit around the Sun, and the path that the Moon and planets typically follow across the sky. This unusual placement for the Moon is a result of it approaching the *lunistice,* or "major lunar standstill," next January. It's an oddity curious enough to get up early for.

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







▲ The Sun and planets are positioned for mid-March; 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.

WEDNESDAY, MARCH 13

One of the month's most arresting sights can be enjoyed this evening as the sky begins to darken. Hanging above the western horizon are the waxing crescent **Moon** and brilliant **Jupiter**. About 3° separates them, which means they're close enough to be viewed together in binoculars.

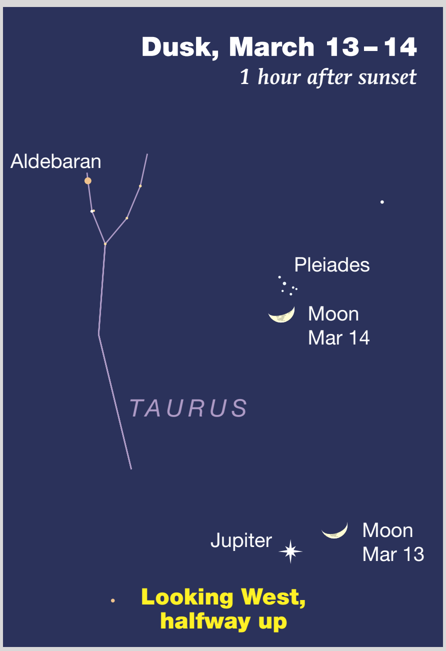
While the boost provided by optics will show extra detail on the Moon and perhaps one or two Jovian moons, the sight is best appreciated with your eyes alone. Indeed, the wide perspective allows you to appreciate the Moon–Jupiter duo as the leading participants in a lovely, luminous parade that includes the bright stars of the winter constellations as they march together toward the western horizon.

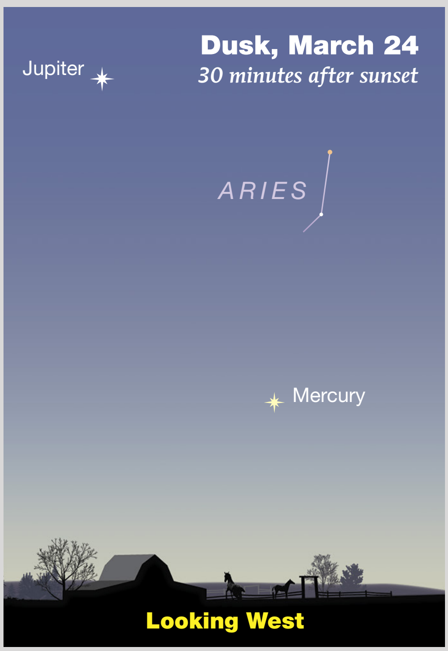
SATURDAY, MARCH 16

Bookending its extreme southern position on the 5th, the **Moon** appears this evening very far north, at a declination of +28°. The first-quarter Moon also sits 2° left (east) of 1.6-magnitude Beta (β) Tauri, otherwise known as **Elnath**. The star is more than 5° north of the ecliptic, so it doesn't get many solar system visitors. Indeed, if you were on a ship in the southern Atlantic Ocean at the right time, you could watch the Moon eclipse the star! All this activity is due to the lunistice mentioned previously. For those with their feet firmly planted on the ground in North America, there's arguably an even more interesting naked-eye sight. Again, taking the wider view, notice that the Moon is neatly parked roughly midway between +0.1-magnitude Capella in Auriga and +0.4-magnitude Betelgeuse in Orion. (It's 18° from the former and 21° from the latter.) The Moon crosses an imaginary line connecting the two stars at around 10 p.m. EDT.

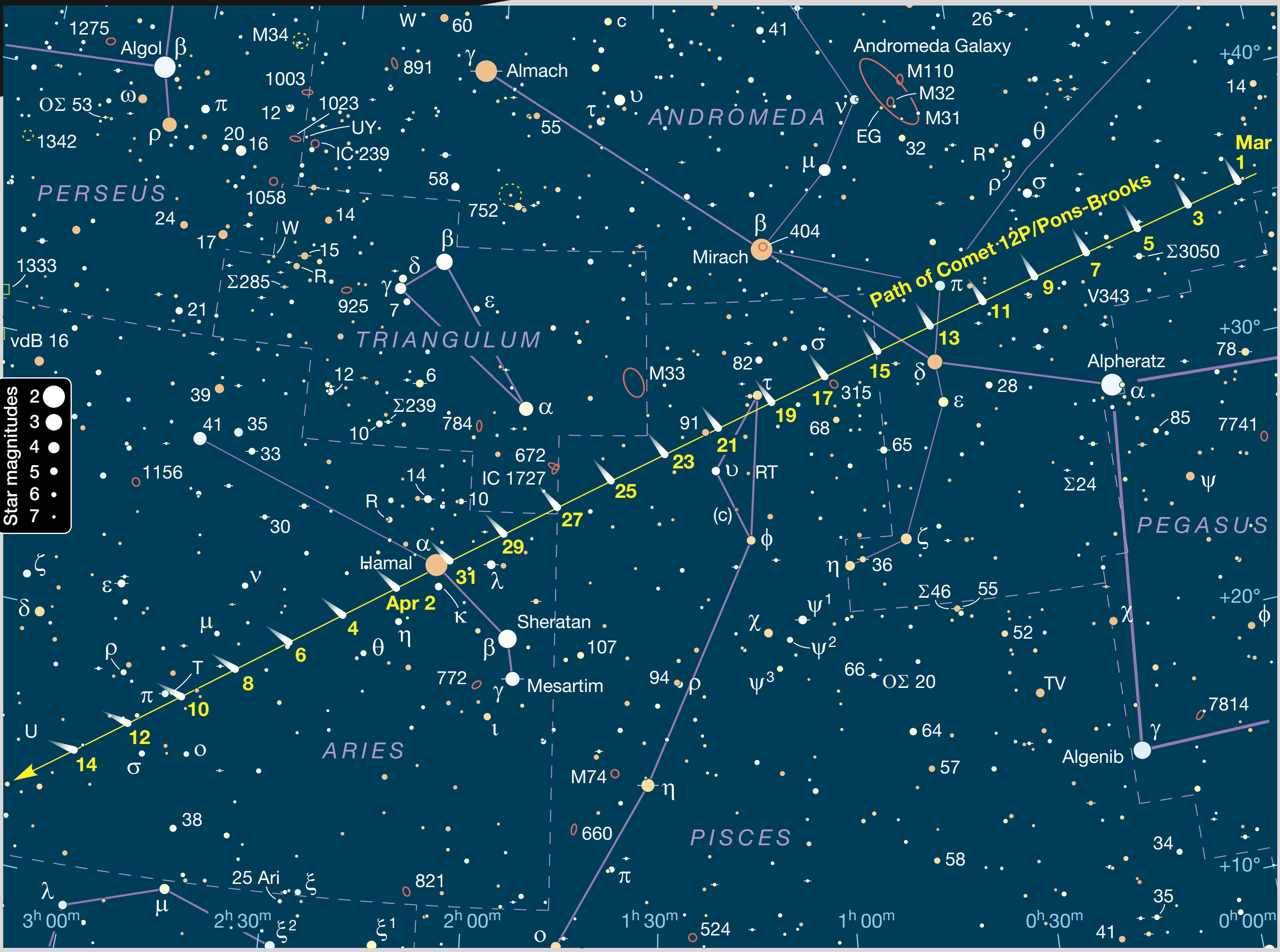
SUNDAY, MARCH 24

Mercury makes three evening appearances in 2024, and this month's is easily the best of them all. The planet reaches its greatest elongation (19° east of the Sun) today and sits some 12° above the west-northwestern horizon half an hour after sunset. Although that's quite a favorable placement for the innermost planet, it's still not terribly high — seek out an observing site with an unobstructed horizon and bring some binoculars along to make the hunt a little easier. At dusk today, Mercury shines at magnitude –0.2, but with each passing evening it loses both brightness and elevation. By next Sunday (the 31st) it has dimmed to magnitude 1.4 and is 3° lower — two factors that combine to make finding the planet considerably more difficult. In other words, don't tarry if you want to catch this fast-moving little world.





■ Consulting Editor **GARY SERONIK** always tries to catch speedy Mercury, especially at dusk.



Comet 12P/Pons-Brooks Takes Center Stage

A once (or, twice) in a lifetime visitor returns.

Comet 12P/Pons-Brooks has been exciting to watch. Famous for its unpredictable outbursts, it provided a first taste of its capriciousness this apparition when it blew its top on July 20, 2023. Overnight the distant visitor brightened a hundredfold, morphing from a 16th-magnitude glimmer into a fuzzy, 11th-magnitude dot resembling a small planetary nebula. In the nights that followed, the solar wind shaped jets of expelled material into an uncanny resemblance of the Millennium Falcon spaceship from *Star Wars*. Others likened it to a horseshoe crab or the cartoon character Yosemite Sam. Additional major outbursts occurred on October 5th and 31st, and on November 14th. Undoubtedly, additional flares will occur before you read this.

During March this famous periodic comet comes into its own and won't have to rely on outbursts alone to vault into visibility. Like Halley's Comet, 12P/Pons-Brooks has a short orbital period and takes just 71 years to circle the Sun. However, for most of us, this spring's appearance will likely be the first and last time we get a look. It starts the month in western Andromeda just above the Great Square of Pegasus, where it glows at a binocular-tempting 7th magnitude. Tracking southeastward, the comet reaches Aries on the 27th, when it gains an additional two magnitudes. Observers under dark, moonless skies may be able to see the comet without optical aid as a soft blur among the stars. Astroimagers will have an enticing photo opportunity when 12P saunters some 3° south of the Triangulum Galaxy, M33, from March 21st to 23rd.

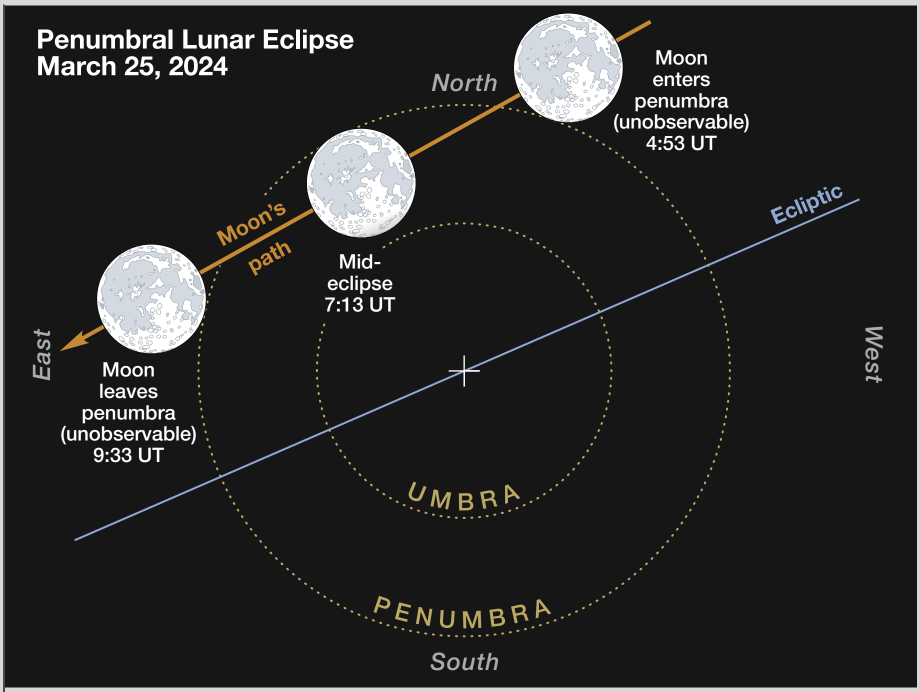
One of the best times to spot the comet with your naked eye will be at month's end. On the 30th, the icy interloper is positioned just ½° northwest of 2nd-magnitude Alpha (α) Arietis, better known as Hamal. The following night it sits just a little farther southeast of the star. And in mid-April the comet passes within 3° of Jupiter. While 12P will glow brightest at that time (possibly reaching 4th magnitude), it will also be a challenging target, hovering low in the western sky in twilight. But who knows? More outbursts are likely in the cards, adding a dash of unpredictability to forecasts.

Northern observers will lose sight of the comet in late April, but for observers in the Southern Hemisphere the comet remains in view low in the western sky well into August as it arcs from Taurus into Vela and beyond. Perihelion occurs on April 21st followed by its closest approach to Earth on June 2nd, when it's 1.5 a.u. (220 million km) distant.

Periodic comets like this can transport us back to an earlier era of astronomy, making a connection that enriches the observing experience. French astronomer Jean-Louis Pons discovered the object in July 1812, and then it was recovered by American astronomer William Brooks in September 1883. Both were prolific comet-finders — Pons still holds the record for the most visual comet discoveries at 37. Although it bears the Pons and Brooks names, records of prior appearances date back centuries. Early observers logged the comet in 1385 and 1457 and perhaps as long ago as 245.

At its most recent previous apparitions in 1883–84 and 1953–54, the comet also experienced dramatic flares. The cause of these spectacular fits may be the same as the one that powers the frequent outbursts from Comet 29P/Schwassmann-Wachmann. Rapid outgassing of carbon monoxide and carbon dioxide from the comet's core occurs when heat from the Sun fractures the overlying crust, expelling millions of tons of fresh ice and dust. The sudden release of so much material into the light of day temporarily boosts the comet's brightness, making it appear as if a bomb has exploded. The debris cloud gradually expands and fades until the next blowup recharges the coma with fresh material. To keep track of 12P and its delightfully erratic behavior, visit the Comet Chasers website at **cometchasers.org/home/comet-12p-observations**.

LEAH TISCIONE / S&T; SOURCE: FRED ESPENAK



A Deep Penumbral Lunar Eclipse

PENUMBRAL ECLIPSES tend to get overlooked. But I'd encourage you to catch the one happening the night of March 24–25 for two reasons. First, solar and lunar eclipses always come in pairs separated by about two weeks. This particular event makes a delicious appetizer for the highly anticipated April 8th total solar eclipse. Second, despite the eclipse's penumbral designation, this will be a *deep* penumbral eclipse with Earth's shadow readily visible to the naked eye.

In a partial or total lunar eclipse, the Moon dips into Earth's *umbra*, or inner shadow, where our planet's globe blocks direct sunlight from reaching the Moon. During a penumbral eclipse, the Moon treads through Earth's *penumbra*, or pale outer shadow, where varying amounts of sunlight dilute the shadow's darkness.

The Moon first touches the penumbra at 4:53 UT (12:53 a.m. EDT) on March 25th. Greatest eclipse occurs at 7:13 UT (3:13 a.m. EDT), when 96% of the Moon's disk will reside within Earth's outer shadow. So, so close to the umbra! Around the time of maximum, the Moon's southern hemisphere will appear obviously darkened, but you should be able to detect shading well before that, perhaps as early as 20 minutes into the eclipse. Watch for the first hint of shadow to shade the lower left portion of the Moon. The eclipse ends at 9:33 UT (5:33 a.m. EDT).

Although the timing of the event isn't especially favorable for East Coast and Midwest eclipse-watchers, farther west the eclipse takes place at a more reasonable time — starting at 9:53 p.m. PDT on the evening of the 24th. Clubs might hold a public event (everyone likes a full Moon) with an informal competition to determine when the first hint of shading is detectable. Anytime we focus our attention on a new challenge we become more discerning observers.

And if you miss this event, you won't have to wait long for another chance. On September 18th there will be a shallow partial eclipse favoring the eastern half of the U.S. and Canada, and Central and South America.

Antares Blinks Again

MOST OBSERVERS will have at least one opportunity to see the Moon occult Antares in the next few years. Perhaps it's your turn this month. On the morning of March 3rd, the last-quarter Moon eclipses Scorpius's brightest star for viewers in the southeastern U.S. and Mexico, Central America, and the northern third of South America. Those outside of the occultation zone will see a very close conjunction.

From the southeastern U.S., observers will witness both the star's disappearance and reappearance, but even as far west as Des Moines, Iowa, Antares will pop out from behind the Moon's dark limb just after local moonrise. Be sure to find a location with an unobstructed view to the southeast, as the pair will hover quite low especially at the start of the occultation, around 2 a.m. EST.

Antares is a double star, so if you're located where the reappearance phase of the occultation is visible, you can try to glimpse the 5.4-magnitude companion star, Antares B. Just before 1st-magnitude Antares A and its glare reemerge, carefully watch the Moon's dark limb for the B star. Antares B is just 2.7″ west of the primary, so it'll precede its brilliant companion by just a few seconds.

A second occultation occurs on the evening of March 18th. That's when the dark limb of the waxing gibbous Moon occults the 4th-magnitude red giant Upsilon (υ) Geminorum, which is situated 2.4° southwest of Pollux. If you live in the southeastern, central, or western U.S., Central America, or western South America, you've got a ticket for the show.

For more details about either occultation, visit the International Occultation Timing website at: **lunar-occultations.com/iota/**.

Minima of Algol

Feb.	UT	Mar.	UT
1	20:25	1	12:39
4	17:14	4	9:28
7	14:04	7	6:17
10	10:53	10	3:07
13	7:43	12	23:56
16	4:32	15	20:45
19	1:21	18	17:35
21	22:11	21	14:24
24	19:00	24	11:13
27	15:49	27	8:03
		30	4:52

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

▲ Perseus is conveniently high in the northwest during evening hours in March. 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

FOR TELESCOPE USERS, March represents the grand finale of Jupiter's current apparition. On the 1st of the month the planet hovers 49° above the western horizon some 30 minutes after sunset, but by the 31st that figure has decreased to just 27°. Generally, when an object has an altitude of less than roughly 30° the steady seeing conditions that high-magnification viewing requires becomes exceedingly rare.

Jupiter has its conjunction with the Sun on May 18th, after which it will reemerge at dawn. In other words, get your last looks in now — you won't get as good an opportunity to inspect the planet again until sometime in mid-July.

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

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 Daylight Time is UT minus 4 hours.)

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

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

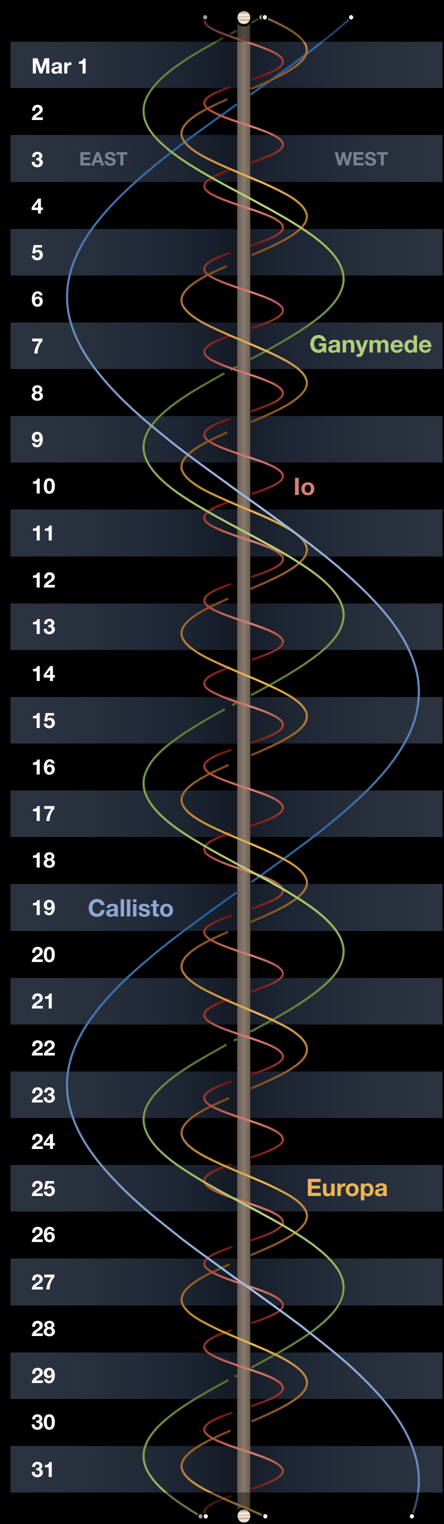
These times assume that the spot will be centered at System II longitude 54° on March 1st. If the Red Spot has moved elsewhere, it will transit $1^{2}/_{3}$ minutes earlier for each degree less than 54° and $1^{2}/_{3}$ minutes later for each degree more than 54°.

Phenomena of Jupiter's Moons, March 2024

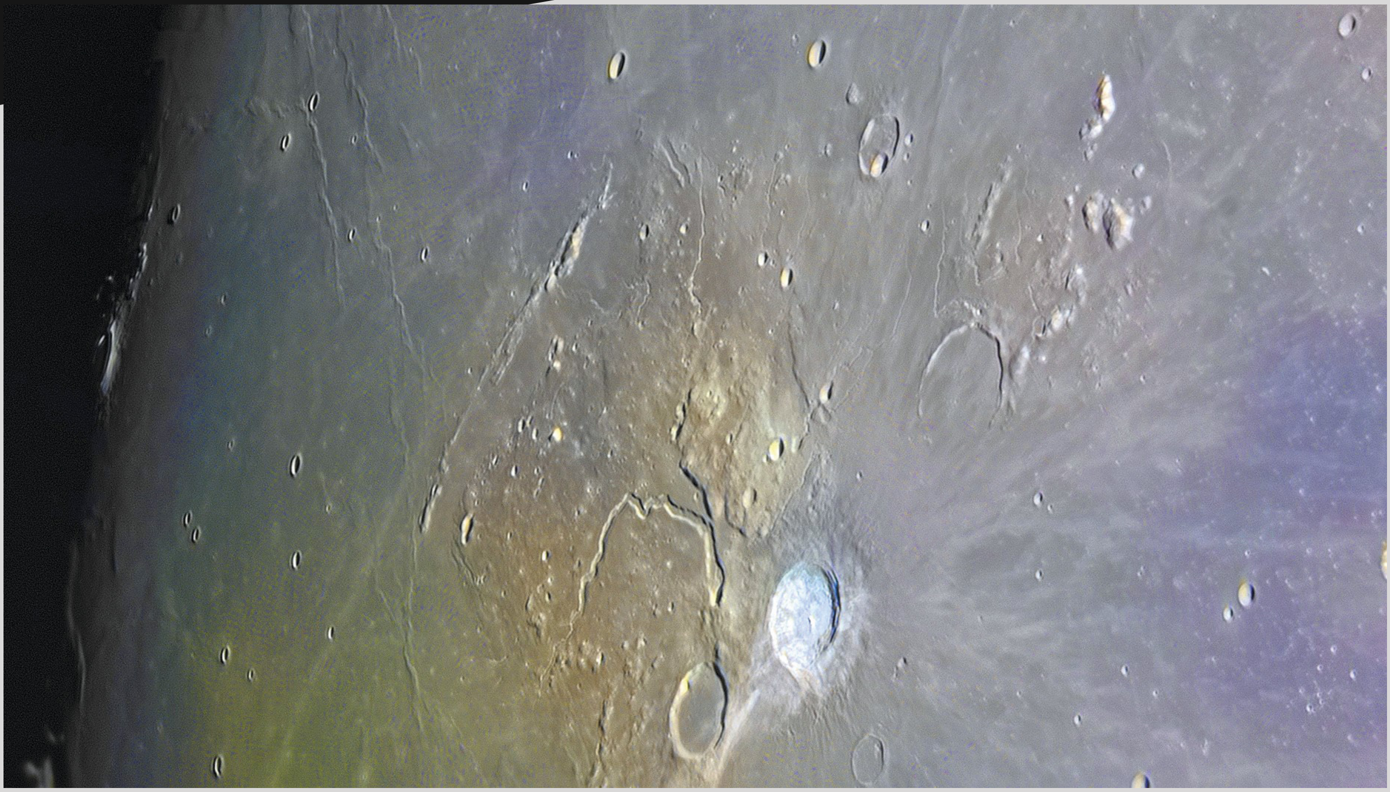
Mar. 1	0:48	I.Tr.E
	1:57	I.Sh.E
	19:47	I.Oc.D
	23:07	I.Ec.R
Mar. 2	0:44	II.Oc.D
	5:30	II.Ec.R
	17:07	I.Tr.I
	18:16	I.Sh.I
	19:18	I.Tr.E
	20:26	I.Sh.E
Mar. 3	14:17	I.Oc.D
	17:36	I.Ec.R
	19:07	II.Tr.I
	21:24	II.Sh.I
	21:31	II.Tr.E
	23:44	II.Sh.E
Mar. 4	5:49	III.Tr.I
	7:51	III.Tr.E
	10:38	III.Sh.I
	11:37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

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 Color on the Moon

There's more to see than light and shadow.

On Christmas Eve, 1968, the Apollo 8 spacecraft swung into orbit around the Moon. Shortly after it emerged from the lunar nightside and passed over the sunlit terminator, Mission Control in Houston asked the crew: "What does the ole Moon look like from 60 miles?"

Astronaut Jim Lovell replied, "Okay, Houston. The Moon is essentially gray, no color. Looks like Plaster of Paris or sort of a grayish beach sand."

Lovell's impression of a starkly colorless world as seen from lunar orbit is like the first glance through a telescope when the harsh glare of the sunlit lunar landscape suddenly dazzles a dark-adapted eye. The dominant mineral in the lunar crust is plagioclase, a gray aluminum-rich silicate mineral. The dusty regolith covering the lunar surface is derived from plagioclase-rich rocks, so it too is predominantly gray. But localized traces of other materials create a rich palette of subtle hues. Most are near the limit of visibility.

▲The tawny color of the Aristarchus Plateau stands out in this color-enhanced image by Japanese amateur Shinichi Watanabe.

When seen just above the horizon, the Moon appears golden because our atmosphere absorbs and scatters more light of short wavelengths. The real lunar colors are best seen when the Moon rides high in a transparent, haze-free sky. Valdemar Axel Firsoff, an accomplished observer and talented artist who worked in watercolors advised:

> *. . . in thinking of lunar colours we must always take the Earth's atmosphere into account. It is there even if the Moon is directly overhead. If all our air could be compressed to sea-level density it would form a uniform layer 5½ miles deep. . . . Thus, in comparing lunar and planetary colourings with those of familiar terrestrial objects we should think not in terms of our immediate surroundings but of horizon views, 7 to 10 miles distant and preferably seen through a telescope . . . Personally I can see hardly any colour on the Moon unless and until I ask the question of how I would paint a certain feature of the surface; then I begin to try in my mind, and even better on paper, to match what I see with paints from a paint-box. Suddenly colour appears where only light and shade were before, and, having come, it stays.*

In 1910 the physicist Robert W. Wood took black-and-white photographs of the Moon through a series of color filters. He was struck by the darkness in violet and ultraviolet light of a diamond-shaped "island" measuring 170 by 200 kilometers (106 by 124 miles) located between Mare Imbrium and Oceanus Procellarum. Wood suggested that a deposit of sulfur might be responsible for this anomalous feature, which became known for much of the 20th century as Wood's Spot.

By far the most conspicuous area of localized color on the Moon, Wood's Spot is known today as the Aristarchus Plateau. Towering 2 km above the surrounding maria, these highlands are more than 3.6 billion years old. As early as 1647 the lunar cartographer Johannes Hevelius commented on their ruddy hue. Many visual observers perceive their color as a dirty yellow reminiscent of Dijon mustard, while others see it as dusky tan or even a brownish hue.

Readily visible through a 3-inch telescope, this tint is due to a veneer of iron-rich volcanic glass that erupted from the feature known as the Cobra Head, the source of the broad lava channel **Vallis Schröteri**, or Schröter's Valley. Just to the east of the Cobra Head is the brilliant, 40-kilometer-wide crater **Aristarchus**, one of the youngest large craters on the Moon. The impact that formed Aristarchus about 450 million years ago exposed underlying bedrock composed of the bluish mineral ilmenite. The cool cast of the interior of Aristarchus contrasts starkly with the warm hue of the nearby pyroclastic materials.

Olivine is probably the mineral responsible for the olive-green and bottle-green hues that transiently appear under low Sun angles in **Mare Crisium**, **Mare Humorum**, **Mare Frigoris**, and on the floors of the craters **Grimaldi** and **Ptolemaeus**. Apollo 15 astronauts collected samples of vivid-green, translucent volcanic glass near **Rima Hadley** in the foothills of **Montes Apenninus**, another location with a history of telescopic observers noting a greenish tint.

The persistent color differences of large expanses of the lunar maria correspond to basaltic lavas that differ in age and composition. They are best discerned under high-Sun angles at gibbous and full phases. The cool, bluish hue of **Mare Tranquillitatis** is due to titanium rich basalts, while the warmer khaki hue of **Mare Serenitatis** corresponds to older, titanium-poor lavas. The sharply delineated boundary of the adjacent mare makes their color difference rather easy to discern. Using basic image-processing software to moderately increase the color saturation of lunar images captured with a one-shot color camera like a DSLR, webcam, or even a cellphone camera can be very effective at revealing these elusive hues.

The bluish tones of Mare Tranquillitatis (center right) contrast markedly with the warm hue that dominates Mare Serenitatis to its northwest. Mare Imbrium at upper left displays the greatest variety of color variations once your eye becomes accustomed to the view.

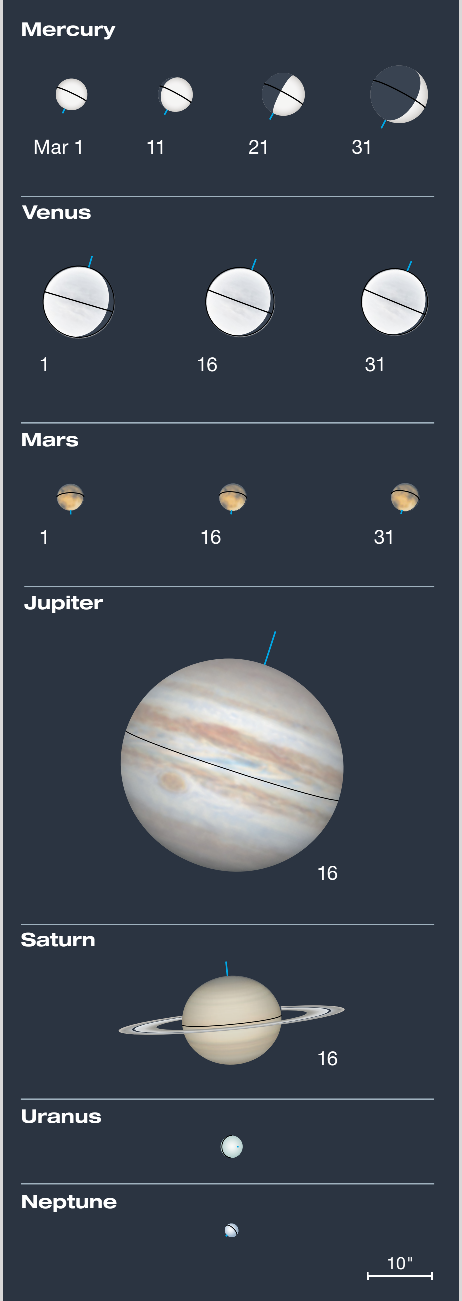
BARRY COWLEY

In his 1621 magnum opus *The Anatomy of Melancholy*, Oxford scholar Robert Burton described the Moon as ". . . a ruined world, a globe burnt out, a corpse upon the road of night."

Our closest celestial neighbor may be a dead orb, but it is by no means uniformly ashen grey. Glimpsing its tinted nuances is a challenging and rewarding activity.

■ Contributing Editor **TOM DOBBINS** is from time to time known to spend an entire evening focused on observing Earth's satellite.

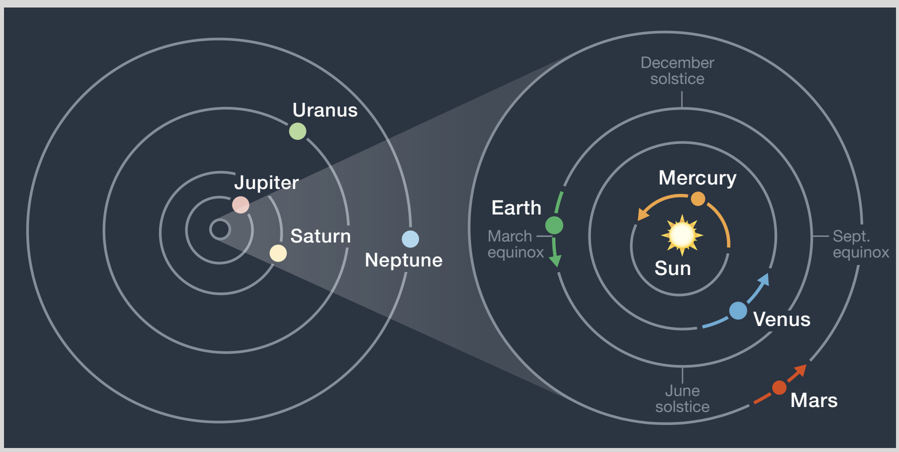
PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dusk starting on the 9th • **Venus** visible at dawn all month • **Mars** visible at dawn starting on the 9th • **Jupiter** high in the west at dusk and sets in the late evening • **Saturn** is lost in the Sun's glare all month.



March Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$22^h\ 48.2^m$	–7° 36′	—	–26.8	32′ 17″	—	0.991
	31	$0^h\ 38.4^m$	+4° 08′	—	–26.8	32′ 01″	—	0.999
Mercury	1	$22^h\ 56.2^m$	–8° 38′	2° Ev	–1.8	4.9″	100%	1.361
	11	$0^h\ 05.2^m$	+0° 09′	11° Ev	–1.3	5.4″	91%	1.239
	21	$1^h\ 05.1^m$	+8° 43′	18° Ev	–0.7	6.7″	59%	1.004
	31	$1^h\ 34.2^m$	+13° 15′	17° Ev	+1.1	9.0″	20%	0.747
Venus	1	$21^h\ 15.4^m$	–16° 40′	24° Mo	–3.9	11.1″	91%	1.504
	11	$22^h\ 04.3^m$	–12° 58′	22° Mo	–3.8	10.8″	93%	1.546
	21	$22^h\ 51.6^m$	–8° 41′	20° Mo	–3.8	10.5″	94%	1.585
	31	$23^h\ 37.6^m$	–4° 00′	17° Mo	–3.8	10.3″	96%	1.620
Mars	1	$21^h\ 01.5^m$	–18° 03′	28° Mo	+1.3	4.2″	97%	2.210
	16	$21^h\ 47.7^m$	–14° 32′	31° Mo	+1.2	4.3″	96%	2.152
	31	$22^h\ 32.6^m$	–10° 29′	35° Mo	+1.2	4.5″	96%	2.094
Jupiter	1	$2^h\ 35.4^m$	+14° 15′	60° Ev	–2.2	36.4″	99%	5.411
	31	$2^h\ 58.3^m$	+16° 04′	36° Ev	–2.1	34.1″	100%	5.773
Saturn	1	$22^h\ 47.0^m$	–9° 29′	2° Mo	+1.0	15.5″	100%	10.711
	31	$23^h\ 00.5^m$	–8° 09′	27° Mo	+1.1	15.7″	100%	10.589
Uranus	16	$3^h\ 09.5^m$	+17° 24′	54° Ev	+5.8	3.5″	100%	20.167
Neptune	16	$23^h\ 50.8^m$	–2° 19′	2° Ev	+8.0	2.2″	100%	30.896

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**.



▲ **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 March. The outer planets don't change position enough in a month to notice at this scale.

Off the Beaten Track

A Gemini backroad leads to modest sights rarely visited.

Behold Castor and Pollux, the Twins. These two bright stars, shining 4½° apart in the constellation Gemini, honor sibling soldiers in Classical mythology. But the siblings weren't equal. Castor was the mortal son of Queen Leda and King Tyndareus of Sparta, while Pollux was Leda's immortal son sired by Zeus. After Castor's death in battle, Zeus reunited the high-ranking half-brothers in the heavens.

Like their mythological namesakes, the so-called twin stars Castor and Pollux aren't identical. Let's examine them, then veer off the beaten track to some lesser-known sights. I explored this Gemini backroad from my suburban yard using three reflectors: a 4¼-inch f/6 Newtonian, a 7.1-inch f/15 Maksutov-Cassegrain, and a 10-inch f/6 Dobsonian. I enjoy comparing the images in these scopes and love star-hopping down newfound celestial trails!

ALAN DYER

The ABCs of Binaries

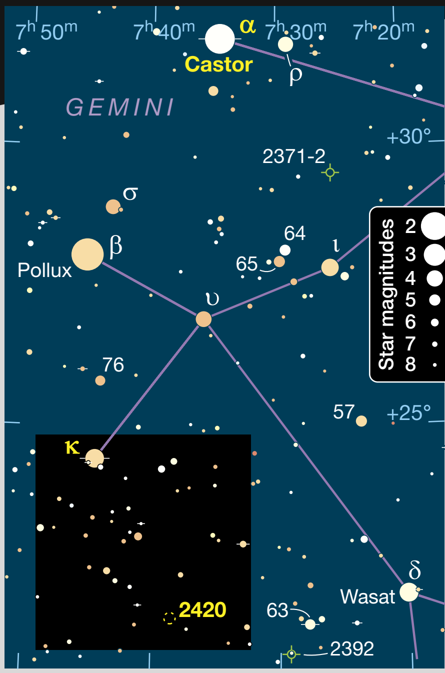
We begin our journey at **Castor**, Alpha (α) Geminorum. Castor is one of the finest multiple stars visible in small telescopes. Its two main components are 1.9-magnitude Castor A and 3.0-magnitude Castor B, which currently lies 5.6″ away (essentially at greatest separation). My three scopes resolve the blue-white pair at around 90×. A superb set!

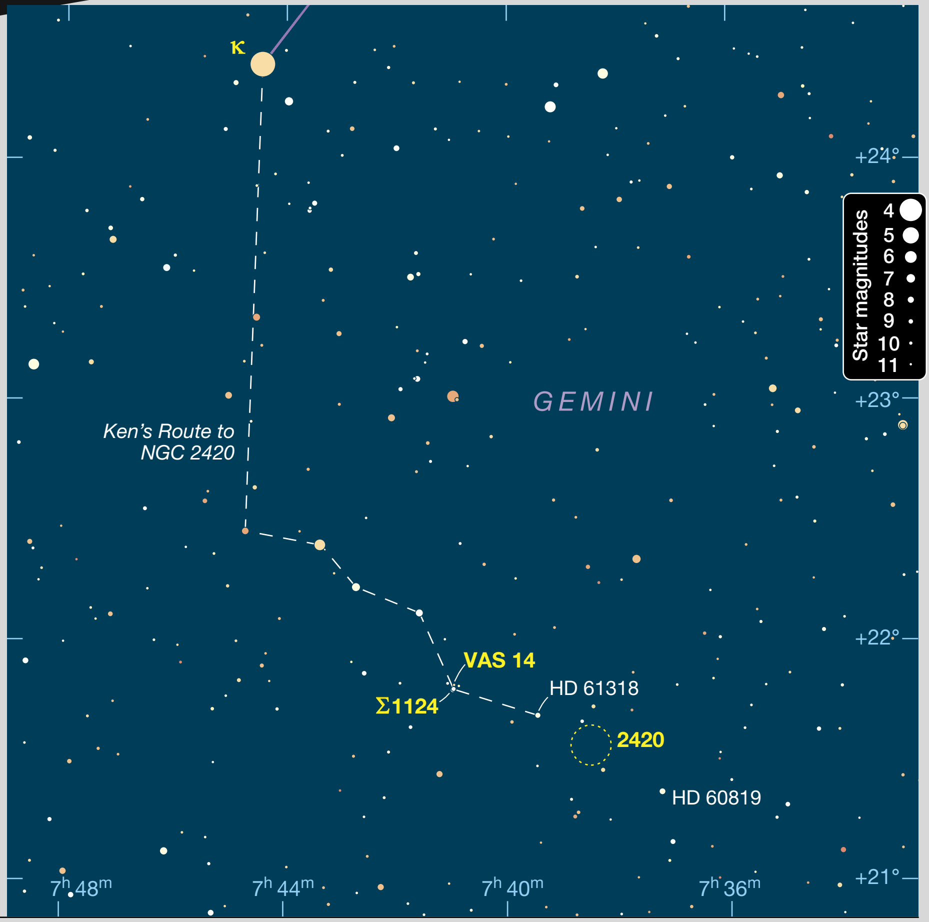
The telescopic view includes Castor C, a 9.8-magnitude red dwarf 71.6″ southward. Spectroscopic observations indicate that Castor C is a tightly spaced eclipsing binary that fades slightly every 19.5 hours. Astronomers have likewise determined that Castor A and B are also each invisibly tight tandems, making this a mind-bending six-star system. It's a fascinating sextet to contemplate as I observe the Castor couple (and the distant dwarf) in my humble backyard telescopes.

▲ **NOT QUITE TWINS** Castor (upper left) and Pollux (middle left), the well-known Gemini "twins," aren't actually twin suns. The very hot, blue-white binary known as Castor shines brightly at magnitude 1.6, while golden-hued Pollux is a warm giant glowing at magnitude 1.1.

Next, we steer southeastward to Pollux, Beta (β) Geminorum. Shining at magnitude 1.1, Pollux is Gemini's brightest star — yet it's officially Beta Gem. If you think Pollux should be Alpha instead of Beta, blame 17th-century astronomer Johann Bayer; he inadvertently consigned Pollux to a lower status than dimmer Castor. In telescopes (and binoculars) Pollux exudes a golden hue, in contrast to Castor's sapphire tint. Beta claims several wide attendants, but they're too faint for my city-based gear.

From Pollux, we shift 3⅔° southward to 3.7-magnitude **Kappa (κ) Geminorum**. Kappa Gem is a challenging





▲▶ **OFF-ROAD IN GEMINI** The author's star-hop route to NGC 2420 starts at Kappa (κ) Geminorum, then follows a ragged line of dimmer stars southwestward to the target. Along the way, the double star Σ1124 is worth a close look to reveal the adjacent, faint triple-star set known as VAS 14.

binary. The glaring yellowish primary (Kappa itself) overwhelms a 10.0-magnitude secondary 7.0″ to the southwest. Resolving these unequal elements is too much to ask of my 4¼-inch reflector; however, my larger telescopes split them starting at around 100× — the more magnification the better.

Motoring 2° further southward, we encounter a half-dozen 6th- to 9th-magnitude stars in a loosely spaced chain, 1½° long, trending southwestward. The fifth link in this raggedy chain is the pretty double star **Struve (Σ) 1124**. The delicate double is an almost perfectly balanced system: The primary is magnitude 9.1; the secondary is magnitude 9.3. Separated by 19.3″, they resolve easily in my bigger scopes. The 4¼-inch needs 72× for a clean split, which is fine because the extra power unveils a tidy little bonus.

Three pinpricks immediately north of Σ1124 form a nearly 3′-long row, tilted west-southwestward. The lineup is listed in the Washington Double Star Catalog as **VAS 14**. The middle star, 10.9-magnitude VAS 14C, lies 78.3″ north-northwest of the primary in Σ1124 (Σ1124A). Flanking VAS 14C are 11.3-magnitude VAS 14D (westward) and 10.4-magnitude VAS 14E (eastward). There isn't VAS 14A or B here; the trio as cataloged is connected to Σ1124. Never mind the ABCs — simply take a moment to admire this double-dubbed trio in your scope.

Now my off-road tour gets a tad trickier. Roughly ⅓° west-southwest of VAS 14 is an 8.6-magnitude star labeled HD 61318 — the final link in the six-star chain I mentioned earlier. A line drawn from VAS 14 southwestward through HD 61318, then extended another ¼°, grazes the northern edge of an often-overlooked deep-sky object.

Phantom Family

The open cluster **NGC 2420** is only 6′ across and glows modestly at magnitude 8.3. Although it contains hundreds of stars, none of them shine brighter than magnitude 11. Needless to say, this phantom family doesn't put on much of a show in my badly light-polluted sky. My naked-eye limit hovers around magnitude 4.2, a constant reminder that the "deep" sky is rather shallow where I live. Even so, I can find the phantom.

The key to success is identifying the cluster's immediate celestial neighborhood. NGC 2420 resides inside a slender triangle, 16′ tall, outlined by a trio of stars of magnitude 9.1, 9.3, and 9.7. The slim asterism sits halfway between the previously mentioned HD 61318 and 8.2-magnitude HD 60819 farther southwest. The triangle is oriented north-south, its vertex at the south end. Moderate magnification should reveal two 11th-magnitude stars running northeastward from the vertex, and two more extending westward from the triangle's west side.

The neighborhood described above materializes even in my 4¼-inch Newtonian operating at 72×. The triangle stars are easy, the others dim but definite.

Also visible, barely, is an 11.3-magnitude star inside the triangle. Hallelujah! — that teeny-weeny dot belongs to NGC 2420. Provided I cup my hands around the eyepiece to block out stray light, and scan the field with averted vision, I can usually perceive the cluster as an ill-defined yet tantalizingly granular mist. This grainy texture becomes more evident when I increase the magnification to 93×. Detecting these subtle features proves that NGC 2420 isn't completely beyond the range of my smallest scope. Faint praise, I know.

Thankfully, NGC 2420 improves with more aperture. My 7.1-inch Mak-Cass cruising at 90× picks up six family members. The three brightest outline a roughly equilateral triangle, a couple of arcminutes wide, in the southern portion of the distinctly grainy mist. Doubling the power gives me up to nine more stars down to at least magnitude 12.5. I'm uncertain about the total number because some of those dim flecks waver at the threshold of visibility.

NGC 2420 puts on a brave face in my 10-inch. At 48×, the Dob shows the seven-star neighborhood clearly, and a mottled patch in the correct location establishes the cluster. Boosting the magnification to 95×, the six brightest stars in the patch are obvious, including the embedded equilateral triangle mentioned earlier. When I push the scope to 169×, NGC 2420 yields 12 stars, maybe 15 during instants of steady seeing. Admittedly, the three most feeble pinpoints are "difficult to hold" in deep-sky-speak.

Ultimately, my Trusty Ten produces no additional threshold stars beyond what the Mak-Cass shows, but the extra aperture resolves the coarse scattering better and slightly intensifies the grainy background mist. Indeed, by staring patiently for several minutes with averted vision, I get tantalizing hints of a densely populated cluster. NGC 2420 isn't a phantom after all! I'll take it.

Satisfaction Guaranteed

I'd like to suggest one final bit of sightseeing. Two stars hang about ¼° south-southeast of NGC 2420. The 9.3- and 9.6-magnitude suns, about 80″ apart, catch my attention because of their warm hues. The brighter one radiates yellow-orange, the other is closer to pure yellow. These amber lights, together with a 10.2-magnitude star northward, make a skinny triangle that's a miniature version of the slender shape framing the diminutive cluster.

Yes, NGC 2420 is one tough target for suburban scopes. My attitude is to embrace the challenge. By applying just enough magnification to spot the cluster's triangular neighborhood, then additional power to nail the cluster itself, I can honestly say I enjoyed a worthwhile observing experience. Detecting stuff at the threshold of visibility might not be exciting, but it sure is satisfying.

■ Despite the quality of his night sky, Contributing Editor **KEN HEWITT-WHITE** likes star clusters of all kinds.

BERNHARD HUBL

▲ **REMOTE CLUSTER** Approximately 9,000 light-years from Earth, the relatively old open cluster NGC 2420 is populated with hundreds of intrinsically dim stars. NGC 2420 is no match for the famous Double Cluster in Perseus, which is only slightly closer yet appears much brighter.

A Gemini Neighborhood

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Castor AB	Double star	1.9, 3.0	5.6″	$7^h\ 34.6^m$	+31° 53′
Castor AC	Double star	1.9, 9.8	71.6″	$7^h\ 34.6^m$	+31° 53′
κ Gem	Double star	3.7, 10.0	7.0″	$7^h\ 44.4^m$	+24° 24′
Σ1124	Double star	9.1, 9.3	19.3″	$7^h\ 41.0^m$	+21° 28′
VAS 14 AC	Double star	9.1, 10.9	78.3″	$7^h\ 41.0^m$	+21° 48′
VAS 14 AD	Double star	9.1, 11.3	106.3″	$7^h\ 41.0^m$	+21° 48′
VAS 14 AE	Double star	9.1, 10.4	125.9″	$7^h\ 41.0^m$	+21° 48′
NGC 2420	Open cluster	8.3	6.0′	$7^h\ 38.4^m$	+21° 34′

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.

Eclipse Megamovie 2024

Help a team of scientists record the Sun's corona during April's total solar eclipse.

Likely the most spectacular aspect of a total solar eclipse is the Sun's corona. The only time we can witness this wispy stellar atmosphere with our own eyes is when the Moon has fully covered the blinding light of the Sun's disk. Not only does the corona provide an unforgettable view, but it is also an important target for solar researchers.

The solar corona is a dynamic entity, varying on time scales of up to 15 minutes or so. Due to the length of totality, though, anybody viewing an eclipse will only catch a few-minutes-long glimpse of the corona. So how can scientists watch longer variations of its tendrils? One nifty way is by having observers stationed all along the path of totality and later collating their data into one long observation. This is exactly what NASA's Eclipse Megamovie 2017 did for the event on August 21, 2017.

Eclipse Megamovies. The Megamovie team had another nifty idea. They tapped into a device that many folks have in their back pocket: a smartphone. Couple this with the fact that an eclipse is an experience most people won't want to miss, and you have millions of cameras transported

▲ **DYNAMIC FEATURES** The Sun's corona varies on time scales of about 15 minutes, but totality lasts only a few minutes. How can scientists study the corona's behavior for long enough to catch the changing phenomena? With a continent-wide citizen-science project!

SEAN WALKER

into the path of totality. In 2017, more than 600 eclipse-viewers all across the United States snapped photos during totality, which the Megamovie team then stitched together. Voilà, you now have a 90-or-so-minute movie showing the evolution of the solar corona.

The 2017 experiment is being repeated this April, with improvements. The Eclipse Megamovie 2024 team, led by Laura Peticolas (Sonoma State University), is again asking citizen scientists to take photos during the eclipse. But this time they're requesting photographers use regular cameras, and that they acquire flats, darks, and calibration frames (for accurate alignment of the images). Individually, the 2017 and 2024 results will highlight the corona's behavior over several hours; comparing the two movies should provide some insight into how the corona behaves over a timeline of seven years.

Post-eclipse, the team, together with computer programmers and scientists, will analyze the treasure-trove of images and extract useful scientific information. To this, they'll add NASA data gathered by satellites and ground-based telescopes, which will help them analyze, e.g., transient plasma flows in the corona. They'll also make the data public for anyone to peruse.

Ready, Set, Film! If you'd like to help the team capture images of the corona, go to the project's webpage, **eclipsemegamovie.org**. You'll have opportunities to participate in training in the form of webinars and/or written instructions. You will, however, need your own camera — a DSLR or mirrorless camera with a 300-mm or greater telephoto lens will do. The camera should be equipped with a GPS receiver or be able to connect to one. A tripod is essential, as is an equatorial tracking mount.

The project's comprehensive FAQ page, at **eclipsemegamovie.org/faq**, has info on the required tech specs. Megamovie Communications Specialist Hannah Hellman urges those interested to join their Discord server (**https://is.gd/Megamovie_Discord**; the project website has instructions on how to use Discord for the uninitiated). "It's already looking like it's going to be a wonderful way for our community of volunteers to engage with one another leading up to and following the eclipse," she says.

Want to go a step further? Become a volunteer! The Megamovie team offer several ways to get involved in the project, including having detail-oriented citizens to help them sift through the data after the event. You can sign up here: **eclipsemegamovie.org/team/volunteers**. Are you a Spanish-speaker? You can volunteer to help the team communicate with the Spanish community along the path.

And now, let's all cross fingers and toes for clear skies on April 8th.

■ Observing Editor DIANA HANNIKAINEN is constantly amazed by what we continue to learn about our Sun.

Perfecting Collimation

With this routine, ensure your Newtonian astrograph will be at peak performance every night.

In the current age of affordable, large-format digital detectors, Newtonian astrographs have become popular among deep-sky imagers. These short-focal-ratio scopes are designed for capturing faint, deep-sky objects quickly and typically at a bargain price. However, these scopes are extremely sensitive to imperfect optical alignment. All too often, the first images taken with them are plagued with poor star images across much of the frame due to imperfect collimation.

Here's an effective method I use to align and test my Newtonian astrograph using commonly available tools, plus a few that you can easily make at home. The goal here is simple: sharp star images from corner to corner.

▼ **IN ALIGNMENT** This image of NGC 7000 shows the results of a finely tuned Newtonian-reflector astrograph using the author's technique to precisely collimate its mirrors and square the focuser. The image was recorded through his Orion 8-inch f/3.9 Newtonian Astrograph and an APS-H-format Atik 16200 CCD camera.

ALL IMAGES COURTESY OF THE AUTHOR

Higher Tool Standards

Imaging the night sky with the large sensors found in many of today's DSLR and other deep-sky cameras, astrophotographers often find what worked well for a smaller sensor is inadequate to cover the real estate of larger chips. The leading culprits are lack of precision collimation tools and a means to evaluate and fix a tilted focuser, which can create havoc with the star images at the very edges of your camera's field of view.

Poor collimation produces a variety of artifacts in deep-sky images, including hot spots, an asymmetrical coma pattern, variable focus across the frame, or a combination of all these issues. Even the best composed and processed images cannot make up for the appearance of distorted star images.

Additionally, the use of a matched coma corrector (a mandatory accessory when pairing a fast Newtonian astrograph with an APS-format or larger detector) complicates diagnosing the problems, as improperly spaced correctors can add their own aberrations as well. The challenge of precision optical alignment may lead you to give up on a telescope that has the potential to become a truly fine instrument. Standard collimation methods are often inadequate to fully correct these issues.

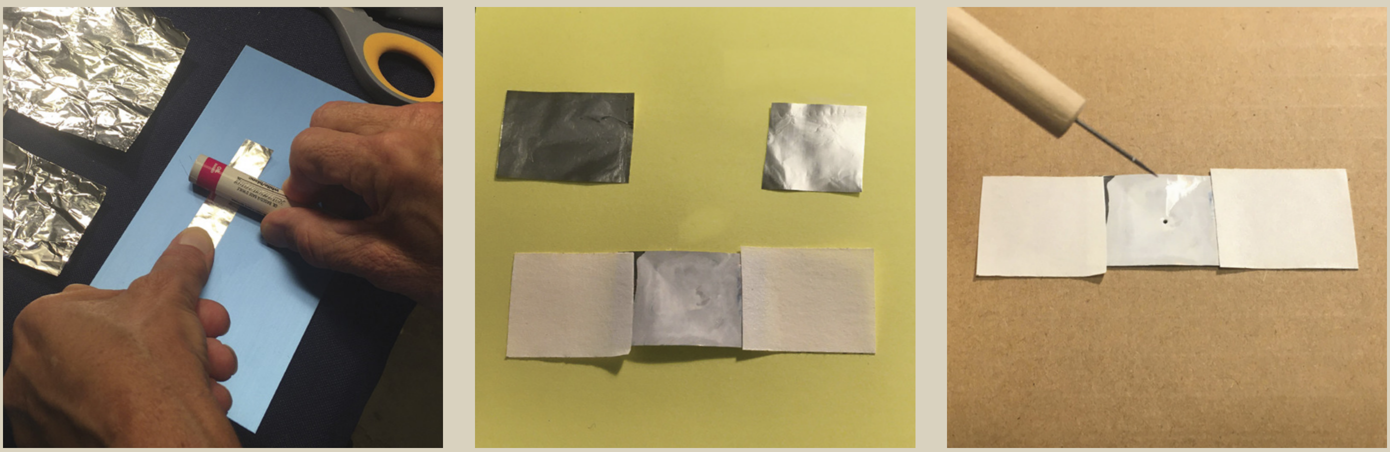
To improve your collimation precision, you'll need several tools. Most important are a laser collimator, a 1¼- to 2-inch eyepiece adapter, a 1¼-inch-format, perforated collimation cap (an accessory often included with new Newtonian telescopes), and a machinist's scale (a type of ruler). In addition, you'll need the tools required to adjust your scope's secondary mirror, typically a hex wrench set and a Phillips-head screwdriver. Other household items necessary include aluminum foil, scissors, masking tape, a fine sewing needle, and a little white paint with a small paint brush or a white paint pen, which you can find at most office supply stores.

▲ **REQUISITE TOOLS** To supercharge your Newt's collimation, you'll need several household items and a few telescope-specific tools. Seen from top to bottom are a roll of aluminum foil, a Phillips-head screwdriver, a pair of scissors, a paint marker, a laser collimator, masking tape, a set of hex wrenches, a collimator cap, a 1¼- to 2-inch adapter, and a machinist's scale. Not shown is the sewing needle needed to make the collimator mask.

Supercharging a Laser Collimator

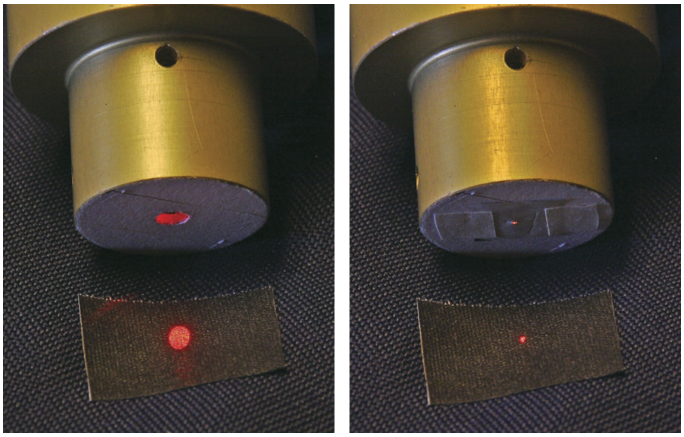
Laser collimators are a very popular tool for aligning Newtonian reflectors and are available from a variety of distributors such as Agena Astro (**agenaastro.com**), Hotech (**hotechusa.com**), or Orion Telescopes & Binoculars (**telescopes.com**). Most of these lasers project a roughly circular dot a few millimeters in diameter. But they aren't all made to the same level of precision — some are better than others.

With your laser collimator in hand, the first task is to verify its beam is mechanically aligned with its barrel. To do this, you'll need to place the device in a groove that allows you to rotate the collimator to see if its projected

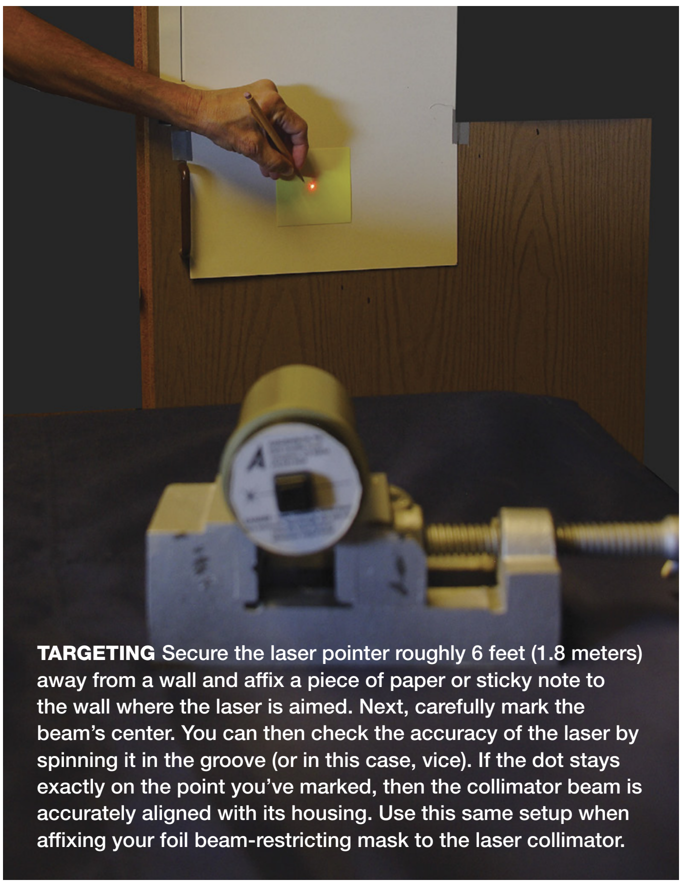


▲ **MASKING THE LASER** *Left:* Construction of the aluminum-foil beam restrictor starts by cutting a ½-inch-wide strip of foil. Place the foil on a flat surface and smooth out any wrinkles by rolling a marker or pencil across it. *Center:* Cut the foil to size, then add masking tape "wings" to affix the completed mask to the laser collimator. *Right:* Place the foil mask on a piece of corrugated cardboard and use a sewing needle to make a tiny round hole in the approximate center. Press straight down to avoid creating an oval-shaped aperture.

dot stays centered. A section of V- or U-channel aluminum stock found at most hardware stores works perfectly. Firmly secure the channel to a sturdy surface with a clamp or other means and aim it towards a wall roughly 6 feet (1.8 meters) away perpendicular to the laser beam. Slowly rotate the laser in the channel and watch to see if the beam stays in one spot or if it traces out a small circle. If the dot stays put, the laser is properly aligned within its housing. If not, check the housing carefully to see if it has any recessed adjustment screws to fix the problem. If it doesn't, you should consider replacing the device.



▲ **TINY DOT** Comparison of the laser collimator's beam before and after adding the aperture mask is shown above. Its smaller beam after adding the mask yields collimation results with greatly improved accuracy.



TARGETING Secure the laser pointer roughly 6 feet (1.8 meters) away from a wall and affix a piece of paper or sticky note to the wall where the laser is aimed. Next, carefully mark the beam's center. You can then check the accuracy of the laser by spinning it in the groove (or in this case, vice). If the dot stays exactly on the point you've marked, then the collimator beam is accurately aligned with its housing. Use this same setup when affixing your foil beam-restricting mask to the laser collimator.

If your laser passed the test, the next step is to improve its accuracy. The dots projected by most commercial laser collimators are often too large to allow extremely precise collimation. To greatly improve its accuracy, you have to narrow the beam using a simple mask created from the aluminum foil. To make this mask, cut aluminum foil into a small strip about a half-inch wide (13 mm) that you'll later fit over the end of the collimator where the beam emerges. Paint the shinier side of the foil with white paint and let it dry. This will become our target surface for the returning beam.

Our next task is to use the sewing needle and punch a small hole in the center of the foil on the white surface. For easier handling, you can mount the needle into the end of a pencil eraser by pushing the loop end into the eraser to hold it securely. Place the foil carefully on a piece of corrugated cardboard and prick a tiny hole right in its center. (I used a 0.025-inch-diameter needle.) Cut the foil strip into a square and place a piece of tape on each side of the foil in order to handle and secure it, and you're now ready to mount it on the collimator.

Sit the laser collimator in the channel block and turn the laser on. Tape a piece of paper or place a sticky note on the wall where the beam is projected, then mark the approximate center of the beam with a fine-tipped marker or pencil. Next, put the foil aperture over the end of the laser with the tape sticky side pointing down, but don't stick it to the collimator yet. Move the foil around until its restricted beam appears centered on the mark you made. It may take a few attempts to get it precisely aligned, but this step is very important. Now tape the foil aperture in place by folding the tape wings down along the sides of the device. As a final test, spin the laser again in the channel stock to verify it stays in one spot. If it does, congratulations — you now have a "super collimator" to precisely collimate your astrograph.

Achieving Perfection

Before using your super collimator, first ensure the telescope's secondary mirror is correctly positioned. In a Newtonian telescope with a fast focal ratio, the secondary mirror will be offset from the center of the tube due to the steep angle of the light cone compared to instruments of, say, f/8 or longer. Most manufacturers build this offset into the secondary mirror holder, so you typically don't need to worry about it. Instead, you'll only need to ensure the secondary's mounting post is centered in the tube. Using the machinist's scale, measure a spider vane from the inside wall of the tube to the very center of the central bolt, then do the same for the opposite vane. Average these two values, then using the vane tensioner adjustment screws on the outside of the tube, set the spacings to this average value. Do the same for the opposing vanes. This ensures that, even if the tube is slightly out-of-round, the secondary mirror's post mount will be exactly in the center.

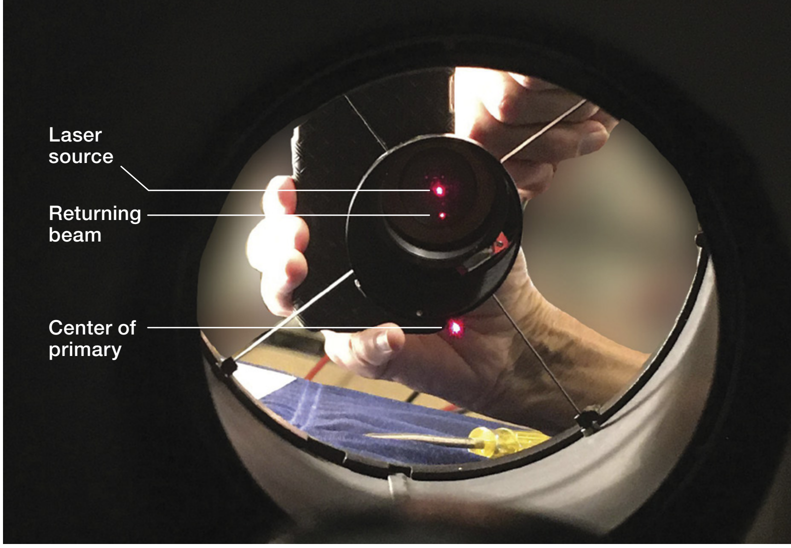
Next, you'll center the secondary beneath the focuser.

To avoid seeing the confusing reflection from the primary mirror, it's helpful to insert a black plastic bag into the tube between the secondary support and primary to mask it off. Once this step is completed, remove the plastic bag.

Insert a peep-sight collimator cap into the focuser and rack the drawtube all the way in. Peer into the cap's hole and center the secondary mirror's round reflective surface under the focuser by adjusting the center-post bolt to move the mirror towards or away from the primary mirror as needed. You should see the same spacing all the way around the secondary in the peep sight. Taping a white piece of paper inside the tube opposite the focuser makes it easier to make this adjustment. The goal here is twofold: First, you need to exactly center the converging light beam in the focuser drawtube to minimize any vignetting. Second, this also aligns the drawtube to be perpendicular to the converging beam in order to minimize tilt errors, which we'll discuss later. This alignment procedure works for both normal and offset secondary mirrors.

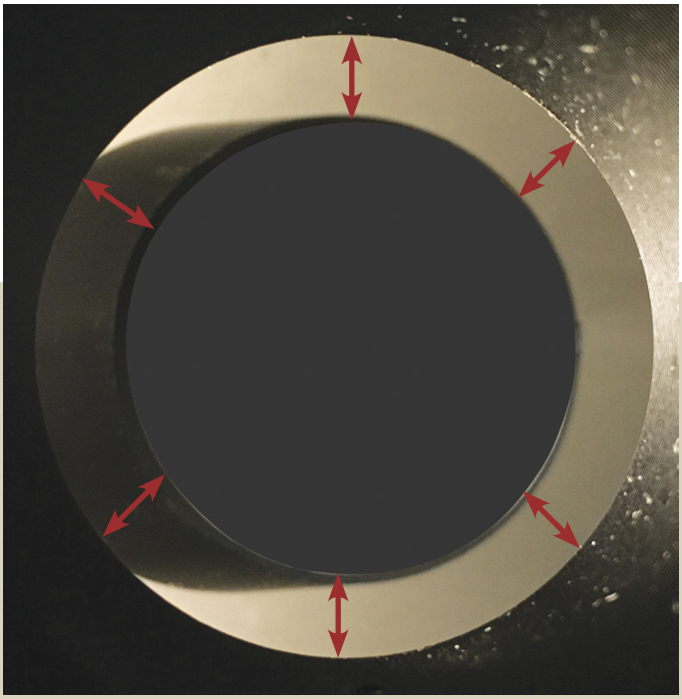
Now, use the three secondary-mirror adjustment screws to set the tilt of the secondary mirror to center the primary mirror. You should see an even gap all the way around the primary, and its retaining clips should be plainly visible. The secondary mirror is now roughly positioned and ready for laser collimation refinement.

Remove the sighting cap (as well as the plastic bag) and insert your super collimator into the focuser. Fine-tune the tilt of the secondary mirror using its three screws to center the tiny laser dot in the exact center of the primary mirror. If your primary mirror lacks a central mark, you'll have to remove the mirror cell from the back of the telescope tube and, using the machinist's scale, locate and mark its very center. This is essential for accurate collimation. Even if your scope came from the factory with its center marked, there's no guarantee it was done correctly. You should verify that it is before moving on to the next step.



▲ **LASER COLLIMATING** Use the reflection from the primary mirror to see the returning laser beam on your painted mask. Here the beam is off to the lower right, revealing focuser tilt that must be corrected.

▲ **CENTERING THE SECONDARY STALK** Use the machinist's scale to measure the centering of the secondary-mirror holder. Be sure to measure from the inside of the tube to the center of the secondary mirror mounting post on each side, then determine the precise length that both vanes need to be. After adjusting the left and right spider vanes, do the same for the top and bottom pair.



▲ **CENTERING THE SECONDARY MIRROR** Use a collimation cap to see the exact centering of the diagonal mirror. The spacing indicated by the arrows here should appear equal. The reflection of the primary mirror has been blocked for clarity. The goal is to capture all of the reflected cone of light from the primary to minimize vignetting in your images.

With the laser now aimed precisely at the primary mirror's center, adjust the primary's tilt to return the laser beam to the exact center of the white target on the laser. When the mirror is properly adjusted, the return beam will merge with its source.

Focus on the Focuser

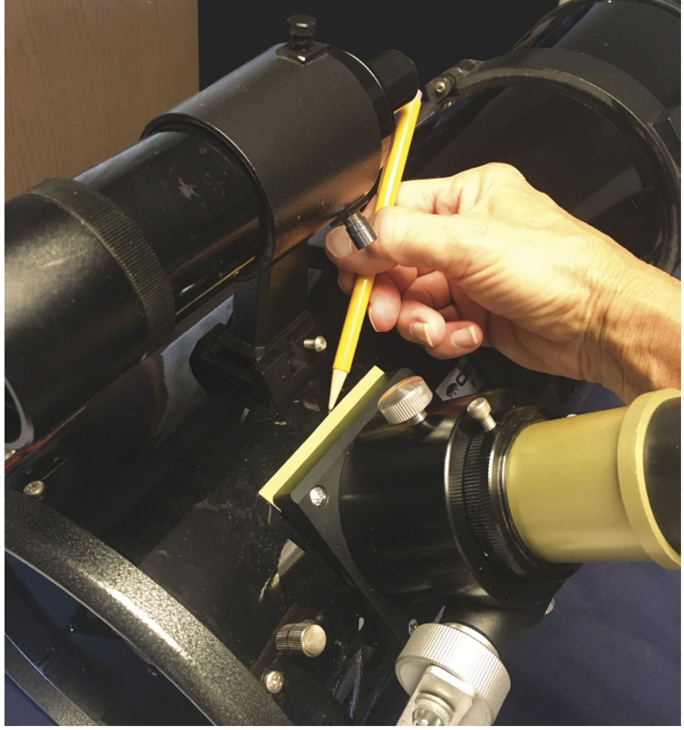
The scope is nearing excellent collimation. It's now time to check and adjust the tilt of the focuser — an extremely critical task for imaging. With the super collimator in the focuser and turned on, rack the focuser all the way inward until it stops. Readjust the tilt of the primary if needed to return the beam exactly to its pinhole source. Now rack the focuser all the way out. You can see the returning beam on the painted foil target by looking at its reflection in the primary mirror or using a small inspection mirror held inside the tube. The laser dot should still be exactly in the center. But more often than not, it's offset in one direction, and this indicates a tilted focuser or one with unacceptable mechanical slop. If this alignment is not spot on, you must adjust the four tilt-adjust screws found along the base plate of the focuser in order to recenter the beam onto the target. If your scope's focuser doesn't include angle-adjustment screws, you'll need to make the adjustments using shims made from plastic or metal.

To find out which ones need adjustment, simply push the focuser drawtube on its side with your thumb and observe the motion of the laser dot. When you find the side that pushes it back to center, that's the side which must be raised up. Turn the tilt-adjustment screws on the focuser no more than half a turn at a time. Lock the focuser tilt-adjust screws back down and then repeat all the collimation steps — changing the focuser's tilt negates all the earlier secondary and primary alignments.

You may have to repeat this process a few times before the laser dot stays put at both the inner and outermost positions. You can increase the accuracy of this alignment by adding a 2-inch spacer tube inserted into the focuser drawtube to increase the distance between the inner- and outermost points of measurement. If you do this, be sure to alternate the clamping screws on the extension tube with the focuser clamp screws to even out any potential offset errors.

Testing the Results

To use your camera and evaluate your astrograph's collimation, select a rich star field or open cluster and point the telescope in the general vicinity of your target. Take a few short exposures, being careful to accurately focus on a star as close to the center of the frame as possible. It's best to also guide your exposure on the star near the center of the field to avoid field rotation, which can ruin the accuracy of this test. When the exposure is complete, examine the image closely at 100% magnification or greater. Look for round stars at the center to ensure that the tracking was accurate, then inspect each of the four corners of the field one at a time. Any residual distortion should be similar in



▲ **FOCUSER ADJUSTMENT** Using the methods described in the article, the author determined he needed to raise one side of the focuser mounting plate to correct the tilt of the focuser in his 8-inch f/3.9 astrograph. This particular focuser didn't include adjustment screws, so the focuser was raised using thin, metal shim material.

all four corners, with stars in the center of the frame sharp dots. Even the best coma correctors will still have less sharp or slightly distorted stars in the corners, but our goal here is to even out the residual distortions so everything is symmetrical about the center of the field.

For *PixInsight* users, there are two tools available in the current version to aid analysis. One is the ***AberrationInspector*** script (***Script*** > ***Image Analysis*** > ***AberrationInspector***), and the other is the ***FWHMEccentricity*** inspector (***Script*** > ***Image Analysis*** > ***FWHMEccentricity***). Run the latter and hit the ***support*** button to generate a map of your distortions. A tilted focuser reveals itself in this script as a distorted area on one side or corner of the image. The program *CCDInspector* (**ccdware.com**) is also a great tool for analyzing your test results. In fact, that's the only thing the program does, and it does it very well.

In Closing

Proper collimation of your fast Newtonian astrograph will vastly improve the quality of your deep-sky astrophotos and should be repeated whenever stars begin to appear asymmetrical in your images. This technique is just as useful for visual observers, as well-corrected stars across the eyepiece are a pleasure to behold. The rewards of this effort are razor-sharp star images, not to mention the intricate details of nebulae and galaxies over the maximum amount of the field your scope can produce.

■ Retired engineer CHRIS SCHUR continually brainstorms ideas to perfect his astrophotography. See his work at **schursastrophotography.com**.

◀ SOLAR FILTERS

Orion Telescopes & Binoculars now offers a line of solar filters just in time for the great total solar eclipse this year. The Orion Safety Film Solar Filters ($99.99 to $149.99) are manufactured in the USA from high-quality, streak- and blister-free solar safety film rated as ND-5. They filter out 99.9999% of the visible spectrum, in compliance with ISO 12312-2 safety specifications for solar viewing. Available in sizes ranging from 3½ to 9½ inches, they are mounted in a metal cell that secures over the aperture of your telescope using plastic thumbscrews or foam inserts. The filters will fit telescope apertures ¼-inch smaller than the inner dimension of the filter cell.

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

◀ SOLAR BINOCULARS

Celestron rolls out a dedicated pair of binoculars for eclipse watchers. The Eclipsmart 10×42mm Porro Solar Binoculars ($87.95) are full-sized binoculars with permanently mounted, white-light solar filters over each objective lens. These binoculars permit users see magnified views of all the partial phases of a solar eclipse (or an entire annular eclipse) without fear of the filters falling off and accidentally revealing the unfiltered Sun. The optics are multicoated to provide high-contrast views of sunspots, granulation, and bright plage surrounding active regions free of ghost images and internal reflections. Each pair provides 12.7 mm of eye relief and can accommodate interpupillary distances ranging from 56 to 72 mm. The body has a durable rubber armor coating to protect it from damage. Four lens caps, a neck strap, and a padded cloth carry case are provided with purchase.

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

◀ ALT-AZ GO TO

Mount manufacturer iOptron continues to expand its line of strain-wave mounts with ever-increasing weight capacities. The HAZ71 Alt-Az Strain Wave Mount ($3,768) uses high-torque strain-wave drives in both axes to achieve precision slewing and tracking throughout the sky. The mount head weighs just 8.3 kg (18.3 lb) yet boasts a load capacity of 31 kg, without the need of cumbersome counterweights and shafts. Its multi-position saddle can be set up on the side or top of the drive base in order to accommodate binoculars. It comes with iOptron's powerful Go2Nova 8409 hand controller, which includes more than 212,000 objects in its internal database. The mount is also compatible with smartphone apps, including *SkySafari*, and links to your smart device via a built-in Wi-Fi. Its black, CNC-machined casing encloses all wiring, and your optics are secured with a dual Losmandy/Vixen-style saddle plate. Each purchase includes a soft carry case and a limited two-year warranty.

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

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

ZWO's Seestar S50 Smart Telescope

This smart telescope could be a game changer for people entering the world of astroimaging and observing.

◀ ZWO's new Seestar S50 smart telescope is notably compact and lightweight. The telescope itself is approximately 13 centimeters (5 inches) square and 25 cm tall. Its extendable, carbon-fiber tabletop tripod adds another 23 cm to the overall height. The scope and tripod together weigh less than 3 kilograms (about 6 lbs.).

ALL IMAGES ARE COURTESY OF THE AUTHOR

ZWO Seestar S50

U.S. Price: $499

seestar.com

What We Like

Excellent performance

Easy-to-use app

Noteworthy image quality for a 50-mm aperture

What We Don't Like

No direct entry for pointing to specific celestial coordinates

IN A 1968 LETTER to *Science* magazine, science-fiction writer Arthur C. Clarke penned what has become famously known as Clarke's Third Law: "Any sufficiently advanced technology is indistinguishable from magic." I had a powerful example of Clarke's observation only hours after receiving ZWO's Seestar S50 smart telescope.

Sitting on the steps of my backyard observatory in the light-polluted suburbs of Boston, it had been less than 10 minutes since I'd powered up the Seestar for the first time under a night sky and began controlling it with an app on my iPhone that I knew virtually nothing about. Yet here I was looking at a color image of M27, the Dumbbell Nebula, that rivaled some of the best images I had taken with a much larger telescope during the twilight years of emulsion-based astrophotography. And the image on my phone was getting better as the Seestar automatically added more 10-second exposures to the result.

For someone new to astronomy and astroimaging, this would certainly elicit a well-deserved "Wow!" But for those of us versed in the nuances and technological challenges of astroimaging — setting up and initializing a Go To telescope, centering a faint deep-sky object on a small detector, accurately focusing an astronomical camera, autoguiding, and stacking images made with an altazimuth-mounted telescope — the image of M27 looked like magic was involved. After all, I'd done nothing more than set the Seestar down on a level surface, turn it on, and select M27 as my target from the app's list of "tonight's best" objects. The Seestar took care of everything else automatically and quickly. ZWO promotes its new smart telescope as being easy to use, but it still surprised me by just how easy it was. And there were more surprises in store as I continued to test the device on loan from ZWO for several months last fall.

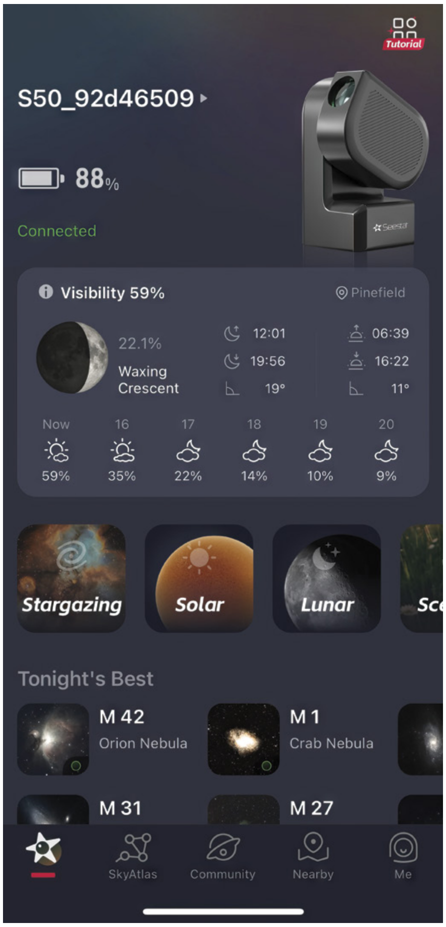
Introducing Seestar S50

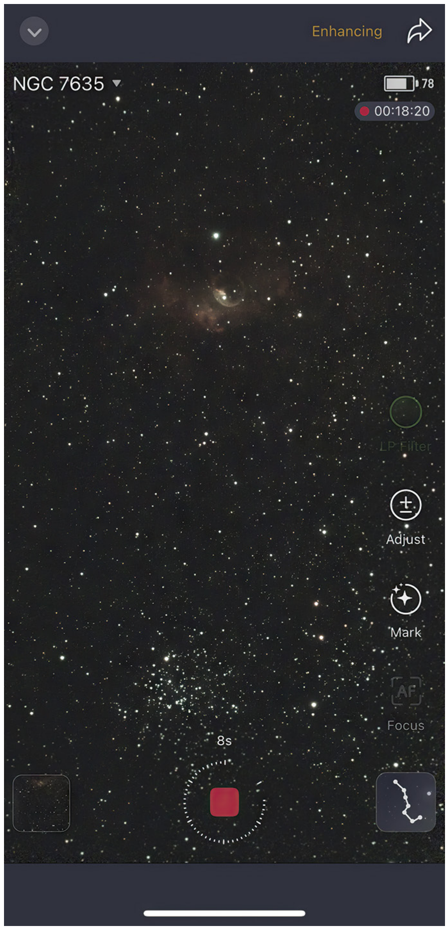
The Seestar is billed as a smart telescope, and it comes as a complete package. You don't need a single accessory (besides your smartphone or tablet) to do everything it's designed to do. Just counting the major items, you get a 50-mm f/5 telescope with an apochromatic triplet objective, a built-in astronomical color camera with a Sony IMX462 sensor, a filter "wheel" with a dual-band O III/hydrogen-alpha filter, a computerized Go To altazimuth mount, a carbon-fiber tabletop tripod, an electronic focuser (with a notably accurate auto-focus feature), and a dew heater to keep condensation from fogging the objective.

Seestar can shoot stills and videos of the Sun (using the included solar filter), Moon, and daytime scenery, and it saves them on your phone. It can also shoot video of the Sun and Moon that's recorded in AVI format to the Seestar's internal 64 gigabytes of memory for later transfer to a computer for stacking.

The powerhouse feature of the Seestar, however, is its stargazing mode, which saves images to your phone as well as astronomical FITs files to the internal memory for later processing with appropriate software.

The Seestar S50 isn't the first smart telescope. In recent years we've reviewed several similar products, including the Stellina (*S&T:* Mar. 2020, p. 68) and its smaller sibling Vespera (*S&T:* June 2023,



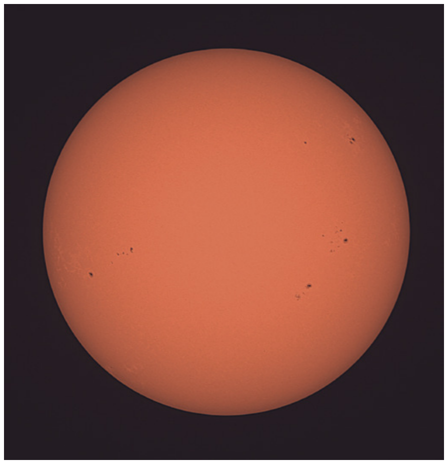


◀ *Far left:* The opening screen of Seestar's app displays weather and observing information as well as the device's current battery level and the four observing modes. Scrolling down brings suggestions of things to observe. *Near left:* While shooting images of objects (in this case the Bubble Nebula, NGC 7635, and nearby open cluster M52), the total exposure time is tallied at upper right, while a countdown "clock" surrounding the red square at bottom keeps tabs on each 10-second exposure that will be added to the total.

p. 66) made by the French company Vaonis, and Unistellar's eVscope (*S&T:* Dec. 2020, p. 66). But the Seestar has several notable differences. Foremost is cost. At $499, the Seestar is currently about $1,000 less expensive than the lowest priced of the other three. It's also very compact. And while a bit more difficult to quantify, its images generally exceed what even experienced astrophotographers would expect from a 50-mm f/5 telescope. That quality was certainly helped by ZWO's experience making high-quality astronomical cameras and associated software for more than a decade before introducing Seestar in April 2023.

Setting up the Seestar is very easy. Out of the box its internal battery was charged to more than 80%, so only a few minutes connected to an old iPhone USB charger topped it off. The free *Seestar* app is available for iOS and Android devices. Simple instructions got the Seestar connected via Wi-Fi to my iPhone 11 Pro so I could complete a one-time activation process. The only caveat here is that the phone needs to be connected to the Seestar and the internet at the same time. In the house, my phone uses its Wi-Fi to connect to our home network and the internet. With the phone's Wi-Fi now used for the Seestar connection, I had to rely on the phone's cellular-data connection to

◀ For many of the brighter deep-sky objects (think Messier list), the Seestar can create a remarkably satisfying view with only a minute or two of exposure, but the best image will always come with longer exposures. These views of the Dumbbell Nebula, M27, are reproduced directly from the files saved on the author's iPhone. The one at far left was saved after only 1 minute of exposure, while one at near left is the result after 41 minutes.



▲ Seestar has observing modes for the Sun and Moon that can save still images and video on your smart device used to control the scope. You can also save AVI-format video files of both objects to Seestar's internal memory to be downloaded later and processed with astronomical video-stacking software. These images of the Sun and Moon (taken last September 26th and 27th, respectively) were made from 10-second AVI video clips processed with ZWO's free *ASIStudio* software.

access the internet. It was a seamless operation for me, but a location with poor cell service might have problems.

Chances are good that the activation process will also include a notification that a firmware update is available, and it will take a few minutes to install it. These updates happened several times during my testing (as well as an update of the iPhone app), each adding more features to the Seestar and occasional bug fixes. All were accomplished without a hitch.

The only requirements for setting the Seestar up outside are that the device be level and its internal digital compass is calibrated. The app will notify you if these conditions aren't adequately met, and there are built-in routines to help you achieve both tasks. The date, time, and location information that Seestar also needs to find objects is gathered from your phone.

A Brief Peak Under the Hood

Here's a quick summary of how the Seestar's stargazing mode works. When the sky is dark enough to show stars (you need to be the judge of this since Seestar doesn't know this on its own), you use the app to select an object to observe. There are several ways to do this, including choosing from a list of "tonight's best," using a search function that accepts common names and designations of astronomical objects, or using a scrollable sky map called SkyAtlas that lets you position objects within the Seestar's fixed 0.72° by 1.28° field of view. As of this writing, there's no way to select a target by its right ascension and declination coordinates, but this never proved to be a problem. I could always find a nearby target that was available with the other search methods and then slide the displayed star map to position my coordinates in the camera's field of view. You'll be warned if your object is below the horizon.

Once you have your target selected in the SkyAtlas, you tap the ***GoTo*** button and Seestar begins slewing rapidly and very quietly to the appropriate area of the sky. When it arrives, it snaps a quick exposure of the star field (the exposure is automatically adjusted if necessary) and uses an internal plate-solving routine to determine exactly where the scope is pointed. The night's first target usually isn't centered in the initial exposure, so the scope automatically moves the appropriate distance to center the target and verifies it with another brief exposure. This whole process usually takes only a minute or two and is amazingly accurate and totally automatic.

With the field centered, the Seestar begins updating the app's display with short exposures. You can use the displayed image to fine-tune the field of view with a virtual joystick that appears on the phone's screen when you hold your finger on the display. Brighter deep-sky objects like M27 are often faintly visible in these exposures, but don't worry if they're not. The fun begins by tapping the ***Enhance*** button. The first time you do this each night the app will pause for about a minute while the Seestar shoots a half-dozen dark calibration frames. The app then displays an enhanced image of your target that is continuously updated as

▶ *Near right:* Although the Seestar has four rubber feet on the corners of its base, suggesting it can be set down on a table, the device must be elevated on its central pivot so that it can rotate during operation.

▶ *Far right:* Seestar's 50-mm f/5 three-element apochromatic objective, coupled with its Sony IMX462 CMOS detector, provides a 0.72° by 1.28° field of view that is well suited for the Moon, Sun, and many deep-sky objects. But its relatively low effective magnification has limited value for observing the planets. A built-in dew heater is effective at keeping the objective free of condensation.

▲ *Left:* This view of the globular star cluster M13 is reproduced from the image saved on the author's iPhone after a 15-minute exposure. A better result is possible by using dedicated astronomical software to process the FITS file saved in the Seestar's internal memory, but it's certainly not a requirement to get good results. *Right:* Because Seestar's fixed field of view is too small to capture the whole Andromeda Galaxy, M31, at once, the author made three overlapping 7-minute exposures and stitched them together. This view is from images saved to the iPhone rather than processing the FITS files.

10-second exposures are automatically snapped and stacked. A countdown "clock" and total-exposure tally keep you informed during the stacking process. After a minute or so even relatively faint deep-sky objects are visible in the displayed image. At any time during the image updating, you can tap a button to save the current result while the stacking continues. And as is always the case with deep-sky imaging, the longer the total exposure the better the result.

Because I was mainly interested in exploring features of the Seestar, my first nights of testing were usually spent making exposures of just a few minutes. Although the individual Seestar exposures are fixed at 10 seconds, the stacking time can vary depending on how much internal calculation is needed to compensate for the image rotation that's inherent when shooting with an altazimuth mount, and this can also vary depending on your target's location in the sky. For one object near the meridian, it took 30 minutes to accumulate a total exposure of 20 minutes, and 90 minutes to complete a 61-minute exposure. For another object high in the northeastern sky, it took 34 minutes to complete a 20-minute exposure.

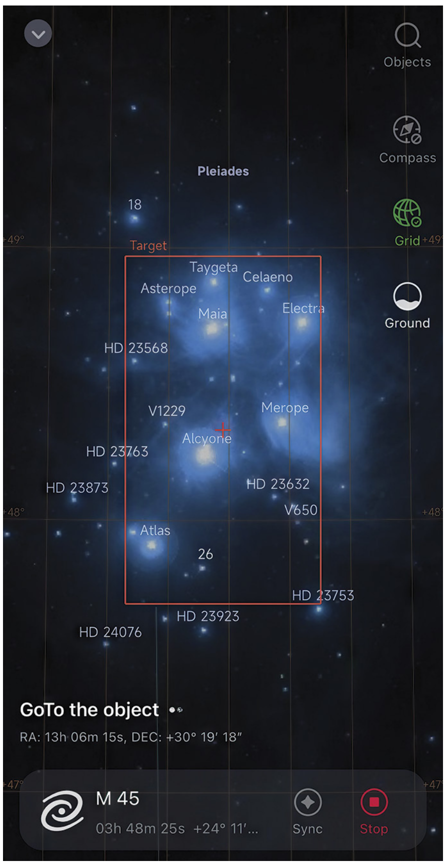
Seestar uses an internal algorithm to decide if images are good enough to stack. I don't know all the criteria for rejecting an image, but there were clearly times when an image was rejected because its 10-second exposure was not added to the total exposure time. The rejection algorithm, however, is not flawless. One night while shooting from the deck on our house, my stacked image was sometimes fuzzy because slightly blurred exposures caused by vibration as I walked around the deck were added to the stack. The lesson here is to always have the Seestar sitting on a solid surface.

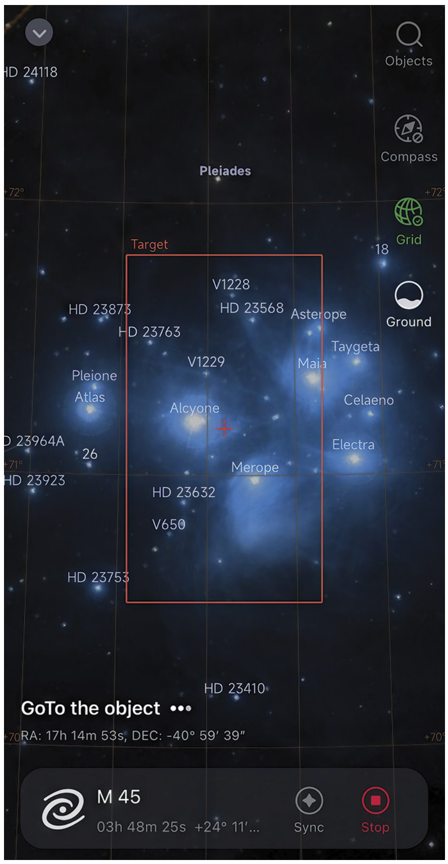
At first it was fascinating to stare at my phone as images were accumulating, but my enthusiasm faded when shooting longer exposures (not to mention the process being a drain on my phone's battery). The good news is that once the Seestar starts shooting a target you can turn off your phone and walk away. You don't need to maintain a phone connection for Seestar to continuously shoot an object. If you want to monitor the image progress, you simply open the app and reconnect to the Seestar. This is also good news if you walk too far from the Seestar while it's running, since the Wi-Fi connection isn't particularly

◀ *Far left:* When using Seestar to view the Sun, the app first asks to confirm that the included solar filter is attached to the scope before automatically pointing toward the Sun. Putting the filter over the objective is on the honor system, and if you confirm it's attached when it's not, you'll almost certainly destroy the detector if you point sunward.

◀ *Near left:* The included fitted hard foam carrying case holds the entire Seestar setup and weighs only 3.6 kg (less than 8 pounds) with everything inside.

▲ This 61-minute exposure of the Helix Nebula is reproduced from the Seestar's FITS file. It is only lightly processed. There are a multitude of software programs specifically made to process and enhance astronomical FITS images, but excellent results are still possible with minimal processing.





▲ As explained in the text, the framing of astronomical objects in Seestar's rectangular field of view depends on their position in the sky at the start of the exposure. These screen shots from the Seestar app show the framing of the Pleiades if the exposure was begun with the cluster in the eastern sky (left) and later in the evening when it's closer to the meridian (right).

robust over longer distances. A lost connection doesn't mean a lost image. I could usually maintain a connection with Seestar on the deck of our house while I was about 6 meters away in the family room. But in the observatory, I often lost the connection when I went downstairs to an office under the telescope floor.

Notes From the Field

The *Seestar* app is very easy to master. Indeed, I can't recall any astronomical software that was easier for me to learn. Nevertheless, during the course of my testing I found a few things that may help people starting out themselves.

The most important one involves Seestar's digital compass, which is used by the device to get its initial bearings when finding objects. In the stargazing mode, the Seestar quickly refines its pointing with the plate-solving routine mentioned earlier. The compass can be way off the mark and this routine still works. But if your first target is the Sun or Moon, plate solving isn't involved, and a compass error can prevent Seestar from finding its target even though it automatically searches the sky area where the compass first directs the scope to point.

Digital compasses are notably finicky when used around steel objects. I've known for years that my observatory is a toxic place for a digital compass. It houses five steel piers, not to mention the steel rails for the roll-off roof; and the cement slab of its floor contains lots of steel rebar as well as some railroad track (really). This is the reason I spent my first night with the Seestar sitting outside on the observatory's steps where I was well away from all the steel — I wanted to give the device a fighting chance during its inaugural performance.

Occasionally the Seestar would prompt me to use the compass calibration routine when I powered it up or it couldn't locate the Sun or Moon. But I found it best to do this even without the prompt if I moved to a new location. Also, when my target was the Moon in a dark sky, I'd start with the stargazing mode and point to a bright star so that the plate-solving routine could precisely refine Seestar's pointing. As such, it never missed targeting the Moon after the star pointing. This of course isn't possible when your target is the Sun or the Moon in a daytime sky, so a compass calibration is a good idea. Even so, I wasn't always successful getting Seestar to automatically find these targets, and I would have to point to them manually.

ZWO claims the Seestar runs for about six hours with its internal battery fully charged, and that agrees well with my tests as long as I wasn't doing excessive slewing to lots of objects. The built-in dew heater is very effective at keeping the objective clear, but it does consume power. One night with the heater on continuously my battery level dropped to 20% after four hours, suggesting that the full charge would have lasted about five hours rather than six. You can charge the battery via the USB cable while the Seestar is operating, but there is no cable-wrap feature, so you need to be mindful of having enough slack in the cable to prevent it from binding up as the scope turns in azimuth.

One night I had the Seestar fail to find its first target in the stargazing mode when the object was in a sparse field of faint stars. Moving to a field with bright stars revealed the reason why — the stars were out of focus enough that faint ones didn't work for the plate-solving routine. Earlier that day I had used the Seestar in the scenery mode and focused on a terrestrial object about 150 meters away. For unknown reasons the Seestar had not automatically returned to its default focus setting for the stargazing mode. Other times when I had focused on close objects during the day the default setting was automatically restored at night. It's worth mentioning that the Seestar's auto-focus routine is exceptionally accurate for all its observing modes and even lets you select the point in the field of view that you want to focus on, something that's especially useful in the scenery mode.

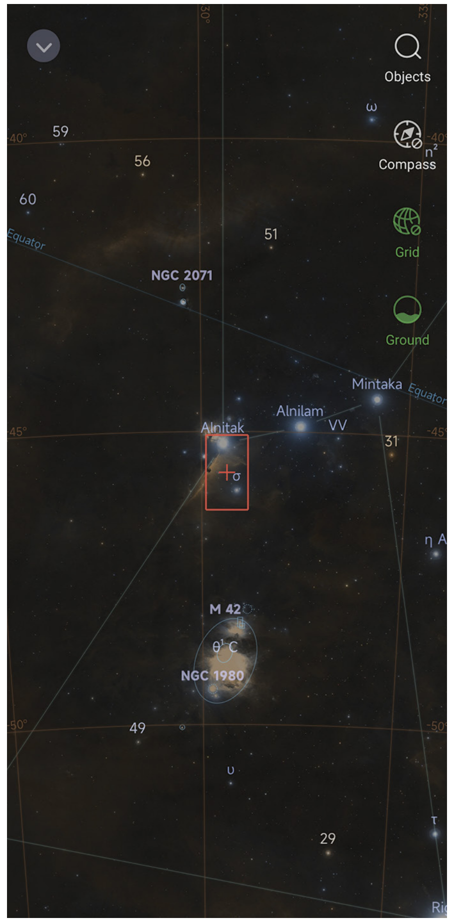
Seestar's camera has a rectangular field of view, with the long axis always oriented perpendicular to the ground. When pointing at objects near the meridian, this makes the long axis aligned roughly north/south on the celestial sphere. But if you move to objects near the eastern or western horizon, the long axis is more closely aligned east/west on the celestial sphere.

This can be confusing for those of us who are used to thinking about celestial directions in terms of right ascension and declination. But Seestar's brain works with altitude and azimuth, and altitude is always aligned with the long axis. As such, Seestar does a clever bit of internal calculating to decide the best way to frame a target depending on its position in the sky. (See the illustration of the Pleiades framing on the facing page.) This initial framing is maintained as the object tracks across the sky while Seestar is shooting images. As mentioned earlier, Seestar automatically rotates images as it stacks them, so in some parts of the sky long exposures will have artifacts at the edge of the frame, where the rotated images do not fully overlap and thus are underexposed and noisier than for the rest of the field.

Final Thoughts

I had mixed emotions while testing Seestar. It was exciting to imagine how much a product like this could get people interested in observing and astroimaging. But I also had reservations because Seestar was yet another reason for having us looking down at a smartphone screen when there was a beautiful starry sky overhead. Before I went too far down that path, however, I reminded myself how many hours I've spent in the past under a beautiful night sky staring at the illuminated crosshairs of a guide telescope — technology changes, but the result may still be the same. These conflicting emotions were before I realized that I could turn off my phone and enjoy the sky in other ways while Seestar gathered images that I would admire later.

But there was another thought, too, as I watched Seestar's images "develop" on the phone's screen as each 10-second exposure was added to the stack.



▲ The *Seestar* app includes a scrollable planetarium called the StarMap, showing a photographic image of the night sky with many deep-sky objects labeled. Simply select a target then click the GoTo button, and soon the device is pointing at it and beginning its recording.

After only a minute or two the view always showed more detail, not to mention color, than I could see visually with a much larger telescope under the same sky. It's not the same as looking through an eyepiece — and I know there are plenty of people who will takes sides on this issue — but you can't discount the excitement many people will get from exploring the heavens with the Seestar if they do nothing more than enjoy the views in real time on a phone's screen. The Seestar just might be a real game changer for a new generation of astronomy enthusiasts. We live in interesting times.

■ **DENNIS DI CICCO** is never far from his cell phone, but he's happiest when it's in his pocket rather than his hands.

Make a Solar Finder

How to point out the obvious

WITH THE UPCOMING total solar eclipse on April 8th, many people in North America are dusting off their solar filters or making new ones so they can safely view the event through their telescopes. (For advice on how to build your own filter, check out my article in *S&T:* June 2017, p. 38.)

One problem you'll quickly discover when you put that filter on your telescope is how difficult it is to aim the scope at the Sun. You'd think it would be easy, given that the Sun is right there in the sky, but it's not. The Sun is too bright to look directly at without a protective filter. And at only ½° across, it doesn't appear in a filtered view until you're right on it. (You won't see a gradual brightening of the field as you get close, because solar filters are too dense for that.)

In order to aim reliably at the Sun, you need a solar finder. I wrote about several types back in 2017, too (*S&T:* July 2017, p. 72), but I've since become fond of another simple design that I only mentioned in passing then.

This design is made from a short piece of PVC pipe. One-inch-diameter works well, but pretty much anything will do. Cut a piece three to five inches long. Put a cap on one end, with a hole drilled in the center of the cap. You can use an end cap designed for the pipe size you're working with, or any opaque material will do. Cardboard works fine. For the one pictured below, I made a circle cut from a sheet of white PVC plastic and glued it to the front of the pipe.

The hole in the center of the cap allows a beam of sunlight to enter the tube. You can make it any size you want, within reason. (I used a #43 drill bit for mine.) If you put a translucent screen on the back of the tube, that beam will fall on the screen when the body of the finder is pointed at the Sun.

Thin paper works okay for the screen, but depending on its density it might be a little too opaque to be ideal. I found a piece of plastic shopping bag

◀ Steve Edberg cut the rear end of his finder at an angle to make the screen viewable from the side.

to be perfect for the task. California ATM Steve Edberg made his from a piece cut out of a report folder made from translucent plastic.

Steve added one further refinement to his finder that I like quite a bit: He cut the rear of the tube at an angle in order to view the finder from the side or from above. No hunkering down necessary!

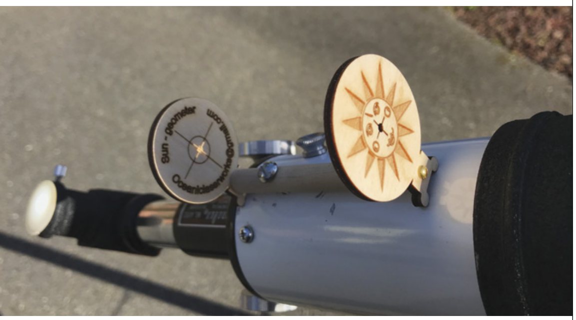
Steve uses tool clips to mount his solar finder to the body of his optical finder. Note that if you do this, you *must* cap the lens of the optical finder — it can be dangerous without the cap, not to mention the finder's crosshairs will melt away.

I built a dovetail foot for my solar finder so it completely replaces the optical finderscope. That also lets me move the solar finder onto any scope that has a universal dovetail mount, provided I have a solar filter for that scope.

You'll be tempted to put a center dot on your projection screen, and you should certainly dot it, but the odds that you'll need it exactly on-center

▲ *Left:* This simple solar finder uses a short piece of PVC pipe with an opaque cap on front, with a hole in the cap to allow a narrow beam of sunlight through. *Right:* The rear of the finder uses a thin piece of white plastic shopping bag for a screen. Note that the index mark isn't on-center. That's because the dovetail bracket that holds the finder isn't perfectly aligned with the telescope's optical axis.

FRONT AND REAR VIEWS OF THE FINDER: JERRY OLTION (2); SOLAR FINDER WITH ANGLED SCREEN: STEVE EDBERG



BOB SCHALCK

▲ Bob Schalck's Sun Geometer is laser-cut, works well, and can be mounted on any telescope. Contact Bob at **oceaniclaserworks@gmail.com**.

are pretty slim. That's because finder mounts are seldom perfectly aligned with the optical axis of the telescope. What you'll want to do is aim the properly filtered scope at the Sun, using your solar finder to help get you in the ballpark, then, when the Sun is centered in the field of view, put a mark on the screen in the middle of the dot of sunlight that makes it through the hole in the front of the finder. That'll give you a repeatable target to hit, one that will put the Sun in the field of view every time.

Of course, if you move the finder to a different scope, that dot will likely not be accurate. Simply mark a new dot where the Sun is centered in the second scope with a different color pen. Problem solved!

I seldom mention commercial products here, but if making your own solar finder isn't for you, I'm particularly fond of the laser-cut finders made by Oregon ATM Bob Schalck. Featured in our November 2023 issue on page 70, Bob's "Sun Geometer" is cute, lightweight, and very functional. It projects a cross against the back target, and if you're far off target, the cross becomes a line that tells you which way to move the scope. Nice touch!

Whichever way you go, make sure you have a good finder by eclipse day. You don't want to be wasting time trying to locate the Sun while the eclipse is happening!

■ Contributing Editor **JERRY OLTION** plans to cut a diagonal screen into his finder.

How Are Asteroids Named?

THERE ARE MILLIONS of asteroids in the solar system. Some are as small as an ostrich, while others outspan Iceland; however, most first appear as faint blips caught moving among the background stars in a sequence of photographs. So it may come as no surprise that an asteroid's path to recognition is long and, ahem, rocky.

What Is an Asteroid?

Functionally, an asteroid is a small, rocky body that orbits the Sun. They're essentially leftovers of the planet formation that occurred in the solar system 4.6 billion years ago. Most of them have changed little in the intervening eons, though they can be altered by impacts and solar heating.

Technically, "asteroid" is somewhat trickier to define since, surprisingly, the International Astronomical Union (IAU) has never offered an exact definition. Instead, in the same resolution in which the organization set out a new understanding of "planet" in 2006, it also lumped together asteroids, comets, and other objects as "small solar system bodies." That designation covers anything that is not a planet, dwarf planet, or natural satellite.

However, since the IAU defines meteoroids as being smaller than 1 meter (3 feet), then anything larger could logically be called an asteroid. The smallest asteroid known to date, 2022 WJ_1, is barely 1 meter across.

Most known asteroids orbit the Sun in what's called the main belt, which lies between the orbits of Mars and Jupiter, 2.2 to 3.2 astronomical units (a.u.) from the Sun. That is, their orbits are roughly 2 to 3 times wider than Earth's. Thousands of asteroids, known as Trojans, share Jupiter's orbit, at an average distance from the Sun of 5.2 a.u. Others are renegades, with elongated or unusual orbits. Small objects much farther from the Sun, near and beyond Pluto's orbit, have icy rather than rocky compositions. But all of these also receive designations that follow the rules for asteroids.

IAU's rules for proposed asteroid names:

- 16 characters or less in length
- preferably one word
- pronounceable (in some language)
- not offensive or political
- must differ from existing name by at least one letter

A Brief History of Asteroid Discoveries

Astronomers spotted the first asteroids in the 19th century. On New Year's Day of 1801, Giuseppe Piazzi was cataloging the faint stars of Taurus when he came across 1 Ceres (now classified as a dwarf planet). A year later, Wilhelm Olbers found 2 Pallas; he later proposed that the asteroids had once been part of a planet between the orbits of Mars and Jupiter. The next few years saw the announcements of 3 Juno and 4 Vesta.

Then, despite energetic efforts, came four decades of nothing. But the lull was only temporary: The next discovery occurred in 1845, and by 1868, observers had visually discovered some 100 asteroids. Driven by the advent of photography, by the late 20th century

◀ **HISTORY OF A NAME** Wilhelm Olbers discovered Vesta in 1807 from Bremen, Germany, while searching for more objects like Ceres and Pallas. But Olbers didn't name Vesta; he gave that honor to Carl Gauss, whose calculations of the object's orbit had led to its confirmation. Gauss named the asteroid for the Roman goddess of the hearth and home.

NASA / JPL / MPS / DLR / IDA / DANIEL MACHÁČEK discoveries climbed into the hundreds each year. Now, it's in the thousands.

Of course, the influx of new finds meant that astronomers needed to find a way to categorize them. Initially, the discoverers named the asteroids, typically after female Greco-Roman deities such as the aforementioned Ceres, Pallas, Juno, and Vesta. By the 1850s, the editors of the *Astronomische Nachrichten* had begun assigning numbers to new discoveries. As the number of new asteroids multiplied, modifications had to be made, making these early efforts at organization increasingly complex and sometimes clumsy.

A New Way to Name

Starting in 1892, a new scheme emerged, and the IAU still uses it today. Here's how it goes: First, there is the discovery, which entails at least two nights of observations of a new object. The observer submits these to the IAU Minor Planet Center, which assigns a provisional designation according to a specific format: It begins with the year of discovery, followed by a letter of the alphabet (except I and Z) to show the half-month of discovery; then, another letter (except I) shows the order of the discovery within that half-month. If there are more than 25 discoveries within a half-month, numbers are added to show how many times that letter has been repeated.

If that's clear as mud, here's an example: Let's take discoveries made between September 16th and 30th in 2021, which receive an initial letter "S." The first few would be designated 2021 SA, 2021 SB, 2021 SC, etc. Once the discoveries in that time period reached 25 (2021 SZ), the sequence would roll over with an additional number (2021 SA_1).

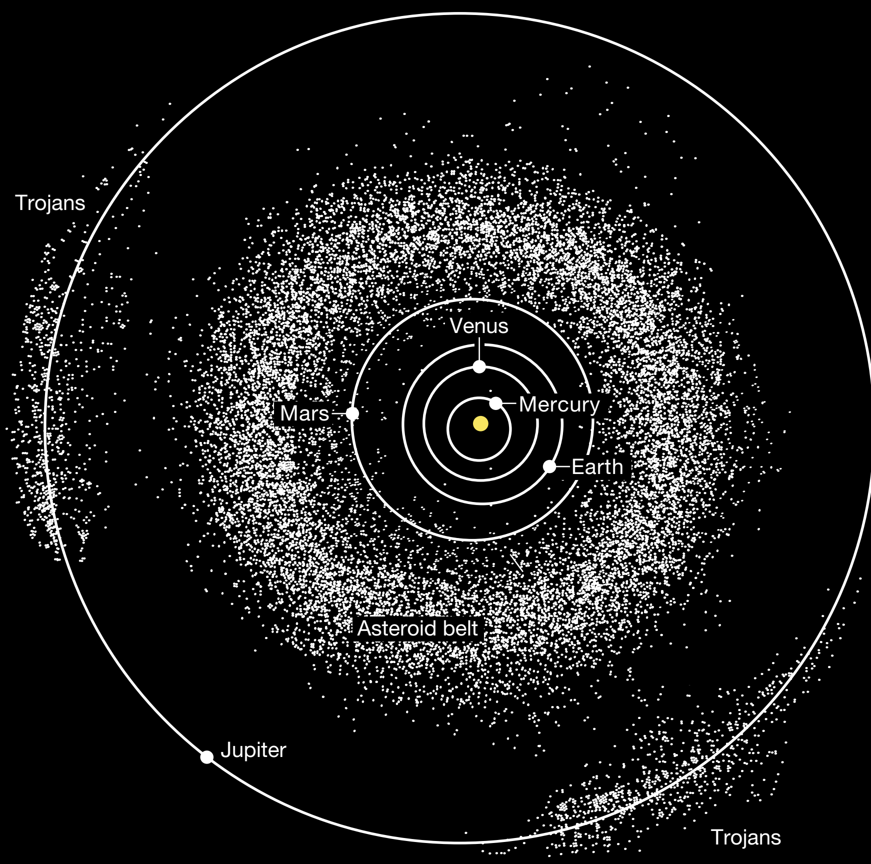
This designation is a placeholder used to identify an object while additional observations are conducted to nail down its orbit. Astronomers need to know the object's position to predict where to find it in the future. Sometimes figuring out the orbit of one object ends up linking it to observations of another one. Once the orbit is determined, the Minor Planet Center assigns a sequential number. As of press time, those numbers (starting with 1 Ceres) are up to 640000!

Identification doesn't end with numbers. Once an asteroid's orbit is well known, the discoverer may offer a name to the IAU's Working Group for Small Bodies Nomenclature. Its rules (at left) are simple and allow a lot of room for creativity. (Note: An asteroid's name cannot be bought!)

To date, 24,534 asteroids have received names, some for influential people, such as 5102 Benfranklin, 284996 Rosaparks, and 316201 Malala; others for ancient gods, like 433 Eros and 99942 Apophis. Some are playful, like 13579 Allodd and 24680 Alleven. Still others, like 13681 Monty Python and 88705 Potato, combine cultural recognition with a touch of whimsy.

▲ **ASTEROID MOONS** Even the moons of asteroids may receive names. Discovered in 1994 after the flyby of NASA's Galileo mission, the moon of 243 Ida was later named Dactyl, after the mythological creatures that lived on Mount Ida on the island of Crete.

Not every discoverer gets around to naming their asteroid, though. The IAU limits a discoverer's naming privileges to 10 years after the asteroid receives a number. After that time, IAU's Working Group may assign names from a pool of submissions. With the uptick in discoveries in recent decades, more than 600,000 asteroids could still receive names. ■



▲ **MAIN BELT** A million or so asteroids reside in the main belt between the orbits of Mars and Jupiter; thousands of additional asteroids belong to the gravitationally stable regions on either side of Jupiter in its orbit around the Sun. (This diagram is based off of data from the Minor Planet Center, published in 2006.)

ASTEROID MOON: NASA / JPL; MAIN ASTEROID BELT DIAGRAM: BEATRIZ INGLESSIS / S&T

EMERGING ECLIPSE
David Thorn
The crescent Sun peeks through thin clouds following maximum eclipse as seen from Seattle, Washington, on October 14, 2023.
DETAILS: *Samsung Galaxy S22 Ultra smartphone. Total exposure: 1 second at f/2.4, ISO 40.*

◁ RED PUFFBALL

Massimo Di Fusco

Purgathofer-Weinberger 1 (PuWe 1) is a large, ancient planetary nebula located in Lynx. Its gas and dust have expanded far from the white dwarf at its center, making PuWe 1 one of the faintest planetary nebulae known.
DETAILS: *Sky-Watcher EvoStar 80ED APO refractor, Konus Konusky 200-mm reflector, and Player One Astronomy Poseidon-C camera. Total exposure: 63 hours recorded with and without an Optolong L-Ultimate narrowband filter.*

▽ EPIC INTERACTION

Vikas Chander

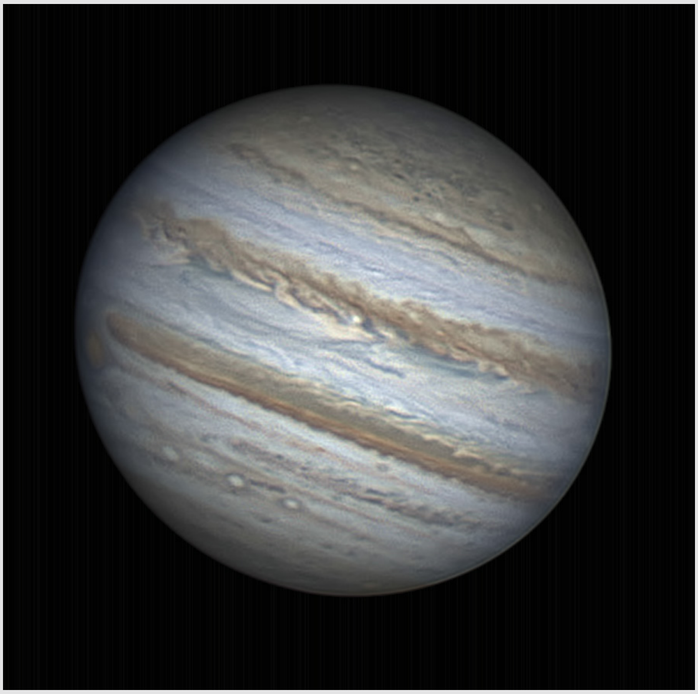
The giant lenticular galaxy NGC 1316 (middle) in Fornax contains several shells and arcs in its outer halo, the result of a collision between two spiral galaxies billions of years ago. Spiral galaxy NGC 1317 is seen to the lower left. North is to the left.
DETAILS: *PlaneWave CDK17 corrected Dall-Kirkham telescope and SBIG STX-11002 camera. Total exposure: 22 hours through LRGB filters.*

FIRST QUARTER

Oleg Bouevitch

The Moon is far from a colorless desert. Mare Tranquillitatis reveals its purplish tint in this saturated image taken during first quarter on March 21, 2021. Read more about the hues visible on the Moon on page 52.

DETAILS: *14-inch Schmidt-Cassegrain and Sony α7 III camera. Stack of 400 frames through RGB filters.*



◁ STORMY JUPITER

Jeff Phillips

Jupiter displayed a turbulent North Equatorial Belt and Equatorial Zone on November 26th as the Great Red Spot (left) rotated into view. Three white ovals that formed in the 1930s are visible in the South Temperate Zone at lower left.

DETAILS: *Celestron C14 Schmidt-Cassegrain and ZWO ASI224MC camera. Stack of several video frames.*

▽ EMISSION IN AURIGA

Greg Meyer

This nebulous region in Auriga contains the open star cluster M38 (top left) as well as several brighter regions, including NGC 1931 (far left), IC 417 (left), bluish nebula IC 410 (below center), and the Flaming Star Nebula, IC 405 (upper right).

DETAILS: *Radian Raptor 61 refractor and ZWO ASI2600M camera. Total exposure: 15 hours through narrowband and color filters.*

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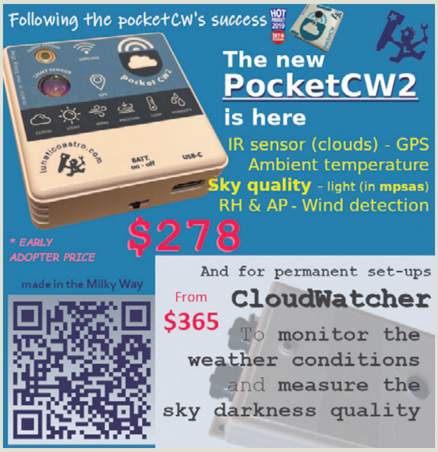

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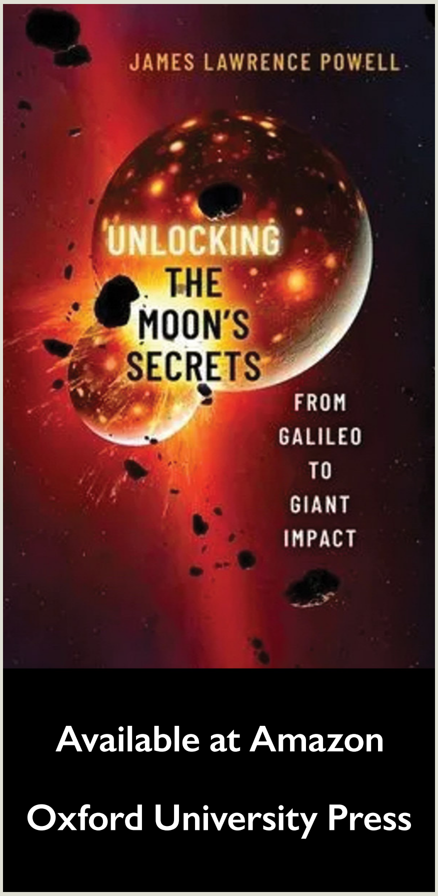

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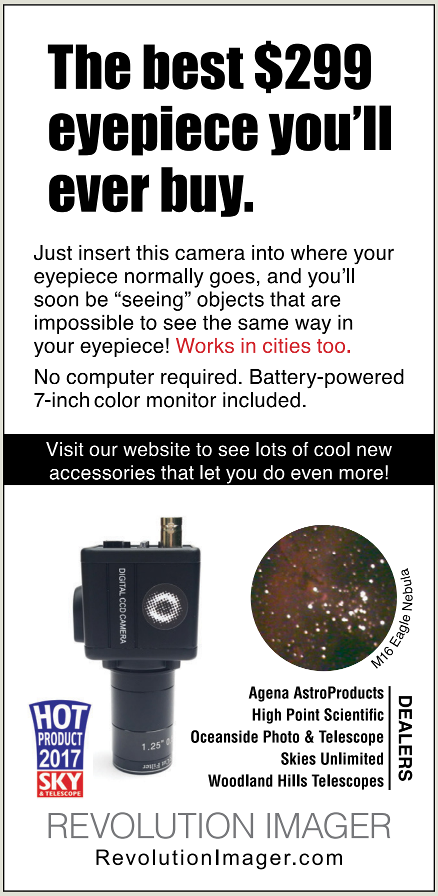

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Event Calendar

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

February 2–3
EUROPEAN ASTROFEST
London, England
europeanastrofest.com

February 5–11
WINTER STAR PARTY
Scout Key, FL
scas.org/winter-star-party

March 2
TRIAD STARFEST
Jamestown, NC
greensboroastronomyclub.org

April
GLOBAL ASTRONOMY MONTH
Everywhere!
https://is.gd/astrowithnoborders

April 5–9
TEXAS STAR PARTY
Aquilla, TX
texasstarparty.org

April 20–21
NORTHEAST ASTRONOMY FORUM
Suffern, NY
neafexpo.com

May 8–11
MIDSOUTH STARGAZE
French Camp, MS
rainwaterobservatory.org/events

May 18
ASTRONOMY DAY
Everywhere!
https://is.gd/AstroDay

June 1–8
GRAND CANYON STAR PARTY
Grand Canyon, AZ
https://is.gd/GrandCanyonStarParty

June 5–8
BRYCE CANYON ASTRONOMY FESTIVAL
Bryce Canyon National Park, UT
https://is.gd/brca_astrofest

June 5–9
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

June 5–9
YORK COUNTY STAR PARTY
Susquehannock State Park, PA
http://yorkcountystarparty.org

June 6–9
CHERRY SPRINGS STAR PARTY
Cherry Springs State Park, PA
cherrysprings.org

June 6–9
WISCONSIN OBSERVERS WEEKEND
Hartman Creek State Park, WI
https://is.gd/WIObserversWeekend

July 28–August 2
NEBRASKA STAR PARTY
Valentine, NE
nebraskastarparty.org

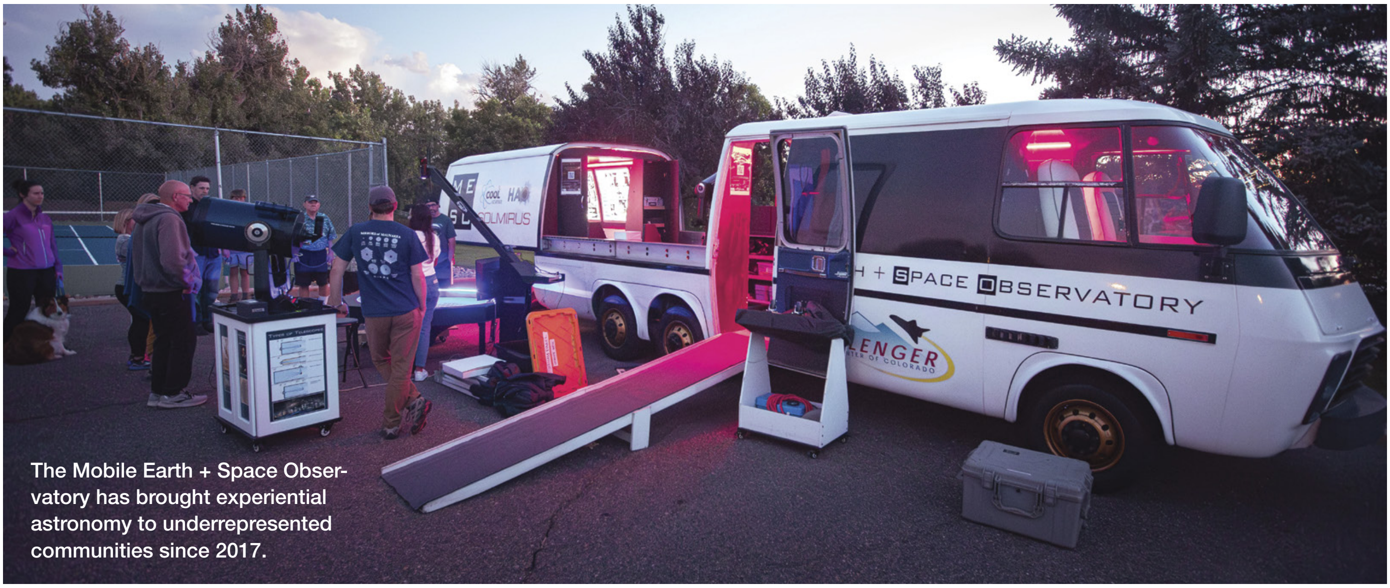
July 30–August 3
OREGON STAR PARTY
Indian Trail Spring, OR
oregonstarparty.org

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

NASA / JAY WESTCOTT

A Mobile Observatory

A tricked-out science vehicle and its team offer hands-on astronomy to underserved communities.



The Mobile Earth + Space Observatory has brought experiential astronomy to underrepresented communities since 2017.

HOW DO YOU SHARE your passion for astronomy with your community? When you think back on the impetus for your own interest in the field, it may have grown thanks to some form of outreach. Whether peering through a telescope at a star party, attending a lecture about some celestial discovery, or enjoying incredible images shared by recent NASA missions, you may well have gotten your first taste of astronomy through the efforts of an individual or a dedicated team.

▲ A gravity well is one of the exhibits that travels with the MESO "science center on wheels."

For some, such resources are already an integral part of their community. For many, however, these resources are logistically, geographically, or financially inaccessible, leading to a disconnect between passion and science.

The Mobile Earth + Space Observatory (MESO) grew out of a celebration of engineering design, love of science, and a need for equitable access to meaningful astronomy experiences. First conceptualized in 2008, and following many years of design and redesign as well as sourcing, repairing, and building out the vehicle, the MESO motorhome took on its now-familiar shape. (If you're a fan of *2001: A Space Odyssey*, you may recognize the design inspired by the movie's iconic Moon bus.)

In 2017, the MESO team embarked on its maiden voyage to Sutton, Nebraska, to view the total solar eclipse that August. Since then, the crew has provided one-of-a-kind experiences to thousands of students and families across MESO's home state of Colorado. It has done this by travelling to schools and libraries to attend family STEM nights and public daytime events.

While reaching the public is a key form of outreach, most of MESO's programming involves more structured astronomy and physics lesson plans that teachers can use in their classrooms for a day. These lessons feature topics such as gravity, optics, light and color, stellar classification, and more, all facilitated by hands-on experiments and exhibits that travel with the vehicle.

The concept of mobile labs is not unique to MESO, nor does it guarantee that all science education will become equitable, of course. The project is the work of a small team of scientists and educators who wish to inspire those in underserved areas about astronomy and encourage students to consider pursuing careers in STEM. Altogether, MESO demonstrates that being a positive influence in a child's experience of astronomy takes little more than attentiveness, passion, and, if you're feeling ambitious, maybe even a modified 1976 GMC motorhome.

■ **ANA BUCKI LOPEZ** has degrees in astrophysics and natural-science education. For more on MESO: **gomeso.org**.

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