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Picture Perfect

IT'S AMAZING HOW INVENTIVE astronomers can be when they want to record a celestial object they can't see. They simply won't be stopped by distance, overwhelming starlight, or intervening gas and dust. If there's a workaround, they'll find it.

To show you what I mean, I direct your attention to four images in this issue. Collectively, they display the prodigious skills that both professionals and amateurs wield to secure pictures of elusive entities.

First, look at the image of Sirius, the Dog Star, on page 29 of Ken Croswell's cover story. As the brightest star in the night sky, Sirius is easy enough to photograph, but notice the tiny dot in the lower left. That's Sirius B, a companion white dwarf star. Sirius B is smaller than Earth and roughly 10,000 times fainter than Sirius (aka Sirius A). How did astronomers possibly get a picture of it next to that blinding spotlight? In short, they used the Hubble telescope and some technical cleverness. (As it turns out, even amateurs with modest scopes can pick out Sirius B — see **https://is.gd/SiriusB**.)

▲ Another exquisite portrait: The planetary nebula HFG 1 (see page 20)

NICO GEISLER / FRANK IWASZKIEWICZ

Now, turn to page 12, where you'll see a silhouette of the black hole residing at our galaxy's center. Why is this image astounding? Because the black hole is 26,000 light-years away, its shadow on the sky is roughly the size of a grapefruit seen at the distance of the Moon, and, most significantly, it's hidden behind clouds of dust and gas. How did astronomers obtain its portrait? Camille Carlisle gives you full details in her article, but the key was using a slew of radio telescopes that can "see" right through interstellar dust.

Next, behold the image on page 60, particularly its inset. Taken by amateur Rolf Wahl Olsen, this photo captures light echoes from SN 1987A, the closest supernova to have appeared in modern times. Like sound echoes, light echoes bounce off distant objects — in this case, cosmic dust clouds — and reach us later than the direct light from an event like SN 1987A. Again, you'll have to read Olsen's feature to learn just how he pulled off this stunning feat. But just think: You're viewing light from a supernova that occurred decades ago.

Finally, consider the sketch on page 57. See all that nebulous stuff on either side of the Andromeda Galaxy? That's *galactic cirrus* — dust and gas spewed out by supernova explosions. Sketching enabled amateur Mel Bartels to depict the gauzy cirrus in a strikingly effective way.

Of course, many other images in this issue (and all issues) of *S&T* exhibit just how creative astronomers can be when they want a picture. As our field advances, who knows what celestial scenes we'll enjoy down the road?

Peter

Editor in Chief

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The Essential Guide to Astronomy

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Deep-Sky Imaging with *Sequator*

I read Sean Walker's Test Report "Nightscaping with Sequator" (*S&T:* Aug. 2022, p. 66) with great interest. I have been using *Sequator* for many years because of its ease of use and great results.

I've used *Sequator* for the quick exposures mentioned in the article for nightscapes. But to my surprise, I found *Sequator* also works well for images of deep-sky objects with longer exposures, by stacking a great number of subexposures to create the image.

I took the image of M51 at left on June 28, 2022, using a Sony α7 camera and Astro-Tech 72-mm ED refractor on a Star Adventurer mount. The total image integration time was 74 minutes and contains 150 subexposures, each 30 seconds long with 20 dark frames. I stacked them all in *Sequator* and adjusted it in *Photoshop*.

Greg Cisko • St. Charles, Illinois

The Hunt for Technosignatures

As a member of the board at the SETI Institute, I just wanted to congratulate and thank Jeff Hecht for the superb article "SETI's Big Boost" (*S&T:* Aug. 2022, p. 34). Hecht captures both the excitement and the challenges of the new work effectively for the lay reader.

This article is now my go-to place for explaining what is happening in the field to students and anyone who is interested in the Search for Extraterrestrial Intelligence. I have shared the article with all our board members and will also include a reference to it in the online textbook I write for OpenStax (**https://is.gd/OpenStaxSETI**).

Andrew Fraknoi
San Francisco, California

I read with great interest the latest update on SETI. However, I would like to offer a different approach: Instead of listening for a signal from outer space, why not generate our own? What if we sent laser light beams out in a shotgun approach to different points in the sky? Based on the speed of light, it might take hundreds of years to get to some locations, but at least it could be said that we are trying to reach out beyond our own planet.

All the research now seems to be focused on attempting to receive random signals from somewhere. I think the search for extraterrestrial life should, in part, focus on generating our own signals.

It can be argued that those Earth signals already exist from the early 1900s in AM radio signals and from the 1950s' first television signals. Some of those signals did in fact leak out into our solar system, but not in an organized fashion.

One problem with this argument is the inverse square distance law — or the further a radio or light wave travels the weaker and wider it becomes. Signals designed for Earth communications back when radio and television were new were never meant to be received in outer space. The further they traveled, the weaker they became.

On the other hand, scientists could transmit a laser light beam to specific targets. However, just a beam of light by itself is not enough. If it were blinking in such a way to suggest that it was artificially made, it might at some future point spark the interest of some life form from another galaxy to investigate the location of its origin.

Mike Malloy
Corpus Christi, Texas

I am intrigued by the term *technosignature* in Jeff Hecht's article on SETI. It seems rooted in the assumption that an intelligent species would necessarily develop technologies capable of being detected over many light-years. The examples Hecht gives strike me as extrapolations of human technologies that have existed for 100 years or less — a vanishingly brief period in the history of our species.

Humans have demonstrated their intelligence in astonishingly diverse ways over the past 150,000 years. The peoples who created such artifacts as the Mayan calendar, Chinese calligraphy, and the bronze sculptures of Igbo-Ukwu were assuredly as intelligent as contemporary scientists. Could their technologies have generated the sorts of technosignatures sought by SETI?

The questions asked by scientists often reflect biases of their own culture. For example, as noted in *S&T*'s July 2018 issue, the terrestrial "Canal Mania" of Percival Lowell's day may have shaped his observations of the purported canals on Mars. Are the "extraterrestrial" artifacts contemporary SETI scientists seek perhaps only reflections of ourselves?

Thomas Whitman
Philadelphia, Pennsylvania

Thanks for the Laugh

Last night, I was reading August's *S&T* and started laughing out loud. To be sure, I have never previously laughed out loud at anything in *S&T*. (My wife thought I'd finally lost it.)

I was reading Fred Ringwald's letter ("Comet IRAS-Araki-Alcock," *S&T:* Aug. 2022, p. 6), in which he was tempted to point callers to Venus instead of the comet. I can understand his frustration and his temptation, but kudos to him for being honest!

I recently was asked to help find "Dave's Star." My friend Dave had been given one of those "official star named

GREG CISKO

for you" certificates about 30 years ago but never knew where to look for it.

I compared the chart he'd been given with my star charts and planetarium program, and even plugged the supposed coordinates into my Go To scope. Nothing! At least, nothing was visible from within city limits.

If there *was* a star there, it must have been very dim. I'm pretty sure he got taken. I didn't want him to be disappointed and considered pointing out something fairly bright and declare that to be "Dave's Star," but I just couldn't do it.

Ringwald's letter reminded me of that incident, and his thought of pointing to Venus was hilarious. Thanks for the laugh!

Michael Coon
Tempe, Arizona

Phobos

The short quote from a review of A. T. Sinclair's work in Roger W. Sinnott's 75, 50 & 25 Years Ago ("Wandering Phobos," *S&T:* Aug. 2022, p. 7) left the reader with the impression that Mars's satellite Phobos is *not* undergoing a secular acceleration in longitude. The opposite is true.

Much work has been done on the motion of Phobos since Sinclair's 1972 study. Of note is Sinclair's 1989 study (**https://is.gd/Sinclair1989**), in which he informs us that Trevor Morley discovered an error in the database of observations used by Sinclair and George Wilkins before him. With the error corrected, Sinclair finds a significant value of 0.00124°/y^2 for the secular acceleration of Phobos, in close agreement with current values, and about one third smaller than the value first reported by Bevan Sharpless of the Naval Observatory in 1945 (**https://is.gd/Sharpless1945**).

Considering that Sinclair fit an updated theory to the motion of Phobos, included additional modern observations in his solution, and used more sophisticated computational methods, Sharpless' value should be considered a valid result despite the sizable difference with modern values.

Robert Jacobson wrote a good review of the work on the Martian satellites in his 2010 article (**https://is.gd/Jacobson2010**).

[Re Sinnott's comment], had anyone taken Shklovskii's suggestion seriously, it would not have been Sinclair's 1972 paper that convinced them that Phobos was not artificial. Rather, the photographs of the two Moons taken by Mariner 9 that same year would have.

Dan Pascu and Steven J. Dick
U.S. Naval Observatory (retired)
Washington, DC

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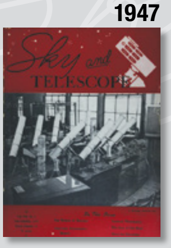
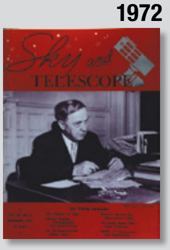
75, 50 & 25 YEARS AGO by Roger W. Sinnott

1947



1972



1997

◖ December 1947

Messier's Mistake "During the course of [other recent] work, Dr. [Helen Sawyer] Hogg found a letter from Pierre Méchain in Paris to M. Bernouilli, published in Bode's *Jahrbuch* for 1786. This letter clears up the identification of No. 102 in [Charles Messier's catalogue]. Although Messier confirmed the discovery of most of these, Nos. 101, 102, and 103 are listed as seen by Méchain only.

"In the letter now brought to light, Méchain corrected the listing by stating that No. 102 is 'one and the same with No. 101,' and that Messier made a mistake in reading its position from the star chart. Some astronomers had tentatively identified M102 as . . . NGC 5866."

Lying just north of the Big Dipper's handle, M101 is the magnificent Pinwheel Galaxy. Some 9° east of it is NGC 5866, a much fainter galaxy. Some writers still wrongly equate M102 with NGC 5866.

◖ December 1972

Space Telescope "The 1980's should see the establishment of the first major observatory in space, as a result of the Large Space Telescope (LST) program of the National Aeronautics and Space Administration. This observatory will contain a long-lifetime reflecting telescope of about 120 inches clear aperture, and will be repairable and refurbishable while in earth orbit . . .

"The instruments [will include] a television camera capable of resolving the diffraction-limited images, and low- and high-dispersion spectrographs. . . . Although the first launch date, in 1980, seems remote, our long lead time indicates the many developments that must be made in building a cost-effective new system."

After this forward look by C. R. O'Dell, the launch was much delayed, the aperture shrank, and the cost soared. But that meant the renamed Hubble Space Telescope could use a modern CCD detector instead of a "television camera."

◖ December 1997

Asteroid Moons "Three asteroids have been photographed close-up by spacecraft: [951 Gaspra in 1991, 243 Ida in 1993, and 253 Mathilde last June]. The most surprising discovery in these encounters was the little moon that orbits Ida. One asteroid satellite seen in just three good looks — those numbers led some solar-system specialists to suspect that asteroid satellites are common. Now it looks as if they're right. . . .

"Earth itself bears graphic evidence that asteroids sometimes come in pairs. Of the Earth's 28 largest impact craters, three are doublets formed by the nearly simultaneous impacts of two bodies. And planetary scientist William Bottke (Cornell University) sees comparable rates of double-impact features on Venus, Mars, and the Moon."

Currently, William Robert Johnston's online archive lists 469 asteroids known or strongly suspected to have satellites.

▲ Astronomers have found candidate record-breakers in the first images obtained for the Cosmic Evolution Early Release Science Survey (CEERS).

COSMOLOGY

Webb Shatters Galaxy Distance Records

THE FIRST RESULTS FROM the James Webb Space Telescope seem to indicate that massive and luminous galaxies had already formed within a couple hundred million years of the Big Bang. If confirmed, these discoveries could seriously challenge current cosmological thinking; however, for now that's still a big "if."

As galaxies' light moves through expanding space, the wavelengths stretch (*redshift*) all the way into the infrared, to which Webb's instruments are sensitive. But not all light makes it to Webb. Intergalactic hydrogen absorbs radiation at wavelengths shorter than 91.2 nanometers. That threshold, too, redshifts into the infrared for the most distant galaxies.

Thus, a quick-but-rough way to determine a galaxy's distance is to watch for its light to "drop out" at certain wavelengths. Webb's Near-Infrared Camera, NIRCam, has 29 filters that each cover a different wavelength band. A galaxy may thus be visible in some channels but not in others. The wavelength band in which the galaxy disappears may indicate its redshift and as a result its distance.

Just a week after Webb's first science data became available, two independent teams of astronomers, one led by Rohan Naidu (Center for Astrophysics, Harvard & Smithsonian) and the other by Marco Castellano (Rome Observatory, Italy), used the dropout technique to find two relatively bright galaxy candidates at redshifts of about 11 and 13, residing in a universe about 400 and 300 million years old, respectively.

In the days that followed, another two independent teams, led by Callum Donnan (University of Edinburgh, UK) and by Yuichi Harikane (University of Tokyo), announced the tantalizing find of an unexpectedly massive galaxy at a redshift of 17. That corresponds to looking back to just 225 million years after the Big Bang.

In yet another study, Haojing Yan (University of Missouri, Columbia) and his colleagues even claimed that some of their candidate galaxies might reach a redshift of 20 (180 million years after the Big Bang).

The distant galaxies seem to be more numerous and more massive than expected from the standard model of cosmology. "It worries me slightly that we find these monsters in the first few images," says cosmologist Richard Ellis (University College London).

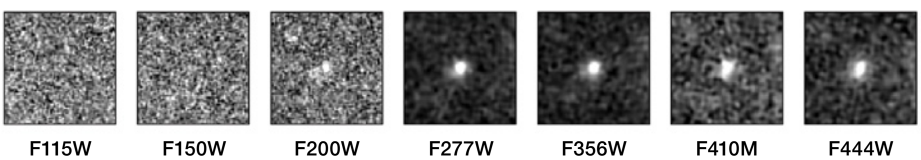
But these candidates still await confirmation via spectroscopy, which would give precise redshifts. "I'm sure some of them will be [confirmed], but I'm equally sure they won't all be," Mark McCaughrean (ESA) tweeted. "It does all feel a little like a sugar rush at the moment."

And there is reason to doubt at least some of the supposedly distant galaxies. For example, the galaxy candidate at a redshift of 17, variously referred to as CEERS 1749, CEERS 93316, and CR2-z17-1, has also earned the nickname "Schrödinger's Galaxy" because of its undecided nature. A team led by Jorge Zavala (National Astronomical Observatory of Japan) has made the case that this galaxy is actually much closer, at a redshift of 5. It would then reside in an older universe, 1.2 billion years after the Big Bang. It's so dusty that it vanishes at longer wavelengths in the same way more distant galaxies do. Post-launch instrument calibration may also affect distance measurements.

The fast pace of Webb science is keeping everyone on their toes, and there's a lot of work to do to confirm the most distant galaxies are really so far away. "Every day is a little adventure," Ellis says.

■ GOVERT SCHILLING

Find more details at https://is.gd/JWSTdistances.



▲ These "postage-stamp" images from Webb's NIRCam show the galaxy CEERS 93316 in seven wavelength filters. The galaxy isn't visible in the two shortest-wavelength bands (F115W and F150W).

DEEP-FIELD IMAGE FROM WEBB: NASA / STSCI / CEERS / TACC / S. FINKELSTEIN / M. BAGLEY / Z. LEVAY; LYMAN ALPHA DROPOUT: DONNAN ET AL. / ARXIV.ORG / 2207.12356

NEUTRON STARS

Black Widow Pulsar Sets Mass Record

THE PULSAR PSR J0952–0607 already holds the title of second-fastest-known rotator, spinning around its axis 707 times per second. Now, it has also broken the record for the most massive neutron star known.

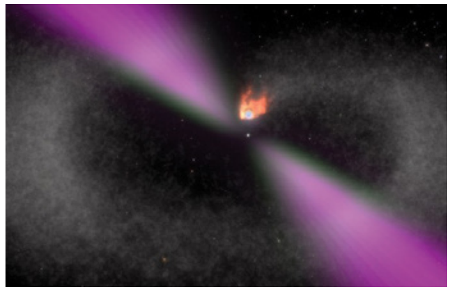
Discovered in December 2016, PSR J0952 is 20,000 light-years away in Sextans and rotates every 1.41 milliseconds, just shy of the 1.40-millisecond record holder, PSR J1748–2446ad. The surfaces of these objects whip around at some 20% of the speed of light.

These *millisecond pulsars* spin so fast because they're accreting material from an orbiting companion star. This slow devouring has also earned them the nickname "black widows."

Roger Romani (Stanford University) and colleagues have now succeeded in taking spectra of the pulsar's extremely faint (23rd-magnitude) companion using the Keck telescope on Mauna Kea, Hawai'i. In a study to appear in *Astrophysical Journal Letters*, the team reports that the companion, which has the mass of a few tens of Jupiters, orbits the pulsar at 380 km/s (850,000 mph). Combined with brightness measurements over the orbital period of 6.42 hours, this yields a mass estimate for the neutron star of 2.35 solar masses.

No one knows how matter behaves under the extreme conditions present in neutron star interiors. But gauging how massive a neutron star can become before collapsing further into a black hole helps narrow down what types of matter might exist there.

The mass estimate of J0952 is still quite uncertain, with a possible error of ±0.17 solar masses. More precise measurements, Romani and colleagues write, await the 30-meter telescope era.

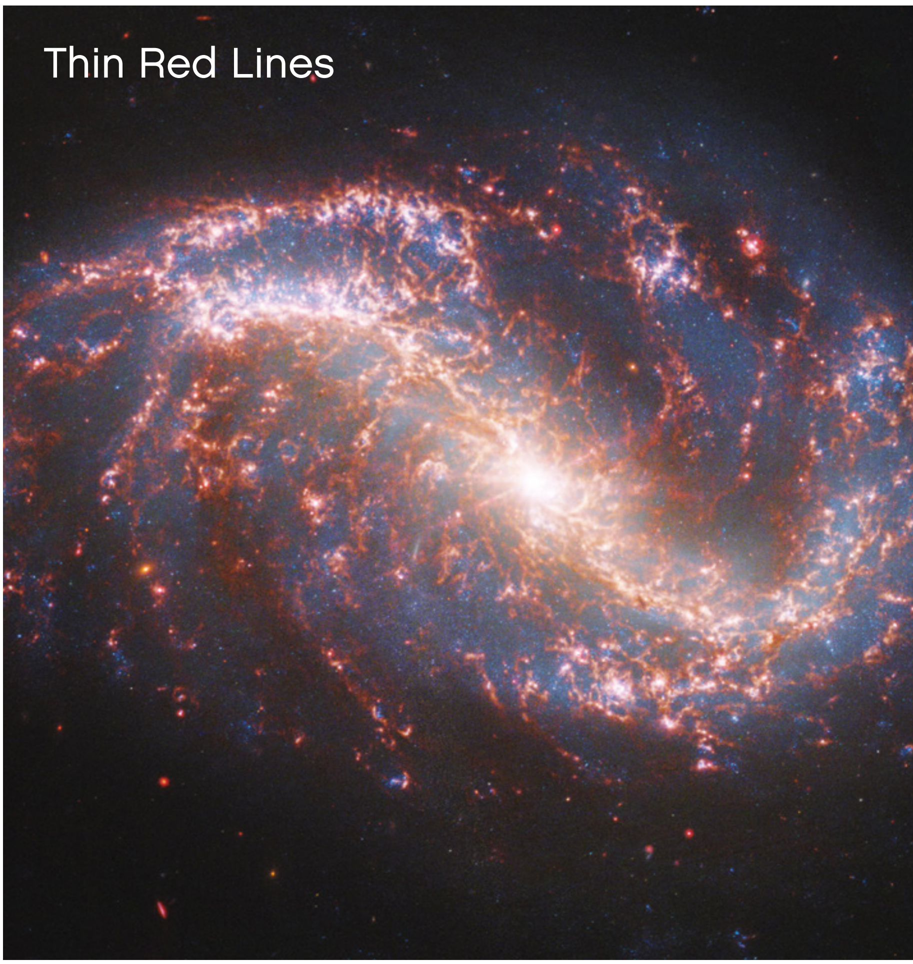


▲ An artist illustrates a black widow pulsar with its small companion.

"I think this result sends a warning to modelers of ultra-dense matter that neutron stars may be capable of having pretty high masses," says Victoria Kaspi (McGill University, Canada), who wasn't involved in the current study. "If I were a theorist wedded to a model that permitted only lower-mass neutron stars, I'd start scratching my head about now, though I wouldn't yet be in full panic mode."

■ GOVERT SCHILLING

Thin Red Lines



There's no such thing as the birth of a single star. Star formation is a global phenomenon, and its grand scale becomes clear in the James Webb Space Telescope's sharp image of NGC 7496. The galaxy is one of those being surveyed as part of the Physics at High Angular Resolution in Nearby Galaxies (PHANGS) project. "In the [Webb image], we can see through the dust — for the first time with this detail — to see the bright clusters and bubbles that signify the early stages of star formation," says PHANGS principal investigator Janice Lee (NSF's NOIRLab). The web-like pattern is a result of the interdependent, regulating effects that govern star formation over vast regions of space. Glowing dust outlining the star-blown bubbles reveals evidence of both positive feedback, which compresses clouds of gas and dust to create new stars, and negative feedback, which disperses molecular clouds and interrupts star formation. The PHANGS collaboration will be using Webb to examine another 18 nearby galaxies to see star formation in unprecedented detail.

■ ARWEN RIMMER

ILLUSTRATION OF BLACK WIDOW PULSAR: NASA GODDARD SPACE FLIGHT CENTER / CRUZ DEWILDE; WEBB IMAGE OF GALAXY: NASA / ESA / CSA / JUDY SCHMIDT

OBITUARY

Remembering Donald Machholz, 1952 – 2022

ONE OF AMERICA'S PREMIER comet hunters, Donald Machholz, died on August 9th, passing away unexpectedly from COVID-19. He is survived by his wife, Michele, and their two sons.

Born in 1952 in Portsmouth, Virginia, Don became interested in astronomy at age 8. At age 13, he started exploring the sky with his first telescope: a modest 2-inch refractor.

Then, on New Year's Day of 1975, he kicked off a comet-hunting project. It took him 1,700 hours to discover his first comet on September 12, 1978; his second find took another 1,742 hours. Eventually, he spent nearly 9,000 hours comet hunting, during which he discovered a total of 12 comets that bear his name. He became the leading visual comet discoverer in the U.S.

Don took in the sky from a variety of different instruments. He swept up Comet C/1985 K1 using a mostly home-made 10-inch telescope that provided a more expansive field of view than most commercial telescopes. He found Comet 96P/Machholz in 1986 using a giant pair of homemade 29×130 binoculars. And in 2004 he spotted his 10th comet, C/2004 Q2, through his 6-inch f/8 Criterion Dynascope that he'd bought 36 years earlier. His final discovery — C/2018 V1 — came in November 2018.

▲ Don Machholz (*right*) showed his large comet-hunting binoculars to Brian Marsden (*left*) during a visit in the 1990s.

While all of Don's comet discoveries were made from California, he and his wife relocated to the high desert of Arizona a few years ago. There, from his "Stargazers Ranch" at an altitude of 4,800 feet, he had access to clear and dark (Bortle 2) night skies.

In addition to comet-hunting, Don was one of the inventors of the Messier Marathon and authored a book on the subject: *The Observing Guide to the Messier Marathon: A Handbook and Atlas*. He also wrote two books on comets: *Decade of Comets: A Study of the 33 Comets Discovered by Amateur Astronomers Between 1975 and 1984* and *An Observer's Guide to Comet Hale-Bopp*.

More recently, Don had begun writing a column for EarthSky and was producing an astronomy podcast, "Looking up with Don."

Fellow comet observers are celebrating Don's life and legacy. "He was one of the last of a rapidly vanishing breed, a visual comet hunter who was successful," writes John Bortle. "I recall a time when visual discovery by amateurs came at a steady rate of 6-8 per year, but no more. Not simply as a fellow comet hunter, but Don was a truly kind human being. His ilk will not come again soon."

■ JOE RAO

STARS

Amateurs Help Discover Star's Dusty Disk

A HUGE DUSTY DISK surrounds a close companion of Propus in Gemini, astronomers report in a new study to appear in the *Monthly Notices of the Royal Astronomical Society*. The discovery depended on measurements from amateur variable star observers.

Propus (Eta Geminorum or η Gem) is a 3rd-magnitude red giant in the foot of Castor, one of the heavenly Twins. Slow pulsations cause the star's brightness to vary semi-irregularly over a period of 230 days. It has two companions: a 6th-magnitude star that orbits the giant every 470 years and a much fainter star that orbits much closer in.

Guillermo Torres and Kristy Sakano (Center for Astrophysics, Harvard & Smithsonian) have now analyzed 11.5 years of spectroscopic data obtained with 1.5-meter telescopes at Oak Ridge Observatory in Massachusetts and Whipple Observatory in Arizona. Combined with data from the 1930s and 1940s, these observations yield a precise 8.16-year orbital period for Eta Gem and its closest companion.

Interestingly, this orbital period coincides with another pattern amateurs have long reported: Propus dims by half a magnitude every 8.2 years.

To test whether this long variation is real, Torres and Sakano compared their orbital model of the system against tens of thousands of brightness estimates from members of the American Association of Variable Star Observers (AAVSO) and similar organizations in France, the United Kingdom, and Japan. "[We] identified many instances where light minima were close to the predicted times of eclipse," they write. "This leaves no doubt as to the eclipsing nature of Eta Gem."

However, each observed eclipse lasts for around five months, and Propus's companion star can't possibly produce such long-lasting obscurations by itself. The team concludes that dust surrounds the companion in a disk that's at least half again as wide as Earth's orbit around the Sun.

Astronomers have found a handful of other examples of dust-encircled companions orbiting giant stars, the most famous one being Epsilon Aurigae. Such situations might even be common, suggests Steve Howell (NASA), but they require a lot of detective work to uncover.

To help with the next observations, mark your calendar: The next eclipse of Propus will occur between late October 2028 and early March 2029.

■ GOVERT SCHILLING

PHOTO SUPPLIED COURTESY OF D. W. E. GREEN (CENTRAL BUREAU FOR ASTRONOMICAL TELEGRAMS)

ACCESSIBILITY

Rendering the Universe in Sound

THERE'S NO SOUND in space. But with new data methods, there could be.

In *sonification*, astronomers translate data — ranging from stars' brightness to the strength of gravitational waves — into sound. The technique most obviously, and vitally, makes such information accessible to those who are blind or have low vision. But sonification also opens up new experiences for the general public and researchers alike, Anita Zanella (National Institute for Astrophysics, Italy) and colleagues report on August 15th in *Nature Astronomy*.

Humans are generally a visually oriented species, but our other faculties have capabilities that seeing does not. For example, we're always processing audio input, and we're capable of listening to several things at once. We're especially good at filtering out noise to home in on something we want to understand.

Cardiff University's Black Hole Hunter (**blackholehunter.org**) demonstrates these concepts. A simulated signal from two merging black holes is impossible to see amidst typical background noise. But in audio form, it's a different story: Despite the roar of noise, the quiet "chirp" of coalescence is surprisingly audible.

Black Hole Hunter is an online game built for public engagement, not a research project; indeed, 36% of sonification projects list public engagement as their primary objective. Other objectives include research (26%), art (17%), accessibility (13%), and education (8%), according to Zanella's analysis.

Even so, "data as sound" has been enabling scientific exploration for decades, from the discovery of the cosmic microwave background to the study of lightning-induced plasma waves known as "whistlers."

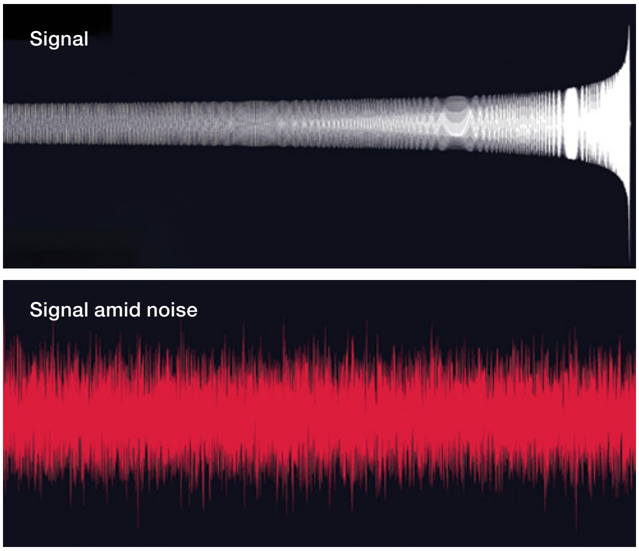
More recently, sonification efforts have been ramping up. In addition to serving the blind and those with low vision, the technique also appeals to those with dyslexia, autism, and anyone interested in listening to data, Zanella and colleagues note. They find that the cumulative number of sonification projects has been increasing rapidly since 2010, to a total of 98 as of December 2021. However, it will remain a niche approach until it can be standardized.

For example, understanding uncertainty in the data can be vital to distinguishing real differences from noise. But most sonification efforts don't include error bars. We need more studies to gauge how well different techniques work, Zanella's team concludes.

Henry Winter (ARISA Lab), who wasn't involved in the study, adds that studies require support: "I think that all of those challenges result from a lack of funding for serious sonification and accessibility work."

■ MONICA YOUNG

Hear examples at https://is.gd/sonification.



◀ The gravitational-wave signal expected from two colliding black holes (*top*) is difficult to distinguish visually in a realistic depiction of background noise (*bottom*). But listen to the same data and you can hear the quiet "chirp" amid the noisy roar.

IN BRIEF

Korea's Orbiter Heads for the Moon

South Korea's first Moon mission, the Korea Pathfinder Lunar Orbiter, launched successfully on August 5th. Now officially called Danuri, the $180-million mission will test technologies for an eventual orbiter, lander, and rover. The solar-powered spacecraft will arrive in lunar orbit by December 16th, then it will scout out the Moon's surface using six instruments. One from NASA will search for water ice in permanently shadowed craters. Another four instruments from the Korea Aerospace Research Institute (KARI) will return data on surface composition and texture, local magnetic "swirls," and future landing sites. The final instrument, also built by KARI, is an experimental payload to test a rudimentary interplanetary internet and address the technical issues that arise in a communications network that lacks continuous connectivity. Danuri will start one year of science operations in early 2023. If the mission performs well, an extended science phase might have it skimming even closer over the lunar surface.

■ DAVID DICKINSON

AAVSO Selects New Director

The American Association of Variable Star Observers (AAVSO), founded in 1911, is pleased to welcome Brian Kloppenborg as the new Executive Director, effective September 16th. "Brian brings to AAVSO the skills needed to advance our scientific impact, combined with experience in management and project budgeting," notes AAVSO President David Cowall. Prior to joining the AAVSO, Kloppenborg worked as a research scientist at Georgia Tech Research Institute. He holds a PhD in physics with an astrophysics specialty, from the University of Denver, and a B.A. in Physics from Hastings College. Brian also ran a small business that provided data science, machine learning, and GPU accelerated computing services. His research interests span photometry, spectroscopy, astrometry, and long-baseline optical interferometry of eclipsing binaries, novae, and young stellar objects. "With my background," Kloppenborg says, "not only do I understand where the science is and how the AAVSO can contribute to it; but also how to raise funds and implement successful programs."

■ LINDSAY WARD

THE BIG BLACK HOLE NEXT DOOR by Camille M. Carlisle

Unmasked

The first image of our galaxy's central black hole gives us a peek at a bizarre object.

Enthroned in the Milky Way's heart sits the cowardly lion of black holes. Known as Sagittarius A*, this object holds the equivalent of 4 million Suns squashed into a region less than 20 times as wide as our star. A diffuse tulle of hot gas skirts the beast, fueling a glow about 100 times brighter than the Sun — so feeble that, if it lay in another galaxy, it would probably be undetectable.

Astronomers first discovered Sgr A* (pronounced "Sadj-ae-star") in 1974 as a "compact radio source," just as the realization was dawning that big black holes might sit in most galaxies' cores. Over the decades, observers have tiptoed closer to its lair. By the late 1990s they'd realized the radio signal had structure, but it would take another decade before they confirmed this structure was on the scale of the event horizon, a black hole's infamous point of no return.

Even with these advances, Sgr A* has remained just out of reach, crouched 26,000 light-years away. But on May 12, 2022, astronomers with the Event Horizon Telescope Collaboration jumped the distance and brought us face-to-face with our black hole. The EHT image, reconstructed from data taken at radio telescopes across the Western Hemisphere, shows a luminous ring encircling a dark center: the black hole's silhouette, marking where light from surrounding gas is either bent around the hole or comes too close and is swallowed.

Three years ago, the EHT team gave us a similar image of the much larger, plasma-jet-shooting black hole in the elliptical galaxy M87 (*S&T:* Sept. 2019, p. 18). With two images in hand of very different beasts — one extraordinary, one ordinary — astronomers can now say that M87*'s ring of light was no fluke; we are indeed seeing extreme gravity at work. But Sgr A*'s blurry visage also carries the beginnings of deep physical insight into our black hole and others like it, insight that already challenges some of our expectations.

As the World Turns

Sgr A*'s "shadow" spans about 50 microarcseconds on the sky, roughly the size of a grapefruit seen at the distance of the Moon. To espy such a minuscule sight, astronomers need an Earth-size radio telescope. They "build" this telescope by observing simultaneously with dishes spread across the planet, then flying data-filled hard drives back to supercomputers in Massachusetts and Germany, where they carefully sync the observations to within trillionths of a second. This technique is called *very long baseline interferometry*, or VLBI.

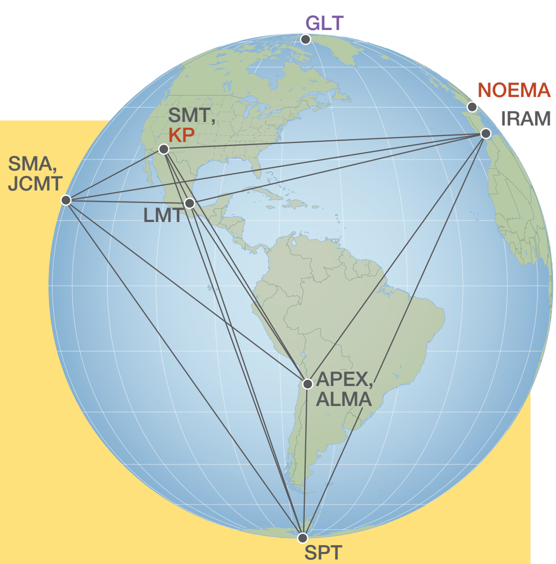
Sgr A*'s "shadow" spans about 50 microarcseconds on the sky, roughly the size of a grapefruit seen at the distance of the Moon.

VLBI combines data from pairs of telescopes; more telescopes give you more combinations. Each pair probes a different scale, with close-together dishes sensitive to large-scale structure and dishes separated by thousands of kilometers picking up small structure. As the planet turns, different stations have different views, and their positions relative to one another change as seen from the target's perspective, filling in bits of the virtual telescope's dish.

◀ **HELLO** This is the first image of the black hole at the center of the Milky Way Galaxy. Scientists created it by averaging thousands of possible reconstructions, built with data from eight radio observatories.

OBSERVATORIES

Atacama Large Millimeter/submillimeter Array (ALMA)	IRAM 30-meter Telescope (IRAM)	South Pole Telescope (SPT)	Greenland Telescope (GLT)
Atacama Pathfinder Experiment (APEX)	James Clerk Maxwell Telescope (JCMT)	Submillimeter Array (SMA)	Kitt Peak 12-meter Telescope (KP)
	Large Millimeter Telescope (LMT)	Submillimeter Telescope (SMT)	Northern Extended Millimeter Array (NOEMA)



▶ **PLANET-SCALE DISH** Eight stations participated in the EHT's 2017 observing campaign. All eight successfully observed Sgr A* on April 7th, collecting data over about 12 hours. In 2018 the Greenland Telescope joined the array, and in 2021 NOEMA and Kitt Peak did as well. (LMT sat the 2021 run out but returned in 2022.)

SGR A* SHADOW: EHT COLLABORATION; TELESCOPE ARRAY: LEAH TISCIONE / *S&T*, SOURCE: EHT COLLABORATION / *ASTROPHYSICAL JOURNAL LETTERS* 930:L12 (2022)

But VLBI's reliance on Earth's rotation comes with a downside: To gather enough information to construct the image, astronomers must observe the target continuously for several hours. That's fine for sources that change their appearance gradually over days or months, like M87*. But smaller Sgr A* flickers constantly and flares daily, and its light travels to us through our galaxy's gas and dust, scattered like a quivering candle flame seen through frosted glass. VLBI smears out all these changes in its single, hours-long exposure.

Unveiling Sgr A*'s shadow thus proved a formidable task. As they had with M87*, EHT members split into multiple teams, each using its own computer algorithms. But while the teams quickly produced remarkably similar images for M87*, this time they were stumped. It was so unclear what the right shape was that people didn't even want to show their images, says computer scientist Katie Bouman (Caltech), who co-led the imaging effort. "That's really what we have spent years trying to figure out," she explains. After intense scrutiny, they were finally confident: There's a ring.

It's important to stress what we can and cannot believe about this shadow image. The image is the average of more than 11,000 different reconstructions, each using data gathered on April 7, 2017. Trust the ring's width and the presence of a central darkness — the ring not only appears in more than 95% of the reconstructed images, but its size also matches the prediction from Einstein's theory of gravity. Yet be cautious with the ring's bright knots. Knots are natural, due to the tangled magnetic fields threading the hot gas and constricting its flow. But the positions of the knots in the Sgr A* image move slightly depending on which reconstruction you use, and they tend to line up along directions with more telescopes, warns Feryal Özel (University of Arizona). "We don't trust the knots that much," she says.

We also must be wary in concluding what the image tells us about the black hole. The team compared more than 5 million simulated images with the data, in order to interpret the underlying physics. Each simulated image makes specific assumptions, not just about the black hole's size and distance (which we knew) but about how fast it spins, its orientation, and the nature and behavior of the gas it eats (which we don't). Combined with multiwavelength observations from a large parallel campaign, EHT data rule out vast swaths of interpretations. What's left suggests a tentative picture: Sgr A* has a smoother gas skirt than predicted, it spins pretty fast, it leans nearly on its side, and it eats from a magnetized flow with properties that, 20 years ago, no one thought were physically possible.

Fair-Weather Friend

Think of watching waves from a beach. The speed at which the tide comes in depends on planet-scale gravitational forces, but the individual waves' heights depend on wind and sea conditions.

Something similar happens with a black hole's glow, explains theorist Dimitrios Psaltis (University of Arizona). There are two kinds of variation: how fast and how much.

TERRI DUBÉ / S&T, ADAPTED FROM R. FRAGA-ENCINAS / E. ROS / BLACKHOLECAM / EHT / FIKSFILM

▼ **A BRIEF HISTORY OF SAGITTARIUS A*** Since the 1970s, astronomers have been edging closer to our galaxy's black hole, using both theory and observation. This graphic focuses on advances at radio wavelengths.

1974

2000

1974 →
Discovery of Sagittarius A* (Sgr A*)
Astronomers find an unusual, very compact, bright structure at the center of the Milky Way.
BALICK & BROWN 1974
11 cm & 3.7 cm

1985 →
Sgr A* is small
Observations show that its size is only about 166 light-minutes wide.
LO ET AL. 1985
1.4 cm

1993 →
First VLBI image at 7 mm
A network of four radio telescopes shows Sgr A* has a slightly elongated structure.
KRICHBAUM ET AL. 1993
7 mm

1994 →
First image at 3.5 mm
Obtained using a network of four radio telescopes
ROGERS ET AL. 1994
3.5 mm

1998 →
First Sgr A* size measurement at 1.3 mm
The IRAM radio telescopes in Spain and France study Sgr A* at the same frequency as the future EHT.
KRICHBAUM ET AL. 1998
1.3 mm

2000 →
"Shadow" calculated for Sgr A*
Astronomers predict that a dark region surrounded by a bright ring should be detectable.
FALCKE ET AL. 2000
1 mm

2008 →
Size at 1.3 mm
Early EHT measurements show Sgr A*'s size is comparable to the predicted size of the black hole shadow.
DOELEMAN ET AL. 2008
1.3 mm

Gravity determines how fast gas moves around Sgr A*; plasma conditions determine how that flow brightens and fades.

It's the latter that surprised the team. Simulations forecasted big changes for Sgr A* — perhaps so big that researchers wouldn't be able to take a decent long-exposure picture. But Sgr A* proved calmer than any simulated image in the library. "It's like making weather predictions for a planet that you've never seen — you do your best, but you have no idea what the conditions there are," Psaltis says. "We predicted the storm, and we got a beautiful sunny day."

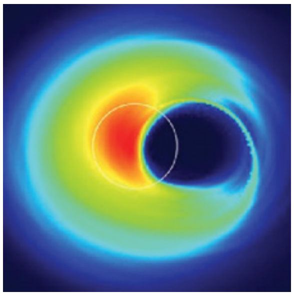
The discrepancy means we're missing something in our understanding of what's happening in the gas flow. Some team members (including Psaltis) think this is one of the most intriguing results. Others are unperturbed. "It is true, not a single model was able to reproduce the variability," says Ramesh Narayan (Center for Astrophysics, Harvard & Smithsonian), who has studied black hole accretion for decades. "For some reason that doesn't bother me, and I can't even tell you why," he adds, laughing.

Myriad solutions abound. Perhaps the gas is less turbulent or thicker than we expected, its magnetic fields are less tangled, or its electrons and ions behave in ways we haven't fully grasped. Adjusting where the light we see comes from — perhaps there's a jet as well as the accretion disk? — might solve the conundrum, too.

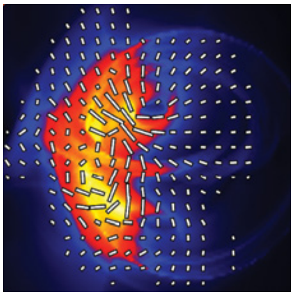
One possibility lies in how gas falls onto the black hole. Sgr A* eats only a billionth as much as a beast of its size is capable of, fed by a trickle of gas blown off as winds from the bright, hot stars that encircle the black hole. These stellar winds billow toward Sgr A* in a disorderly breeze, coming in from all directions, explains Sean Ressler (University of California, Santa Barbara), who studies how such wind-fed accretion works.

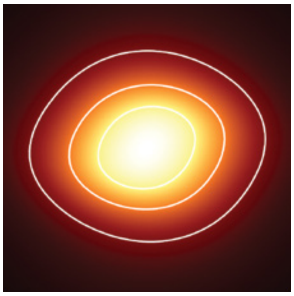
I Dub Thee Sagittarius A*

Codiscoverer Robert Brown (1943–2014) coined the name Sagittarius A* several years after finding the black hole. He later explained, "Scratching on a yellow pad one morning I tried a lot of possible names. When I began thinking of the radio source as the 'exciting source' for the cluster of H II regions seen in the VLA [radio] maps, the name Sgr A* occurred to me by analogy brought to mind by my PhD dissertation, which is in atomic physics and where the nomenclature for excited-state atoms is He*, or Fe*, etc."


2009


2011


2015


2019

2009 — **Extensive theoretical work**
Models built to explain the emission observed from Sgr A*.
MOSCIBRODZKA ET AL. 2009, DEXTER ET AL. 2009, YUAN ET AL. 2009, BRODERICK ET AL. 2006 AND 2009
1.3 mm

2011 — **Feeding black hole**
Comparison of observations with simulations shows that Sgr A* is consistent with a crescent of the right size and shape to be an accreting black hole.
BRODERICK ET AL. 2011, 2016
1.3 mm

2015 — **Magnetic fields detected**
Quickly varying polarization patterns suggest tangled, writhing magnetic fields near the event horizon.
JOHNSON ET AL. 2015
1.3 mm

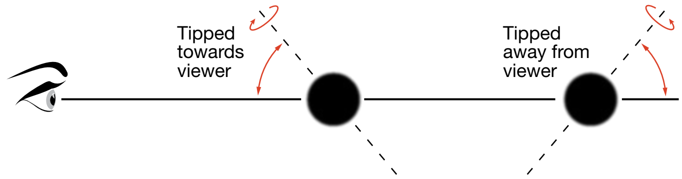
2016 — **Sgr A* is not symmetric**
Detection of asymmetric shape
FISH ET AL. 2016
1.3 mm

2018 — **Ultra-compact and asymmetric structure**
APEX telescope in Chile detects structure in emission from Sgr A*
LU ET AL. 2018
1.3 mm

2019 — **Scattering removed**
Astronomers map and subtract the scattering effect of clumpy interstellar gas on Sgr A*'s light.
ISSAOUN ET AL. 2019
3.5 mm

2022 — **First EHT image of Sgr A***
Shadow provides first direct evidence of the supermassive black hole at the center of our galaxy.
EHT COLLABORATION 2022
1.3 mm

Simulations normally assume gas falls in toward a black hole from a fat surrounding donut called a *torus*, which would feed the accretion disk in an orderly way. But this is a solution of convenience, Ressler says — he doesn't know of a torus ever forming in simulations with realistic initial conditions. Winds, on the other hand, create a diffuse flow with less turbulent motion, and thus less variability. In fact, Ressler and two colleagues recently tested the wind-fed scenario against other observations of Sgr A*'s behavior and found that it matched how the brightness changed with time.



▲ **INCLINATION ANGLE** The spin axis of Sgr A* appears to partially point toward us, angled at most 50° away from our line of sight. It's unclear whether the tilt is toward or away from us (both options shown). Additional data favor an angle of roughly 30° and an axis tipped away from us.

Navigating Oz

If EHT astronomers set aside Sgr A*'s variability — which busts every model tested — then they are left with an interesting subset of findings about the black hole. But there's no yellow-brick road here: We're traveling in shadowy territory, and any of these inferences might be wrong.

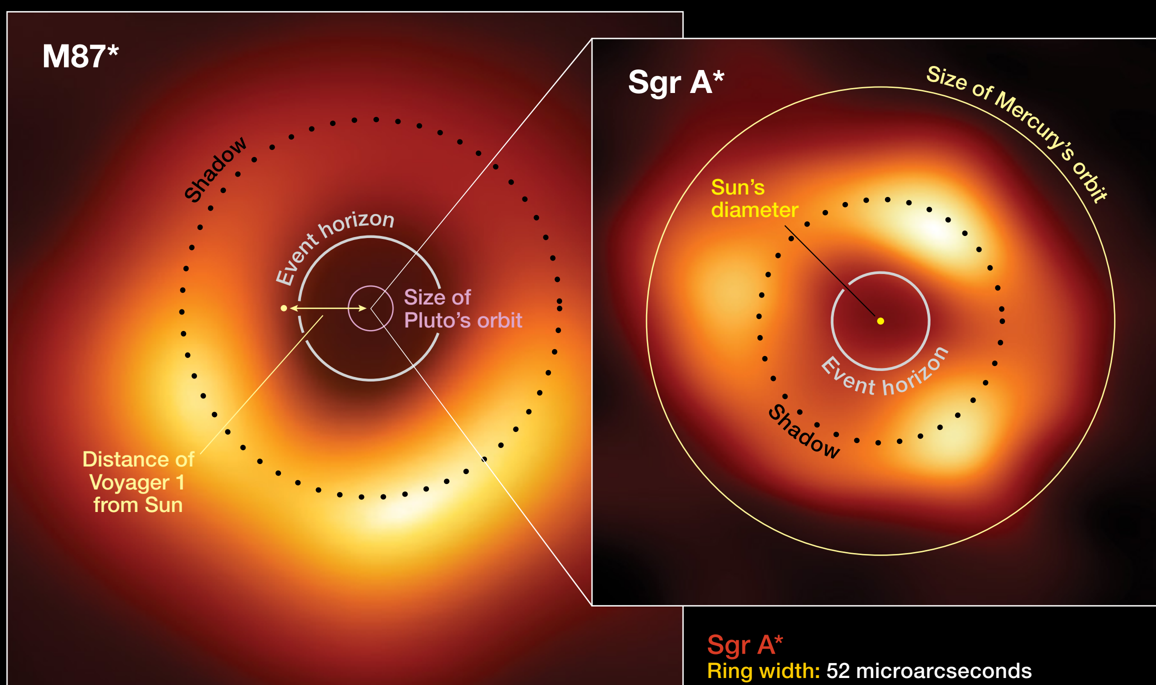
First, the spin. Astronomers define a black hole's spin as a fraction of how fast the object can whirl. The few measurements we have of supermassive black holes similar to Sgr A*'s heft are gas gobblers that spin nearly as fast as they can, likely spun up by a steady stream of gas.

If we rely on the subset of simulations that fit most of what's seen, then Sgr A* also spins fast, at least 50% of its max. But there's reason to doubt that number. Many theorists think that black holes power jets with their spins, and Sgr A* shows no definite sign of shooting jets. Some astronomers have also suggested that if our beast spins quickly, then it should drag spacetime around with itself so much that it would disrupt the orbits of the stars closest to it, which doesn't appear to be the case.

From a galactic-evolution standpoint, Sgr A* perhaps shouldn't spin at all, says Angelo Ricarte (Center for Astrophysics, Harvard & Smithsonian). The Milky Way hasn't

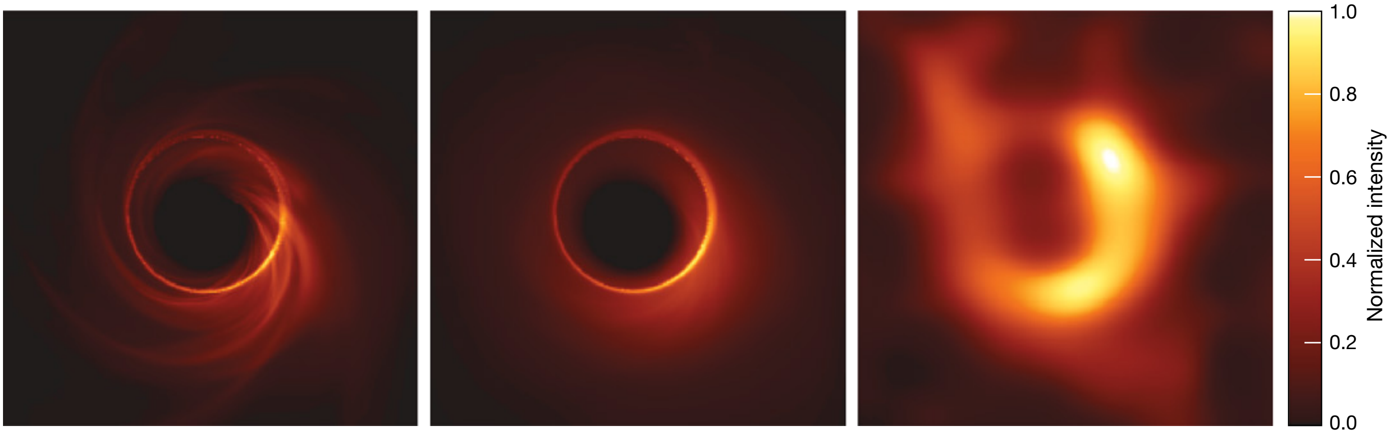
INCLINATION ANGLE: GREGG DINDERMAN / S&T; BLACK HOLE COMPARISON: GREGG DINDERMAN / S&T; IMAGES: EHT COLLABORATION (ACKNOWLEDGMENT: LIA MEDEIROS, XKCD)

▶ **M87* VS. SGR A*** A black hole's shadow is larger than its event horizon: The innermost stable photon orbit lies just outside the event horizon, and the black hole's gravity lenses this light to create an oversized silhouette. If we had perfect resolution, the light would form a narrow ring where the dotted circles are. Because the black hole M87* is 1,500 more massive than Sgr A*, its event horizon is much bigger — the whole solar system would easily fit inside.



M87*
Ring width: 42 microarcseconds
Black hole mass: 6.5 billion Suns
Distance: 55 million light-years
Jet? Yes
Spin axis's inclination to our line of sight: 17°

Sgr A*
Ring width: 52 microarcseconds
Black hole mass: 4 million Suns
Distance: 26,000 light-years
Jet? Unknown
Spin axis's inclination to our line of sight: <50°



▲ **THE RING** Radio photons whizzing around the black hole just outside the event horizon draw a thin circle called the photon ring. *Left:* This snapshot from a simulation shows one possibility for what the photon ring around Sgr A* would look like with perfect resolution. *Center:* The same simulation, averaged to match the cadence of EHT observations. *Right:* What the EHT's reconstructed image of this ring might look like, combining various methods' results.

suffered many dramatic mergers with other galaxies, which funnel gas into galactic centers. If Sgr A* has grown by eating a random assortment of clouds, then there's been nothing to spin it up, he explains.

The second EHT inference is that Sgr A* leans on its throne. Instead of pointing straight up along the rotation axis of our galactic pinwheel, the black hole's spin axis lies more sideways, angled at most 50° from our line of sight. (An angle of around 30° looks likely.) Researchers can't tell whether it's leaning toward us or away — we're either looking down at its forehead or up at its chin.

Astronomers already had reason to suspect this result: Infrared observations of hotspots looping around Sgr A* at breakneck speed also suggest the black hole cants away from us (*S&T:* Feb. 2019, p. 11). That two different experiments give us a similar result is consoling.

Nor is Sgr A* the only supermassive black hole listing sideways. Observations of accreting black holes in spiral galaxies have revealed a range of orientations, says Geoff Bower (Academia Sinica Institute of Astronomy and Astrophysics, Hilo), who coined the cowardly lion moniker. The varied tilts are unsurprising, he explains, because a black hole's orientation depends on how it grew. Mergers with other black holes could cause a jumble of spin tilts, and for less active black holes like Sgr A* there may have been no hefty gas stream to force the black hole into a particular orientation. Thus there's no reason Sgr A* ever had to point straight up.

Some have wondered what this orientation means for the Fermi bubbles, the giant dumbbell-shaped outflows that extend up and out from the galactic center for tens of thousands of light-years (*S&T:* Feb. 2021, p. 60). Many astronomers suspect that a fantastic roar from the black hole blew the bubbles a few million years ago. Hsiang-Yi Karen Yang (National Tsing Hua University, Taiwan), who uses computer simulations to investigate the bubbles' formation, says that outflows from tilted jets would still be funneled up and out of the Milky Way's disk by the dense surrounding gas, creating bubbles that align with the galaxy's rotation axis rather than that of the black hole. She's currently working to simulate this scenario, although preliminary results suggest that creating the bubbles this way doesn't as easily explain the lobes' appearance, she says.

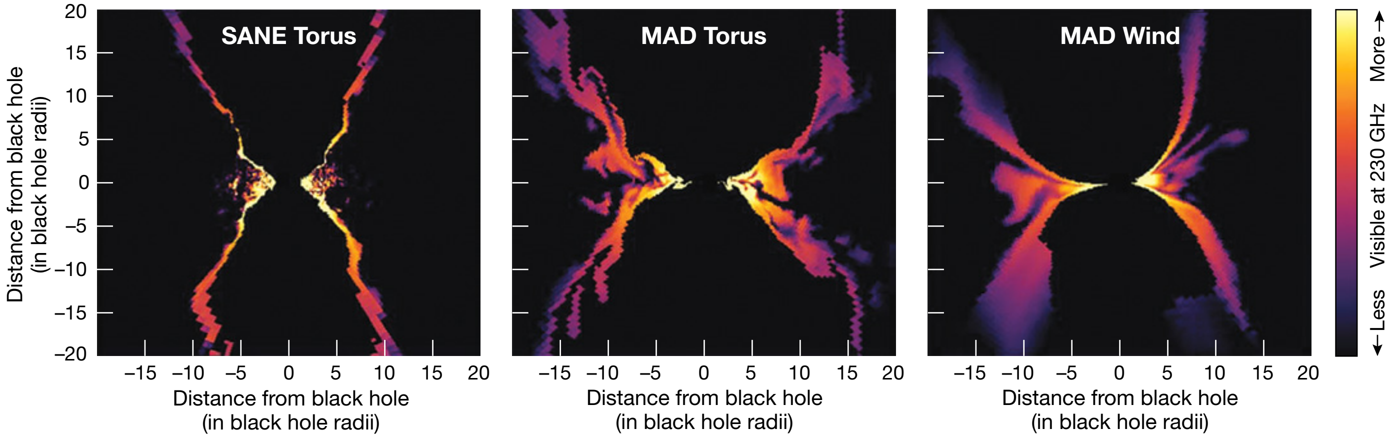
The Lion's Mane

Then there's the inflowing gas itself. The gas in the disk feeding a black hole drags magnetic fields with it as it spirals in toward the event horizon. Scenarios for the conditions in the disk fall into two categories: SANE and MAD. *Standard and normal evolution* (SANE) disks are more turbulent, with weak and messy magnetic fields threading them. *Magnetically arrested disks* (MADs) are packed with fields all stuck upright, which can choke the gas flow and serve as a highway for magnificent jets.

Twenty years ago, MADs were astrophysical insanity. Narayan and his collaborators fought to publish the scenario in scientific journals against referees' complaints that magnetic field lines would never behave like this. Even Narayan didn't think they'd happen in the real universe. "I thought it was just a cute idea," he says.

But younger scientists in his group saw the idea's potential, particularly Sasha Tchekhovskoy (now Northwestern University), who as a graduate student demonstrated that a MAD with a "booming jet" would arise naturally. Even so, Narayan didn't expect MADs to be common.

The EHT results might indicate otherwise: Overall, the EHT team favors a MAD feeding Sgr A*. "That's huge!" exclaims Michael Johnson (Center for Astrophysics, Harvard & Smithsonian). "People generally expected that it was SANE, turbulent, and nonspinning, because we don't see powerful jets. We're saying it's MAD, strongly magnetized, and spinning." The same holds for M87*, but given its jet, that's expected. "If this is true, then MAD systems are everywhere."



▲ **GAS INFALL** A black hole might eat from a thin, weakly magnetized stream of gas *(left)* or a flow choked with magnetic fields *(center and right)*. Many of the EHT team's simulations used a MAD torus to feed the accretion disk, but a trickle from stellar winds *(right)* might be smooth enough to explain the calm glow from Sgr A*.

Tchekhovskoy says that, on reflection, maybe it makes sense that a MAD feeds Sgr A*. The key factor that determines the flow's nature is whether magnetic fields can dominate the gas motions.

As gas streams into the black hole in a MAD, the black hole binges on the magnetic fields in the material, stuffing itself. There are so many field lines threading the black hole that they're like a handful of uncooked spaghetti. And like uncooked spaghetti, magnetic fields don't like to be squeezed or shoved into place: Loosen your fingers, and strands will pop out of the bunch. In an accretion disk, the only thing keeping the fields stuck in the black hole's throat is the gas pouring in. Concentrate enough fields together, though, and they'll fight back, buoyant against the gas. They'll form a dam or even shoot out and rip through the disk, creating hotspots and flares.

Given how little Sgr A* eats, even a relatively small magnetic buildup could control the gas flow, Tchekhovskoy says. "Maybe this is not such a big surprise, that it is MAD," he says. "What's surprising is that it pretends to be *not* MAD." For example, if the accretion flow is MAD and the black hole spins quickly, then there should be a jet, if only a stubby one, Tchekhovskoy and Narayan agree.

Perhaps the jet has been stifled. A jet will stream out along the black hole's spin axis while it's still close to the black hole, but if enough gas flows in along that axis, then the flow will re-route the jet in a completely different direction. "Through that process [the jet] loses a lot of power, and so it fizzles out much more easily," Ressler says. Stellar winds could potentially quash the jet this way, because they can feed the black hole from any direction.

The Quest Continues

The picture drawn so far might be confusing, and it should be. Although this work involved collecting 3½ petabytes of data — equivalent to one-seventh of the entire digital collection of the Library of Congress — it's only a first look.

"We've done the best job we can," Narayan says. But the inferences are self-contradictory: For example, how can we have a rapid spin and MAD flow with no jet? "I'm a little nervous," he admits.

The EHT team has plenty of data to keep exploring these questions: Observations from 2018, 2021, and 2022 all remain to be studied, as well as Sgr A*'s 2017 polarization data. The light's polarization will reveal the magnetic fields' orientation and, potentially, a more precise spin estimate if the black hole drags everything around with it enough to affect the pattern. The team is still discussing which data set to attack next.

But what several members of the collaboration are turning their eyes to is the next-generation EHT (ngEHT). No matter how good the algorithms, the EHT's true limits are the number of radio dishes and their locations. M87*'s image used data from seven stations at five sites; Sgr A*'s image involved eight at six sites (the eighth being the South Pole Telescope, for which M87* lies below the horizon). The team has continued adding telescopes to the array, and in 2022 eleven stations at nine sites participated in the campaign.

But it's not enough. "Right now we're on the edge," says EHT founding director Shep Doeleman (Center for Astrophysics, Harvard & Smithsonian). "We lose one of these antennas, it's very difficult to recover the image. . . . If we have a weather pattern that takes two of our antennas out in key locations, we're done for the night. Might as well not even observe."

The ngEHT could change that. Phase I aims to rope in five additional dishes, three grabbed and refurbished from a former National Science Foundation project and shipped to new locations. Proposed to be up and running in 2026, Phase I will increase the number of baselines by a factor of eight compared with 2017. It will also observe in both the existing 230 GHz band and a new 345 GHz one, which will not only effectively change the image from monochrome to color but also improve resolution by 50%. Even without resolving shadows (only possible for a handful of objects), the enhanced array could enable astronomers to "weigh" dozens of supermassive black holes and clock spins for about 10 of them.

Then comes Phase II, which by 2030 would add another five dishes (this time custom-built) as well as potentially partnering with proposed observatories in Namibia and Argentina. That would increase the number of baselines to more than 200, substantially filling in the virtual dish and revealing features 100 times fainter than the 2017 observations could pick out.

That kind of observing power will reveal M87*'s shadow and jet in exquisite detail. Astronomers don't fully understand how black holes make jets: Either the accretion disk powers jets, or the spin does. Observations favor the latter.

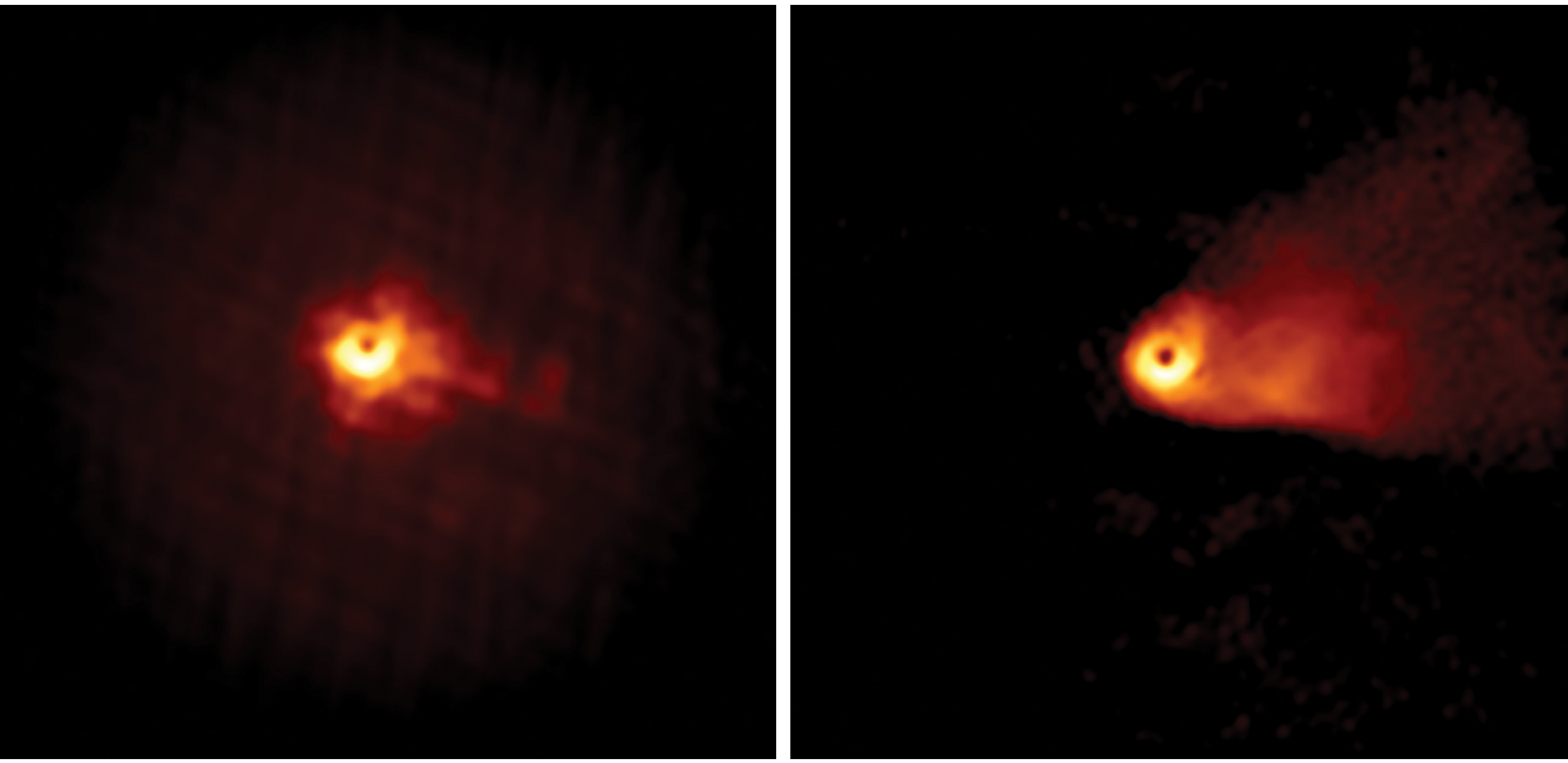
In this scenario, the magnetic field is like an eggbeater, twirled around by the black hole's spin, explains Doeleman. These fields are sweeping through charged particles, and the particles drag on the fields like pancake batter drags on the eggbeater when you dip it into the mixing bowl. The fields strain against the resistance, sucking energy from the black hole's spin like the eggbeater does its motor.

Charged particles corkscrew around magnetic field lines, but they also have to follow where a magnetic field leads, so as the fields whip around, the particles whip around, too. "They're orbiting and they're going on this Tilt-A-Whirl, all at the same time," Doeleman says. "They're very dizzy particles." This whipping about accelerates the particles and flings them out along the field lines, making the jet.

Astronomers don't fully understand how black holes make jets: Either the accretion disk powers jets, or the spin does. Observations favor the latter.

By decade's end, EHT scientists hope to have full-blown movies of both M87* and Sgr A*. The measurements will show M87*'s jet-launching process in action and reveal whether this eggbeater picture is true, as well as tell us whether Sgr A* has a jet. The Sgr A* movie will take longer than the M87* one, for the same reasons that the portrait took longer. But the lion no longer lies hidden in its lair — the safari is under way.

■ Science Editor **CAMILLE CARLISLE** wrote part of her master's thesis about the EHT's quest to image Sgr A*. Now that the team has succeeded, her career has come full-circle. (Alas, the editor in chief won't let her retire early.)



▲ **OBSERVING FORECAST** These are simulated images of what the Event Horizon Telescope would see of M87* using seven stations (as in 2017) and 20 stations (as in Phase 2 of the ngEHT). Both are based on the same computer simulation of conditions around the black hole, not real data, so that they can be easily compared. In the seven-station version *(left)*, we see the black hole's shadow surrounded by a haze of radio emission from the surrounding gas. But with additional baselines, we're able to resolve larger scales and dimmer features, revealing the black hole's jet (swath extending rightward in the 20-station image).

Cassiopeia's *Planetary Nebulae*

▲ **FAST MOVER** HFG 1 is a planetary nebula in the far eastern reaches of Cassiopeia that has a spooky appearance in astrophotos. As the binary central star V664 Cassiopeiae plows through the thin interstellar medium, it creates a bow shock (in grayish blue) and leaves a long trace of gas (in red) behind in its wake. While you're admiring HFG 1, can you make out the small planetary nebula Abell 6 about 0.6° to the west-southwest?

Her celestial majesty holds a pleasing selection of planetary nebulae that you can enjoy all in one winter's evening.

Toward the end of the year, we find Cassiopeia, the Seated Queen, high overhead shortly after sundown. Under my rural skies the constellation's distinct W blazes in front of a fairly bright section of the Milky Way. By area, it's the 25th-largest constellation and adorned in copious open star clusters. Which, as you might imagine, makes it a great constellation for perusing with binoculars.

Recently, though, I was surprised to learn that Cassiopeia also contains a wealth of planetary nebulae. The authoritative *Strasbourg-ESO Catalogue of Galactic Planetary Nebulae* lists 26 objects as "true or probable" planetaries in Cassiopeia. I suspect that most observers pass them over because the brighter ones are nearly stellar while the larger examples are quite faint. In fact, only one of the 26 was actually discovered visually!

Out West

On this tour, we'll visit Cassiopeia's 13 brightest planetary nebulae, which I viewed using nothing larger than my vintage, 10-inch Schmidt-Cassegrain telescope. To make sure you have time to get to them all comfortably, start in the west and work your way east.

While our first target isn't the easiest to find, it compensates by being the brightest. Known as **Hubble 12**, it's visible in my 12×60 binoculars as a faint "star" 5.5° west-southwest of Beta (β) Cassiopeiae (familiarly known as Caph) or about 3.5° south of the elegant open cluster M52. At 94× in my 10-inch, the nebula remains starlike, and a 12.3-magnitude star lies 1′ east-northeast. In fact, even at 520× on steady nights, the planetary remains stellar for me!

However, using his 18-inch at 807×, *S&T* Contributing Editor Steve Gottlieb has seen a very small and faint 2″ halo surrounding the 13.8-magnitude central star. So, without enough magnification, I'm just seeing the faint central star immersed in a tiny nebula, which is nearly two magnitudes brighter. It was — you guessed it! — Edwin Hubble who discovered Hubble 12 as well as four other planetary nebulae a little more than a century ago. Today, we know it to be at an early stage of evolution with a rare, nested bipolar hourglass structure. Interactions between the two components of a presumed binary central star may be instrumental in sculpting its intriguing shape.

Next up is **Abell 82**, which lies 3.7° southwest of Beta Cassiopeiae or 1.6° west-northwest of the rich open cluster NGC 7789. American astronomer George Abell made numerous discoveries during his prolific career, most notably of galaxy clusters and planetary nebulae. We'll encounter several of the latter here. He unearthed Abell 82 in his examination of the *National Geographic Society – Palomar*

▲ **BILLOWING BUTTERFLY** One of several planetary nebulae that Edwin Hubble visually confirmed, Hubble 12 lies in western Cassiopeia. It's a striking example of a bipolar nebula, i.e., it displays two symmetrical lobes on either side of the central object, which in this case is likely a binary star.

▲ **FARAWAY GEM** Abell 82 is often likened to the well-known Ring Nebula (M57) in Lyra due to its similar apparent extent, but it's much fainter. Also, while the Ring Nebula lies at a distance of around 2,500 light-years, Abell 82 is more than twice as far at around 5,800 light-years.

HFG 1: NICO GEISLER / FRANK IWASZKIEWICZ; HUBBLE 12: NASA / ESA / ACKNOWLEDGEMENT: JOSH BARRINGTON; ABELL 82: JERRY MACON

▲ **LONELY OUTPOST** Abell 84 is possibly the hardest planetary nebula to star-hop to on our celestial tour. Lying around 6,400 light-years distant, its apparent size of about 2.5′ translates to a true dimension just shy of 5 light-years.

▲ **BRIGHT SURPRISE** Despite it being one of the brighter and easier planteray nebulae to find among our targets, Abell 2 is actually one of the least interesting visually.

Observatory Sky Survey (POSS) photographic plates. (For a nice roundup of several of Abell's planetary nebulae, see *S&T:* Jul. 2017, p. 34.) Using 94× and an O III filter, I spied it 25′ south-southwest of the gold-hued, 6th-magnitude star HD 223173, and I even suspected it when I removed the filter. At 117× I could see it unfiltered with averted vision as a soft glow a full 1′ wide, only 1.5′ southeast of an 11.3-magnitude star. Several fainter stars are scattered across the immediate area, including a distracting one of magnitude 13.2 on the southeastern edge of the planetary. Increasing to 260×, the 14.9-magnitude central star emerges with direct vision, while the disk is a soft, ill-defined glow.

Abell 84 is challenging to find as it lies far from any bright naked-eye stars. It's situated more than 9° southwest of 2.2-magnitude Alpha (α) Cassiopeiae (also known as Schedar) near the border with Andromeda. For more than 50 years after its discovery it held the distinction of being the planetary nebula with the largest right ascension, appearing last in many lists (until amateur astronomer Matthias Kronberger discovered Kronberger 50 in 2007). It sits 12′ northeast of 7.5-magnitude HD 223152 and is 7′ west of a 4′-wide pair of 10th-magnitude stars. In my 10-inch at 94×, it's invisible until I add an O III filter, which then reveals a faint, 1.5′-wide disk with an 11.3-magnitude star on its eastern side. Keeping the filter, at 117× the nebula's edges are very ill-defined, and I can detect a slightly brighter central area running east to west. Removing the filter and bumping up to 200× and 260×, I was surprised to still glimpse the planetary as an amorphous disk.

Lost Brothers

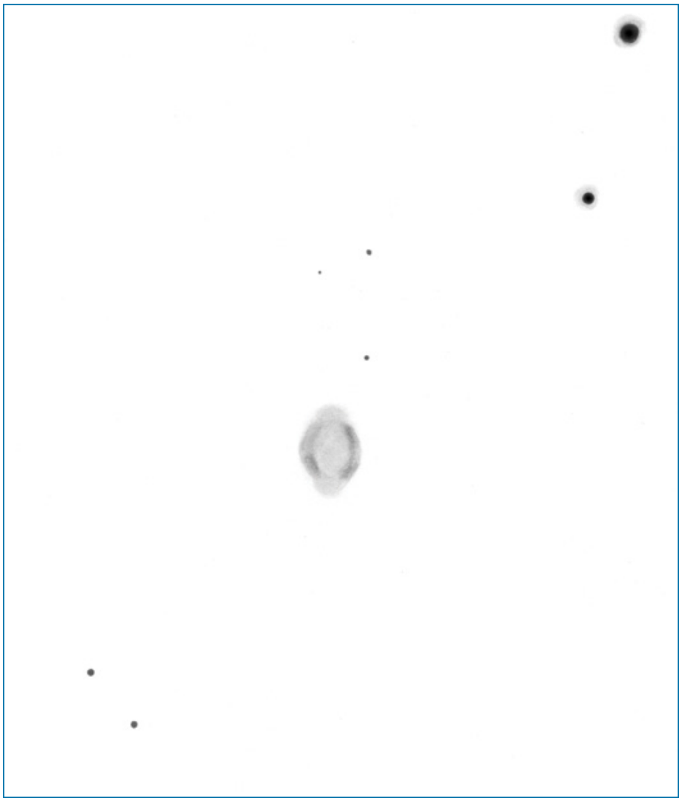
A careful star-hop 1.8° west-southwest of Alpha Cassiopeiae will bring you to our next target, the nearly stellar, 12th-magnitude **Humason 1-1**. It's the faintest of three planetaries that Milton Humason, Hubble's long-time assistant at Mount Wilson Observatory, discovered. He found them in the early 1920s on objective-prism plates taken with a 10-inch f/4.5 Cooke refractor.

Hu 1-1 lies 2′ southeast of a close pair formed by 11.7- and 12.6-magnitude stars. At 150× in my 10-inch, it begins to look like a bloated star with a dull gray-blue hue, while at 200× it's noticeably nonstellar. Under good seeing conditions, bumping the magnification all the way up to 520× allows me to detect the nebula's small, dark center. This planetary takes magnification splendidly because it has a high-surface-brightness annulus, hosts a central star too faint to be visible, and achieves a high altitude in the sky for viewers at mid-northern latitudes.

Our next target is as small as the previous one and lies just 2.5° farther southwest. Russian-born astronomer Alexander Vyssotsky accidentally discovered **Vyssotsky 1-1**, as it came

▶ **CASSIOPEIA'S TREASURES** One of the most recognizable constellations harbors a pleasing wealth of planetary nebulae. Spend your winter nights enjoying this curated selection.

JERRY MACON (2)



▲ **TINY NEBULAE** Humason 1-1 (*left*) and Vyssotsky 1-1 (*right*) are little gems southwest of Schedar, or Alpha Cassiopeiae, with Vy 1-1 lying farther from the star. Vy 1-1 is also the most distant planetary on our tour at more than 20,000 light-years. German amateur Uwe Glahn's sketch shows how he saw Hu 1-1 through the eyepiece of a 27-inch scope at 837×, while the author's sketch presents his view of Vy 1-1 through a 10-inch at 520×.

HU 1-1: UWE GLAHN; VY 1-1: SCOTT HARRINGTON

to be known, in 1942. It was during his 35-year tenure at the University of Virginia's Leander McCormick Observatory that he noticed the planetary on objective-prism plates while searching for nearby stars.

At 94× in the 10-inch, Vy 1-1 looks like an average field star with a faint double 1′ to its southwest. At 150×, I can detect that the more northern star of the pair is itself a close double separated by about 7″. Using 200×, the planetary displays a peculiar softness compared to other stars of similar brightness. Scaling up to 520×, I notice a haze around it with averted vision that's no more than 10″ across.

That may not seem at all impressive, but I was thrilled to catch any snippet considering its bizarre appearance in images.

Fifties Flashbacks

Our next quarry lies just 0.5° west-northwest of the colorful, 13.4″-wide double star Eta (η) Cassiopeiae (magnitudes 3.5 and 7.4) and is noticeably brighter than its cataloged magnitude of 14.1. I know because, as with Abell 84, I can just detect **Abell 2** in my 5.1-inch reflector with a narrowband filter.

At 94× in my 10-inch, I'm able to glimpse it with direct vision by keeping Eta Cas out of the field and looking 4.5′ south of an 8.3-magnitude star (HD 4253). At 200× I see it as a tiny, ghostly 30″ disk with two 15.5-magnitude stars directly southwest. Adding an O III filter makes the entire planetary easier to see but doesn't add any specific details. However, upping the magnification to 260× reveals a mottled or irregular surface. While this is the last planetary Abell cataloged that's on our tour, Cassiopeia harbors three more that bear his designation — the second most of any constellation (after Aquila).

Our next two targets are very challenging and happen to lie on either side of Kappa (κ) Cassiopeiae. To find **B-V 1** (often labeled BV 5-1 or BV 1), aim your telescope 1.5° west of the 4.2-magnitude sun.

Knowing what to look for in advance helps, but even at 117× and aided by an O III filter, all I discern with my 10-inch scope is a tiny, extended spot. Removing the filter and increasing to 200× and 260×, I note a faint, slightly elongated, nonstellar spot with averted vision. What I'm seeing is only just the bright "kink" in the roughly 40″-long arc. That may not seem at all impressive, but I was thrilled to catch any snippet considering its bizarre appearance in images.

B-V 1 is the fainter of two planetary nebulae that German-American astronomer Erika Böhm-Vitense discovered in the mid-1950s while she was in her early thirties. She found them while searching for galaxies in the Zone of Avoidance (the nickname professional astronomers use for the area of the sky that the Milky Way obscures) on plates taken at the Lick Observatory. It has since become the most studied of her discoveries because of its unusual appearance, which is attributed to it being an old, bipolar planetary viewed edge-on.

For our next target **B-V 2** (usually referred to as BV 5-2), start again at Kappa but this time head 0.8° due east. I had trouble finding the planetary because it lies in a field of stars of mostly equal-magnitude stars. At 150× in my 10-inch, I

Regal Attire

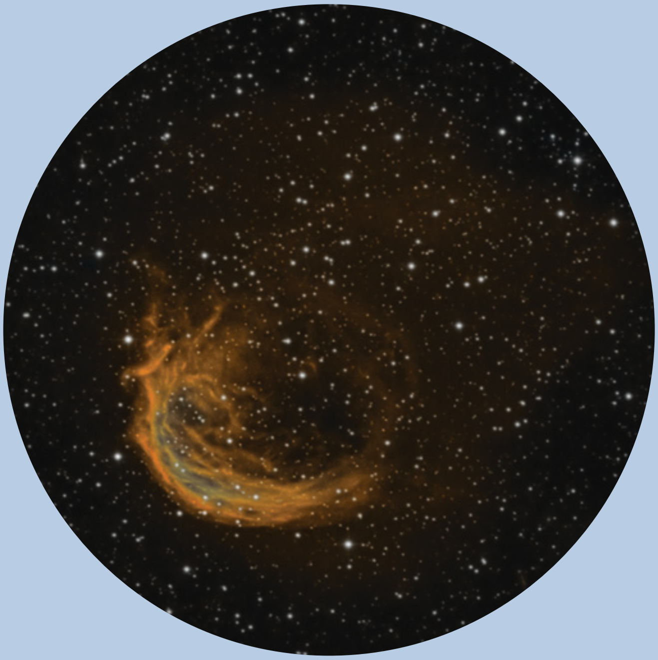
Object	Alt ID	Mag(v)	Size	Dist. (l-y)	RA	Dec.
Hubble 12	PN G111.8–02.8	11.9	16″	7,400	23^h 26.2^m	+58° 11′
Abell 82	PN G114.0–04.6	12.7	94″	5,800	23^h 45.8^m	+57° 04′
Abell 84	PN G112.9–10.2	13.0	152″	6,400	23^h 47.7^m	+51° 24′
Humason 1-1	PN G119.6–06.7	12.3	16″	19,300	00^h 28.3^m	+55° 58′
Vyssotsky 1-1	PN G118.0–08.6	12.5	14″	22,400	00^h 18.7^m	+53° 52′
Abell 2	PN G122.1–04.9	14.1	36″	13,600	00^h 45.6^m	+57° 58′
B-V 1	PN G119.3+00.3	14.7	60″	14,200	00^h 20.0^m	+62° 59′
B-V 2	PN G121.6–00.0	15.4	38″	—	00^h 40.4^m	+62° 51′
Simeis 22	PN G128.0–04.1	12.1	340″	1,400	01^h 30.7^m	+58° 22′
IC 1747	PN G130.2+01.3	12.0	19″	10,000	01^h 57.6^m	+63° 19′
HFG 1	PN G136.3+05.5	—	500″	1,900	03^h 03.8^m	+64° 53′
HDW 2	PN G138.1+04.1	—	340″	2,700	03^h 11.0^m	+62° 48′
IC 289	PN G138.8+02.8	13.2	48″	6,100	03^h 10.3^m	+61° 19′

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.

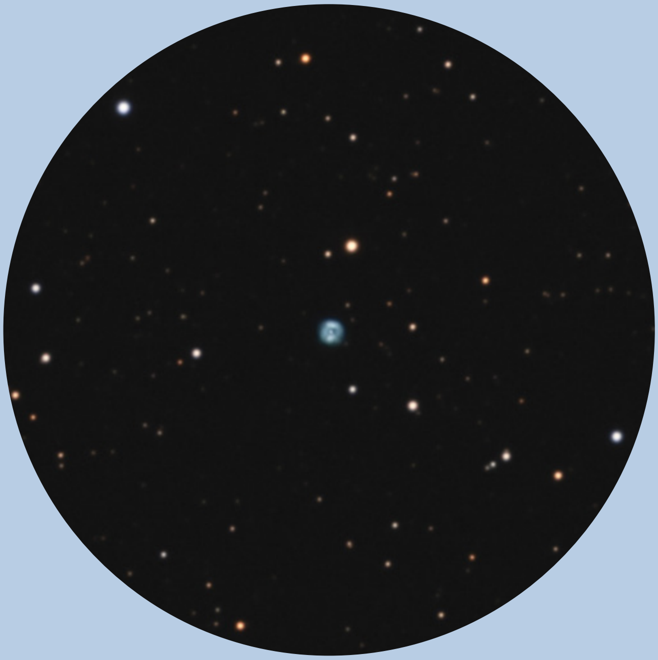
B-V 1: KEVIN QUIN; B-V 2 AND IC 1747: GARY IMM; SIMEIS 22: FRANK BRESLAWSKI

▲ **EDGE-ON BEAUTY** Not all planetary nebulae present almost-perfect ringlike structures or impressive bipolar outflows. Some, such as B-V 1, when viewed nearly edge-on display singular profiles — in fact, in images, it bears a striking resemblance to the galaxy Centaurus A.

▲ **LOPSIDED NEBULA** Astronomer Erika Böhm-Vitense also cataloged B-V 2, another asymmetric planetary nebula only a little more than 2° east of B-V 1. B-V 2 guards its secrets closely — we don't know how far away it is, nor do we know the nature of its central star.



▲ **CELESTIAL CETACEAN** With its strongly asymmetric appearance, Simeis 22 is reminiscent of Abell 21, a much brighter planetary, in Gemini. Not surprisingly, observers refer to Simeis 22 as the Dolphin Nebula — in this image it looks like it just dove back underwater.



▲ **FOLLOW THE STARS** A handy chain of stars leads you directly to IC 1747. This colorful planetary nebula's 15th-magnitude central star, seen peeping out from its center, is actually a rare type of object known as a Wolf-Rayet star.

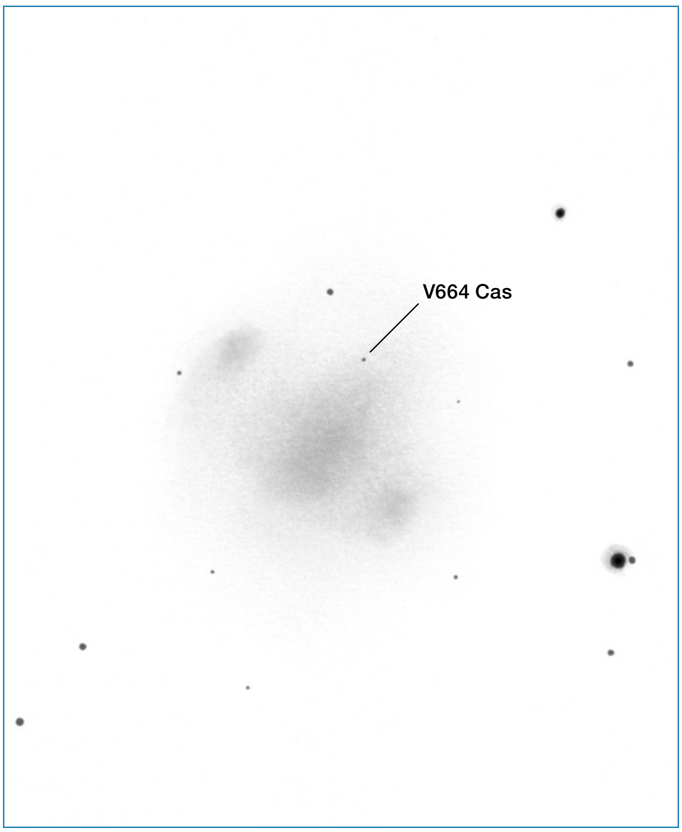
only caught glimpses of its brighter southern edge unfiltered, but at 200× I was certain of it. My best view was at 260× with averted vision when I saw a diffuse spot that had a slightly brighter center. Can you make out more of its disk?

While Böhm-Vitense was the first to catalog B-V 2 as a planetary, she didn't discover it. That honor instead goes to American astronomer Stewart Sharpless, who, in 1953 when he was 27 years old, published a large catalog of diffuse nebulae he found by inspecting POSS plates. His final, expanded work, which appeared six years later, listed the object as Sh 2-179.

On to our next target: Appropriately nicknamed the Dolphin by astrophotographers, **Simeis 22** (pronounced see-MACE) isn't hard to find as it lies just 2° south-southeast of Delta (δ) Cassiopeiae or 1.5° east of the coarse open cluster NGC 457. That being said, I've found *seeing* it always takes a nebula filter. Even so equipped, in my 5.1-inch at 59× I can barely discern a faint arc about 20′ west of the 5.7-magnitude star HD 9352. At 94× in my 10-inch, an O III filter shows a glow mimicking the arc that some fainter stars create. Can you see it without a filter?

In 1949, after World War II, Russian astronomers Grigory Shajn and Vera Gaze began a systematic photographic survey of nebulae along the band of the Milky Way. They did so using two large, high-speed Schmidt cameras at the Simeis Observatory, which lies at the southern tip of the Crimean Peninsula. Simeis 22 was just one of more than 100 of their discoveries.

However, for the next several decades, Western astronomers exclusively referred to it as Sh 2-188 after Sharpless included it in both his first and second catalogs of emission nebulae; they were unaware of the many discoveries at the Simeis Observatory, due in large part to the ongoing Cold War. Although Simeis 22 was initially thought to be a supernova remnant due to its filamentary nature, it wasn't until 1982 that further studies proved it to be an old planetary nebula, whose morphology has been strongly affected by interaction with the interstellar medium.



▲ **EASTERN REACHES** HFG 1's central star, V664 Cassiopeiae, is noticeably offset from the brightest part of the planetary nebula, a feature that Uwe Glahn captured nicely in his drawing.

Out East

Residing a mere 0.5° southeast of 3.4-magnitude Epsilon (ε) Cassiopeiae, **IC 1747** is arguably the easiest planetary nebula to find in Cassiopeia. But don't let the proximity of the nebula to the star fool you — IC 1747 possibly lies 20 times farther than the blue subgiant, placing it on the nearside of our galaxy's Perseus Arm. Despite the large distance, it's still faintly visible as a 12th-magnitude star in my mounted 15×70 binoculars.

At 94× in my 10-inch, IC 1747 has an unmistakable light-blue color and appears as one of the brighter points in an eye-catching, S-shaped chain of mostly 11th- and 12th-magnitude stars that runs east to west. At 117×, the S nicely fills the field, while the planetary is barely nonstellar compared to the 12.5-magnitude star 50″ north-northwest. Using a magnification of 520×, I can discern that the center of the planetary is dimmer and the edge toward the 12.5-magnitude star is brighter. Because of its small size, IC 1747 avoided discovery until 1905, when Harvard astronomer Williamina Fleming spotted it while classifying stars by their spectra on photographic plates.

Our final three quarries are all so far east of Epsilon Cassiopeiae that they're within 1.5° of the border with Camelopardalis. Let's first start with the large and strange-looking planetary **HFG 1**, which lies almost 2° north-northwest of the bright, compact open cluster Trumpler 3.

With my 5.1-inch at 34× and a narrowband filter, I can suspect it about 7′ northeast of a 9.2-magnitude star (HD 18611) — or 18′ southwest of a 7.2-magnitude star (HD 18892). Retaining the filter and increasing the magnification to 59×, I catch strong glimpses of its large glow with heavily averted vision. Using my 10-inch at 94× without a filter, the 13.3-magnitude central star (also known as V664 Cassiopeiae) is visible with direct vision, while I can also detect a large, dull glow when slowly panning across the field. Adding an O III filter, I see a very soft, ill-defined smudge that's brightest southeast of the central star. Backing down to 71×, I still get a good view and can tell that the central star is offset from the bulk of the glow.

Surprisingly, HFG 1 escaped detection throughout all previous photographic surveys and was only discovered about 40 years ago. Astronomers Joy Heckathorn, Robert Fesen, and

Theodore Gull (all at the Goddard Space Flight Center at the time) found it while scouring images from a 1979 emission-line survey of the galactic plane that Robert Parker of the Johnson Space Center conducted with his colleagues.

To reach our next target, find Trumpler 3 again and scan less than 0.5° south for a short arc of several 11th- to 13th-magnitude stars. The first time I sought **HDW 2** was just a year ago, when I turned my 10-inch its way using 94× and an O III filter. I was a bit surprised to notice a large, subtle glow encompassing the group of stars. Previously, I had only read of former *S&T* Contributing Editor Sue French's sighting (*S&T:* Dec. 2015, p. 50) with a 15-inch reflector.

On a whim, due to how the planetary seemed to fill the field more than I liked, I also looked for it in my 5.1-inch. Then came an even bigger surprise. At 34× with a narrow-band filter, a soft glow blossomed out from around those stars as I swept over the field. Increasing the magnification to 59× settled my doubts because the glow was 5′ across, round, and readily evident.

HDW 2 also goes by the designation Sh 2-200, as Sharpless included it in his second *Catalogue of H II Regions* published in 1959. But it was Austrian astronomers Herbert Hartl, Johann Dengel, and Ronald Weinberger who, more than 20 years later, classified it as a planetary nebula after rediscovering it while inspecting POSS red plates.

Our final target is the only planetary in Cassiopeia discovered visually. The famed New York comet hunter Lewis Swift spotted **IC 289** in September 1888 using a 16-inch refractor. To find it, look just shy of 2° south of Trumpler 3 for a 10.1-magnitude star (BD+60 631).

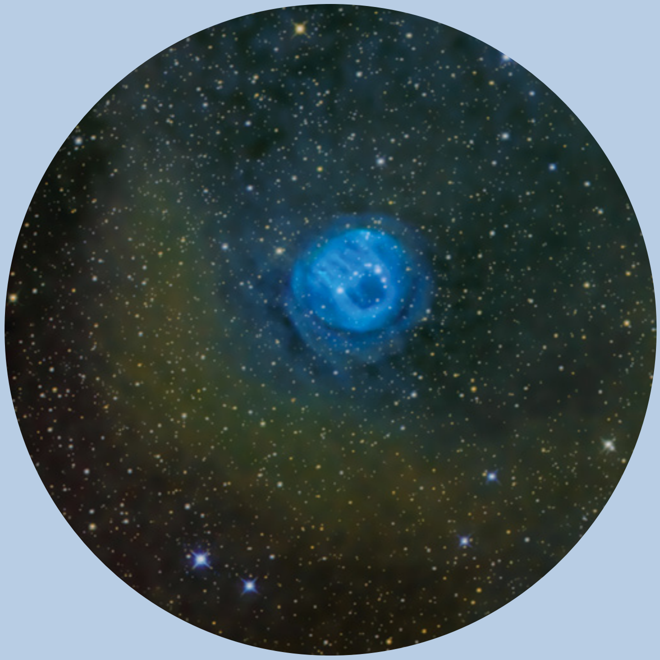
With my 5.1-inch at 59× and using moderately averted vision, the planetary is visible as a faint disk almost 2′ north of the star. At 94× in my 10-inch, its 35″-wide disk is visible with direct vision, while an O III filter gives a decent boost in contrast. At 260×, its disk is almost perfectly round and of even surface brightness.

And with that, we conclude our tour. But let me leave you with this thought: While planetary nebulae are short-lived on an astronomical timeline, the reason we can see so many is because the Milky Way is so vast. Some of those that we see today actually lie far enough away that they've already faded away. Just another reason to savor every one.

■ **SCOTT HARRINGTON** owes a debt of gratitude to planetary hunter Kent Wallace for his massive tome *Visual Observations of Planetary Nebulae*, which he first self-published in 2017.

FINDER CHARTS: Go to **https://is.gd/Cas_PNe** for deeper finder charts of these targets.

FURTHER MATERIAL: For a truly inspiring and massive slate of high-quality planetary nebula drawings, visit Uwe Glahn's web-page at **https://www.deepsky-visuell.de**.
You can purchase Wallace's book at **webbdeepsky.com/publications/books**.



▲ **ACCOMPANIED BY AN ARC** A pretty semicircle of stars adorns HDW 2's nebulosity, its 16th-magnitude central star a mere speck among them. In photos, HDW 2 has a striated appearance, earning it the nickname the Bearclaw Nebula.

▲ **LAST BUT NOT LEAST** A 10th-magnitude star points the way to IC 289. Following Lewis Swift's discovery, Edwin Hubble was the first to classify the object as a planetary nebula.

HDW 2: DALTON WILSON; IC 289: ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA

FAMILY PORTRAIT A trio of stars make up 40 Eridani, all of which are fainter and smaller than the Sun: 40 Eridani A, an orange dwarf (foreground); 40 Eridani B, a white dwarf so hot it's actually blue; and 40 Eridani C, a red dwarf, the most common type of star in the galaxy. The white dwarf is only 43% larger than Earth's diameter.

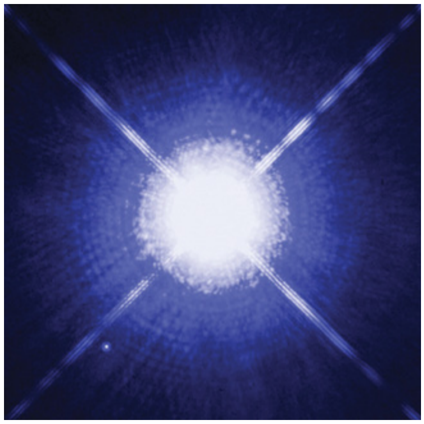
CASEY REED

The First White Dwarf

The road to discovering a new type of star was long and winding.

A white dwarf is an extraordinary object. If you could stand on its surface and drop a pebble, the stone would smash into the star a split second later at thousands of miles per hour. The tiny star's immense surface gravity arises because the typical white dwarf packs 60% of the Sun's mass into a sphere that's only slightly larger than Earth. Its gravity, therefore, pulls that pebble down *hard*.

Yet these extraordinary objects are common, making up 6% of the stellar population of the Milky Way. They represent the eventual fates of most stars, including our Sun, after they run out of fuel. Since white dwarfs abound, many shine nearby. The closest is just 8.6 light-years from Earth, orbiting brilliant Sirius in Canis Major. Designated Sirius B, this near neighbor has an apparent magnitude of 8.4, making it the brightest white dwarf of all. But in backyard telescopes, it's difficult to see, lost in the glare of its dazzling mate.



▲ **SUPER DENSE** Smaller than Earth but as massive as the Sun, the white dwarf Sirius B (7 o'clock position) is so dense that a spoonful of its material would weigh tons. With a surface temperature of 25,000 K, Sirius B is also one of the hottest stars in our vicinity and much hotter than its brilliant mate, which it orbits every 50 years.

NASA / ESA / H. BOND (STSCI) AND M. BARSTOW (UNIV. OF LEICESTER)

Astronomers first suspected the presence of Sirius B long before they actually observed it. In 1844, in Prussia, Friedrich Wilhelm Bessel reported that Sirius wobbled as it traveled through space. He correctly attributed this wobble to the gravitational pull of an invisible partner orbiting the bright star. On January 31, 1862, American astronomer Alvan Graham Clark spotted the elusive companion, which is 10 magnitudes dimmer than Sirius A (*S&T:* Feb. 2008, p. 30). However, no one then knew that Sirius B was a white dwarf. In fact, that term didn't exist until 60 years later.

Today, of course, Sirius B is the best-known white dwarf of all, leading to the claim that it was the first white dwarf ever found. In fact, at least two NASA websites say so. But that honor actually belongs to another stellar neighbor of ours — one that's a lot easier to see.

The Story of 40 Eridani

West of Orion's Rigel, in the northern reaches of the meandering constellation Eridanus, shines a triple-star system named 40 Eridani. It lies 16.3 light-years from Earth, about twice as far as Sirius. The brightest member of this stellar trio is an *orange dwarf* — a *K*-type main-sequence star that, like the Sun, converts hydrogen into helium in its core. Orange dwarfs are less luminous than the Sun because they are less massive. Although common, most are too faint to be visible to the naked eye, but 40 Eridani's proximity makes it an exception.

In 1783, on January 31st — exactly 79 years before the first sighting of Sirius B — the great German-born English astronomer William Herschel, who two years earlier had discovered the planet Uranus, aimed his telescope at 40 Eridani. He saw that the naked-eye star had two faint companions. The tight, dim pair was about $1\frac{1}{3}$ arcminutes east of the orange dwarf, 40 Eridani A.

Herschel recorded the separation and position angle of the companion stars, but he never observed them again. Of course, he didn't know 40 Eridani was special. Neither did anyone else.

The first sign that 40 Eridani stood out from the stellar pack came two decades later when Italian astronomer Giuseppe Piazzi (best remembered for discovering the first asteroid, Ceres) observed that the star had a large proper motion. *Proper motion* is the apparent movement, year after year, of a star across the night sky (*S&T:* June 2022, p. 30). The nearer a star is to us and the faster it dashes across our line of sight, the larger its proper motion.

At that time, however, astronomers had yet to ascertain the distance to any star but the Sun. They had long sought to do so by measuring *stellar parallax*, the apparent shift that occurs when we view a star from different vantage points as Earth circles the Sun. Mistakenly assuming that brightness indicated nearness, astronomers concentrated their parallax efforts on the very brightest stars, expecting them to be the closest. But Piazzi recognized that a large proper motion was a more reliable sign of proximity.

However, the Italian astronomer faced a problem. "They are going to think I am a fool because I have deduced the proper motions of a few stars on the observations of only ten years, and in some cases less than that," he wrote to Barnaba Oriani, director of the Observatory of Brera in Milan. Piazzi therefore confirmed the movements by comparing the stellar positions he had measured with those recorded in the 1600s and 1700s.

"I have found some movements that deserve full attention from astronomers, especially in the constellations of Cetus and Eridanus," he wrote in 1804, mentioning 40 Eridani, correctly suspecting that it was one of our closest neighbors.

That same year, Piazzi discovered the large proper motion of an even fainter star, 61 Cygni. In 1838, using the parallax method, Bessel successfully measured 61 Cygni's distance — a first for any star besides the Sun — thus propelling it to fame. However, 40 Eridani would keep its secrets a little longer.

In the 1880s astronomers on two different continents finally succeeded in measuring 40 Eridani's distance. One was Scottish-born David Gill, who observed 40 Eridani A from South Africa. "This is the principal star of one of the most remarkable systems in the heavens," he wrote from the Cape of Good Hope. Between July 11, 1881, and February 19, 1883, he measured the star's position and derived its parallax.

Meanwhile, American astronomer Asaph Hall, of the U.S. Naval Observatory, learned of the star's importance from a Russian astronomer. Otto Wilhelm von Struve, head of the Pulkovo Astronomical Observatory near Saint Petersburg, Russia, had tracked the motion of 40 Eridani B and C around each other.

"During one of his visits to the Naval Observatory, Director Otto Struve called my attention to this interesting stellar system, and advised me to undertake a determination of its annual parallax, since its position made it a difficult object to observe in Europe," Hall wrote in the German journal *Astronomische Nachrichten* (*Astronomical Notes*). Using the same 26-inch refractor with which he had discovered the Martian moons Phobos and Deimos in 1877, Hall observed 40 Eridani 30 times between February 23, 1883, and March 4, 1884. "These observations were tedious, and took much time," he added. But he succeeded in detecting the star's parallax.

Both Gill and Hall published their work in 1885. Gill's parallax indicated that the star was about 3 light-years farther than the modern figure of 16.3 light-years, whereas Hall's work put the star about 2 light-years closer than it actually is. Either way, the measurements showed that the 40 Eridani system was nearby, which meant that the stars also had to be intrinsically faint. In particular, 9.5-magnitude 40 Eridani B and 11.2-magnitude 40 Eridani C emit much less light than the Sun, which would shine at 3rd magnitude if viewed from the same distance. It takes 40 Eridani B nearly a year to emit as much visible light as the Sun does in a 24-hour day. And 40 Eridani C is even dimmer.

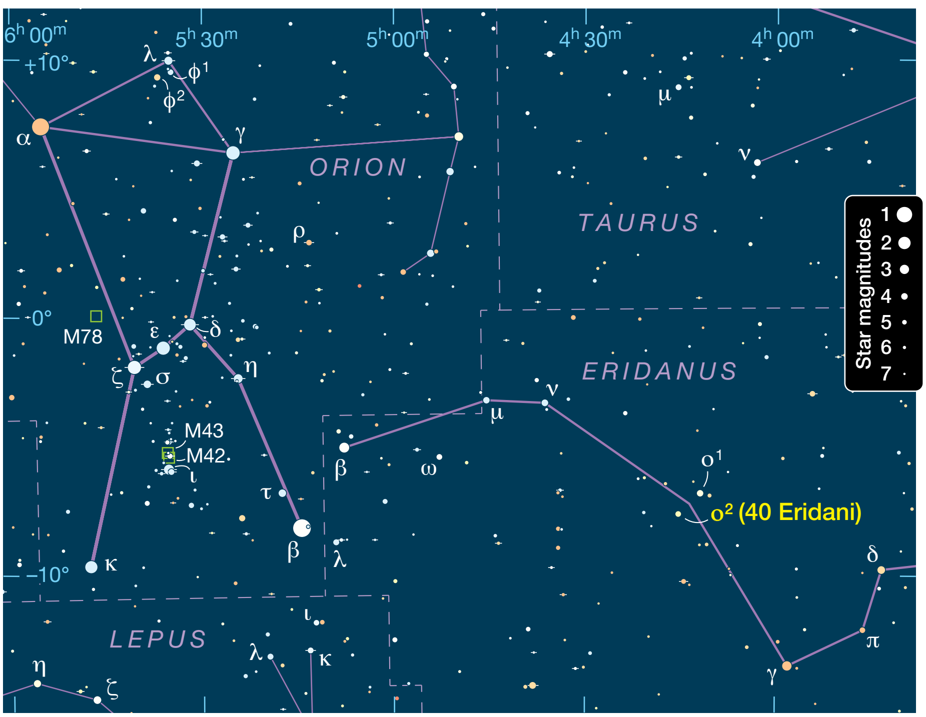
By the late 19th century, however, astronomers were starting to realize that many of the Sun's stellar neighbors were faint and red — what we now call *red dwarfs*. For example, astronomers had previously found that 7.5-magnitude Lalande 21185, a red dwarf in Ursa Major, was closer than any other star then known except the Sun and Alpha Centauri (*S&T:* June 1995, p. 68), and in the 1880s Gill himself measured the parallax of Lacaille 9352, a 7.3-magnitude star in Piscis Austrinus that also turned out to be a nearby red dwarf.

The preponderance of dim red stars seemed to have a clear implication for the nature of the star orbiting Sirius. Although no one could see it well, Sirius B was surely just another red dwarf — one that happened to accompany the brightest star in the night sky.

A White-Hot Discovery

With every new hard-won parallax measurement, astronomers could calculate a star's intrinsic brightness because they now knew its distance. Patterns were starting to emerge. Red stars, now classified as spectral type *M*, came in two varieties. A few, like Antares and Betelgeuse, were luminous, but most, like Lalande 21185 and Lacaille 9352, were much dimmer than the Sun. In contrast, all the blue and white stars (spectral types *B* and *A*) outshone the Sun.

Harvard astronomers had developed these spectral types to classify the stars. Observatory director Edward Pickering led the effort, but his assistants — especially Williamina Fleming and Annie Jump Cannon — actually performed most of the classifications. The discovery of the first white dwarf resulted from combining two pieces of



◀ **A GEM IN THE RIVER** The easiest white dwarf to see in backyard telescopes is unquestionably 9.5-magnitude 40 Eridani B, which lies 83″ east-southeast of 4.4-magnitude 40 Eridani A, also known as Omicron^2 (o^2) Eridani.

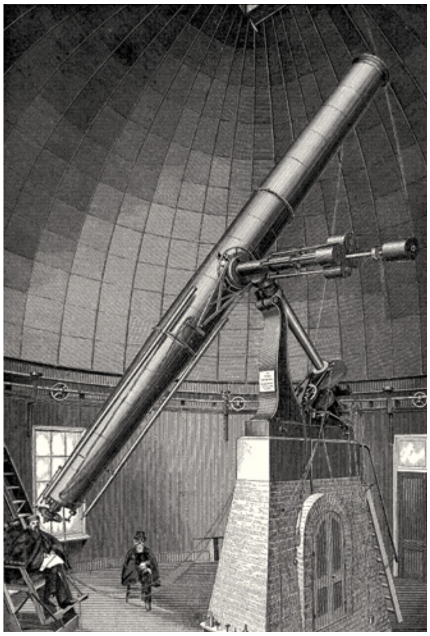
knowledge: spectral type and luminosity, the latter revealed by parallax.

Princeton astronomer Henry Norris Russell was quite interested in this work. In 1910 while visiting Pickering, Russell commented that he didn't think most of the stars with measured parallaxes had known spectral types. Pickering asked for an example of such a star, and Russell cited 40 Eridani B. If the dim star was a red dwarf, it would be spectral type *M*.

Pickering responded, "Well, we make rather a specialty of being able to answer questions like that." As Russell recalled:

> *. . . we telephoned down to the office of Mrs. Fleming and Mrs. Fleming said, "yes", she'd look it up. In half an hour she came up and said "I've got it here, unquestionably spectral type A". I knew enough, even then, to know what that meant. I was flabbergasted. I was really baffled trying to make out what it meant. Then Pickering thought for a moment and then said with a kindly smile, "I wouldn't worry. It's just these things which we can't explain that lead to advances in our knowledge." Well, at that moment, Pickering, Mrs. Fleming and I were the only people in the world who knew of the existence of white dwarfs.*

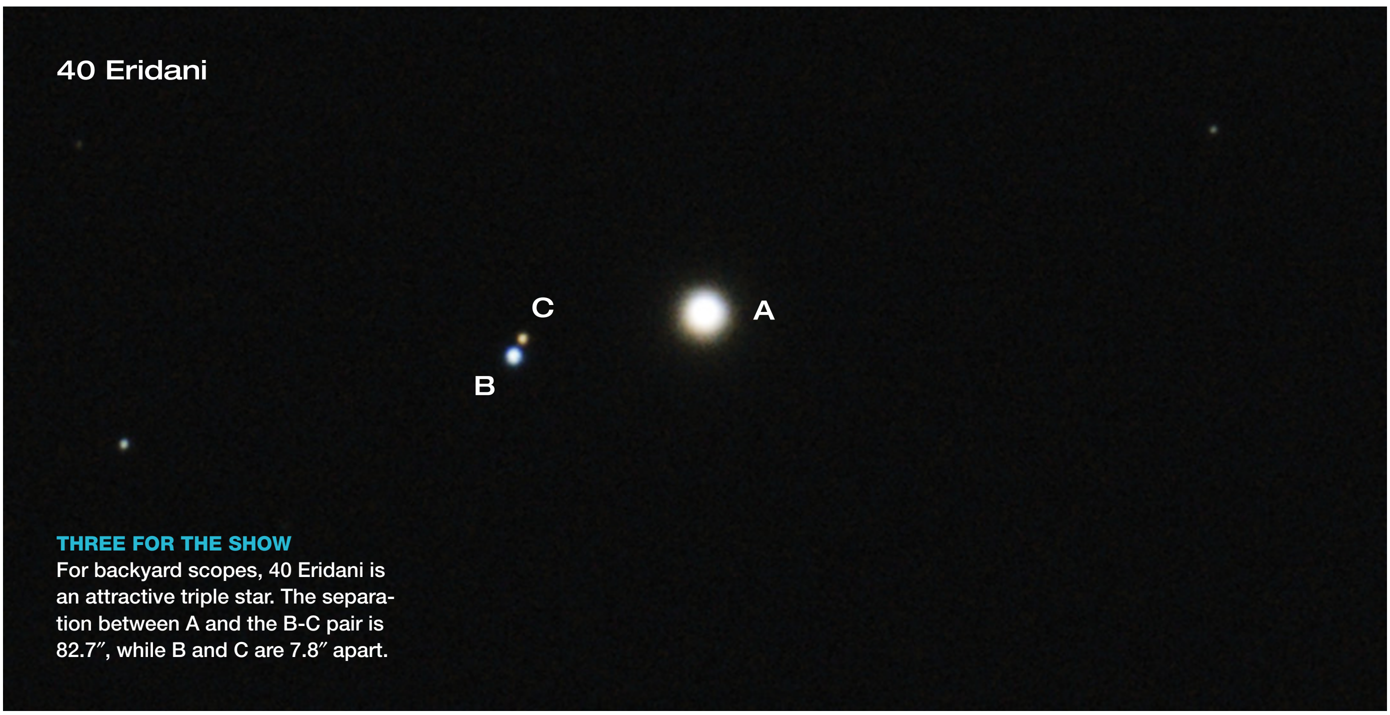
However, Russell gave this account at a Princeton colloquium that occurred four decades after the discovery of 40 Eridani B's white dwarf status. Initially he had been much more skeptical. On June 13, 1913, he addressed the Royal Astronomical Society in England, displaying what we now call a Hertzsprung-Russell diagram — a plot of stars by luminosity and spectral type that Russell and European astronomer Ejnar Hertzsprung had independently conceived.



◀ **MACHINERY OF DISCOVERY** The U.S. Naval Observatory's 26-inch refractor revealed the moons of Mars, the parallax of 40 Eridani, and more recently the orbital period of the white and red dwarfs 40 Eridani B and C around each other.

Russell pointed out the nearly empty quadrant on the Hertzsprung-Russell diagram where intrinsically dim blue and white stars would be, referring to 40 Eridani B without actually naming it: "It is immediately conspicuous that one corner of the diagram is vacant (except for one star whose spectrum is very doubtful). There do not seem to be any faint white stars." Russell couldn't object to 40 Eridani B's low luminosity since both its apparent magnitude and its distance were known, but he did doubt its type *A* classification.

Russell knew that the star's spectral type carried radical implications for its true nature. First, it meant the dim star was hotter than our *G*-type Sun. And that meant every square inch of 40 Eridani B's surface had to emit much more light than every square inch of the Sun's surface. But how could that be if the star shone so dimly? The answer: *40 Eridani B's*



THREE FOR THE SHOW
For backyard scopes, 40 Eridani is an attractive triple star. The separation between A and the B-C pair is 82.7″, while B and C are 7.8″ apart.

26-INCH USNO REFRACTOR: M&N / ALAMY STOCK PHOTO; 40 ERIDANI: STEVE SMITH *surface must have very few square inches*. In other words, the star was tiny. In 1914 Walter Adams at Mount Wilson Observatory in California observed the star and confirmed that it was indeed spectral type *A*.

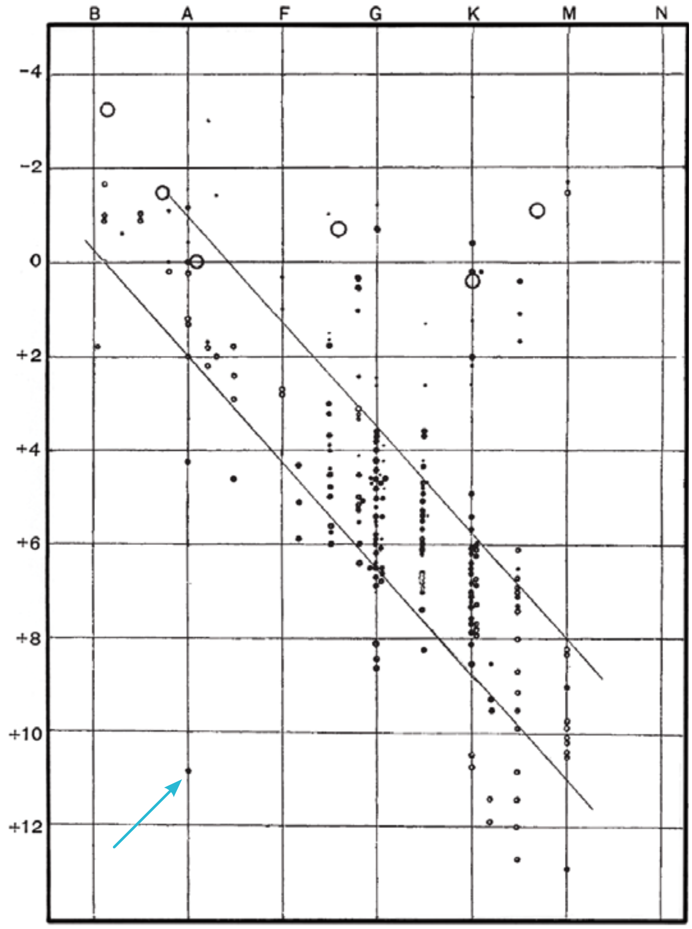
The next year, Adams took aim at a more difficult target: Sirius B, the presumed red dwarf orbiting Sirius A. On October 18, 1915, "under exceptionally good conditions of seeing," Adams succeeded in obtaining the dim star's spectrum. The "red" dwarf wasn't spectral type *M* at all; rather, it was the same type *A* as Sirius itself. Like 40 Eridani B, Sirius B was therefore hot, which in turn meant that every square inch of its surface radiated profuse amounts of light. But because the star was so dim, it had to be tiny. And that led to another radical revelation: Sirius B was incredibly dense. Astronomers had already used the gravitational tug on its brilliant partner to find that it was half as massive as Sirius A. Divide Sirius B's mass by its minuscule volume, and you end up with an extraordinarily dense star.

Several astronomers questioned the result, however, claiming that light from Sirius A had contaminated the fainter star's spectrum. But Adams pointed out that one other feeble *A*-type star was already known: 40 Eridani B.

Soon there was another member of the class. In September 1917 Mount Wilson Observatory astronomer Adriaan van Maanen was searching for a companion to a star in Pisces named Lalande 1299, which had a fairly large proper motion. He noticed on his photographic plates that an unrelated dim star had an even larger proper motion. Now named Van Maanen's Star, it's the nearest solitary white dwarf to Earth, lying just 14 light-years away.

Meanwhile, observations of 40 Eridani continued. In October 1921 Frederick Leonard (Lick Observatory) identified 40 Eridani C to be of spectral type *M*. The 40 Eridani system therefore consists of an orange dwarf, a white dwarf, and a red dwarf.

Hertzsprung recognized the implication of three dim, white stars (40 Eridani B, Sirius B, and Van Maanen's Star) in our immediate vicinity. Despite their bizarre nature, statistically such stars must be common. In a 1922 article that appeared in the *Bulletin of the Astronomical Institutes of the Netherlands*, he wrote, "The absolutely faint white stars seem to be even more frequent per unit volume than the absolutely bright yellow stars" (by which he meant giants like Arcturus).



▲ **EARLY CLUES** Henry Norris Russell's original H-R diagram shows the main sequence (diagonal band from upper left to lower right), giant stars at the upper right, and one stellar outcast at lower left: the first white dwarf, 40 Eridani B (indicated), which possessed two seemingly incompatible qualities: high temperature and low luminosity.

S&T ARCHIVE

Even with three known examples, this class of stars still had no name. That changed later in 1922 when Willem Jacob

The Omicron Variant

The star 40 Eridani also goes by the name Omicron^2 Eridani. Look for it about a degree southeast of Omicron^1 Eridani, an unrelated star that is slightly brighter and a good deal farther from Earth. Because 40 Eridani A shines at magnitude 4.4, you can see it in a dark sky without optical aid.

40 Eridani is about 16.3 light-years away, which means the separation of the orange dwarf from the white and red dwarfs is at least 410 a.u. — more than 10 times the Sun-Pluto distance — while the mean separation between the white and red dwarfs is at least 34.5 a.u.

The 40 Eridani Star System

	40 A	40 B	40 C
Type of star	Orange Dwarf	White Dwarf	Red Dwarf
Spectral type	*K*0.5 *V*	*DA*2.9	*M*4.5 *V*
Apparent magnitude	4.43	9.52	11.24
Absolute magnitude	5.94	11.03	12.75
Visible-light output*	36%	0.33%	0.068%
Mass*	85%	57%	20%

*Compared with the Sun

▲ **DOG AND PUP SHOW** This illustration shows the star Sirius A (the dominant star at left) and its white-dwarf companion, Sirius B (pictured at center right) — sometimes called the "Pup." Although some sources list Sirius B as the first white dwarf discovered, that distinction actually goes to 40 Eridani B. In backyard telescopes, Sirius B is a challenging target, while 40 Eridani B is relatively easy to spot.

NASA / ESA / G. BACON (STSCI)

Luyten, who had earned his doctorate under Hertzsprung the year before, coined the term "white dwarf." Although Luyten went on to discover many additional white dwarfs, their numbers grew so slowly that by 1940 *The Sky* (a forerunner of this magazine) reported that only 25 were known.

The Modern Era

Today astronomers have cataloged many thousands of white dwarfs. As it turns out, the stars come in a range of colors, from blue to red. That's because white dwarfs cool and fade with age — blue ones are the hottest and youngest, whereas red ones are the coolest and oldest. Both Sirius B and 40 Eridani B are as hot as blue main-sequence stars of spectral type *B*. Sirius B's surface temperature is 25,000 kelvin and 40 Eridani B is also hot, with a surface at 17,000K — nearly three times the Sun's temperature of 5800K.

In 2017 Brian D. Mason (U.S. Naval Observatory) and his colleagues observed 40 Eridani B and C with the same 26-inch refractor Asaph Hall had earlier employed. This work revealed that the orbital period of the B and C components is about 230 years, a bit shorter than indicated by older observations. The shorter period means that the two stars must be more massive than previously thought to have enough gravity to dance around each other faster than originally believed. Furthermore, the newly calculated masses resolved a long-standing puzzle regarding 40 Eridani B.

When a star possesses extreme surface gravity, photons lose energy as they're emitted from the star. This stretches the photons' wavelengths toward the red part of the spectrum, a process known as *gravitational redshift*.

Gravitational redshift helps astronomers determine a white dwarf's mass: The more massive a white dwarf, the stronger its surface gravity (both because the greater mass exerts more force and because gravity squeezes the star, reducing its diameter). The gravitational redshift of 40 Eridani B is about 26 km per second — far greater than the Sun's gravitational redshift of only 0.6 km per second. The old orbital period for the pair of stars implied a mass too low and a size too large to produce so great a redshift for 40 Eridani B. However, the new orbital measurements yield a white dwarf mass that's about 57% that of the Sun, which agrees well with the 53% figure derived from the gravitational redshift.

This new mass estimate also means that 40 Eridani B is quite average for its class, because the typical white dwarf is about 60% as massive as the Sun. In contrast, Sirius B is unusually heavy — estimates place it at one solar mass.

Compared with Sirius B, 40 Eridani B is much easier to see. Although it's a magnitude fainter, the Eridanus white dwarf doesn't have to compete with the brilliance of a star like Sirius. In his monumental *Celestial Handbook*, Robert Burnham, Jr., notes that 40 Eridani B is "the only white dwarf star which can honestly be called an easy object for the small telescope."

A century ago this easy-to-see star made astronomical history as the first white dwarf ever found — a star that foretells the destiny of our own Sun.

■ **KEN CROSWELL** has long been interested in the nearest stars. He earned his PhD at Harvard University and is the author of *The Alchemy of the Heavens* and *Magnificent Universe*.

 by Arwen Rimmer

A *Flare* for the DRAMATIC

What does stars' tempestuous activity mean for their planets' habitability?

From the moment a star's nuclear dynamo roars to life, a countdown begins. The frenetic rotation at the core creates convection: The hotter, more diffuse plasma rises, and the cooler, denser material sinks. In stars about the Sun's size or smaller, this convection transfers heat and the star's magnetic field up to the surface. Unlike the stable, donut-shaped field around Earth, however, a star's field is in a constant state of flux, shifting and tangling as the plasma in the stellar body sloshes mercilessly about.

"Magnetic fields in stars are constantly forming, twisting, dissipating, and reforming," says Meredith MacGregor (University of Colorado, Boulder). "They thread all throughout the star."

In the Sun's outer atmosphere, called the *corona*, these threads make big loops that stick out from the star. But the arcs don't sit still like the petals on a daisy; they ripple and crisscross one another, becoming more and more tangled until they suddenly snap back into orderly loops. Meanwhile, various forces within the stellar body cause channels to form that connect the plasma in the interior to the corona. When the fields snap in *magnetic reconnection*, star-stuff can be ejected up through these channels in a spectacular explosion.

These outbursts come in two main flavors: flares and *coronal mass ejections* (CMEs). Flares are flashes of multiwavelength light, including ultraviolet and X-rays, that often begin in the concentrated fields that create a sunspot. CMEs are eruptions of plasma, primarily electrons and protons, which are ejected from the star in a spray. The two are related, though we don't know exactly how, and they frequently (but not always) occur together.

Flares and CMEs are extremely useful to scientists because they tell us about the daily life of a star, its activity, and its impact on its surrounding planets. "For the longest time, the only star we could study in detail was our Sun," says Maximilian Günther (European Space Agency), who studies how stellar flares might impact habitability on exoplanets. "But now we can see much more, which is important as we look for life elsewhere."

▶ **SHIELDS UP** Artist's concept of a red dwarf unleashing an X-ray flare. Would such flares be deadly or helpful to life?

NASA GODDARD SPACE FLIGHT CENTER / S. WIESSINGER

10x to 1,000x

Energy of a superflare, compared with the largest solar flares

This is what has really changed in stellar research over the past few years: Flares aren't just for solar scientists anymore. After all, the search for Earth 2.0 necessitates the search for a suitable star. And astronomers have seen gigantic flares from stars. The question is: Given how often stars blast their planets with radiation and energized particles, how possible is it for life on these worlds to arise and thrive?

Survey the Skies

With the advent of space telescopes such as XMM-Newton, Swift, Kepler, and TESS, scientists have built a catalog of stellar activity encompassing events on hundreds of thousands of stars. We assume that the dynamic processes that drive our Sun's behavior are true for all stars, but they might not be, Günther says.

"We still don't really fully understand how flaring is triggered on different star types, how it all works," he says. "On other stars than our Sun, it might be different."

The Sun has an outer convective layer, wrapped like a thick, simmering shell around its inner, non-convective regions. Convection, rotation, and shear between the outer and inner layers combine to create the Sun's magnetic field. But among the smallest stars, called *M* dwarfs or red dwarfs, the most diminutive are fully convective, meaning material churns all the way from center to surface. The smallest red dwarfs therefore don't have the shearing mechanism inside that helps create the Sun's field. Instead, astronomers think that rotation is the main cause of these stars' strong fields.

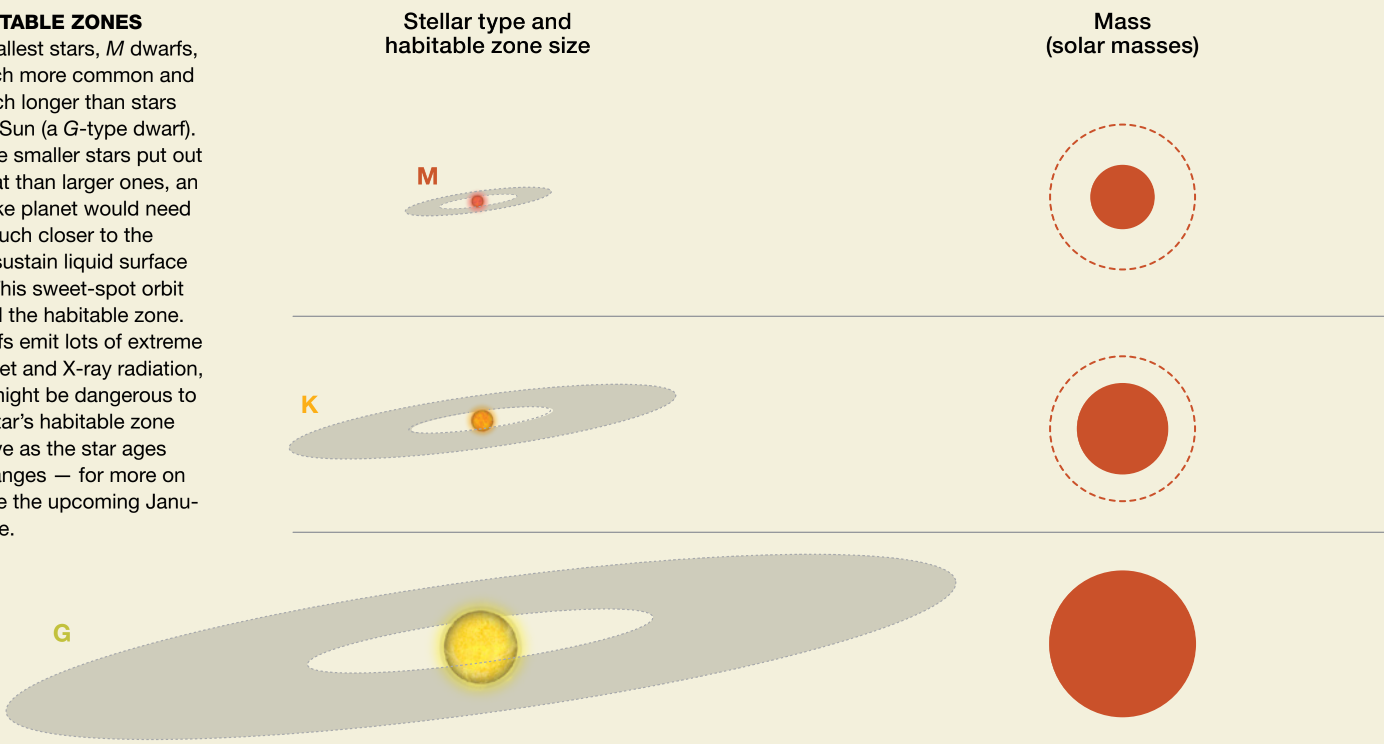
The powerful fields on red dwarfs make these stars prone to unleashing intense flares and CMEs — in fact, smaller, more convective stars are generally more magnetically active and emit more high-energy radiation than Sun-like stars do. But we don't know how exactly stellar outbursts originate on red dwarfs; we need a better grasp of how these stars behave and evolve.

One thing we do know is that flares and CMEs are connected to a star's age. Vladimir Airapetian (American University) studies the effects of space weather, like solar storms, on planetary atmospheres. He compares stellar outbursts to the energy and exuberance of a small child.

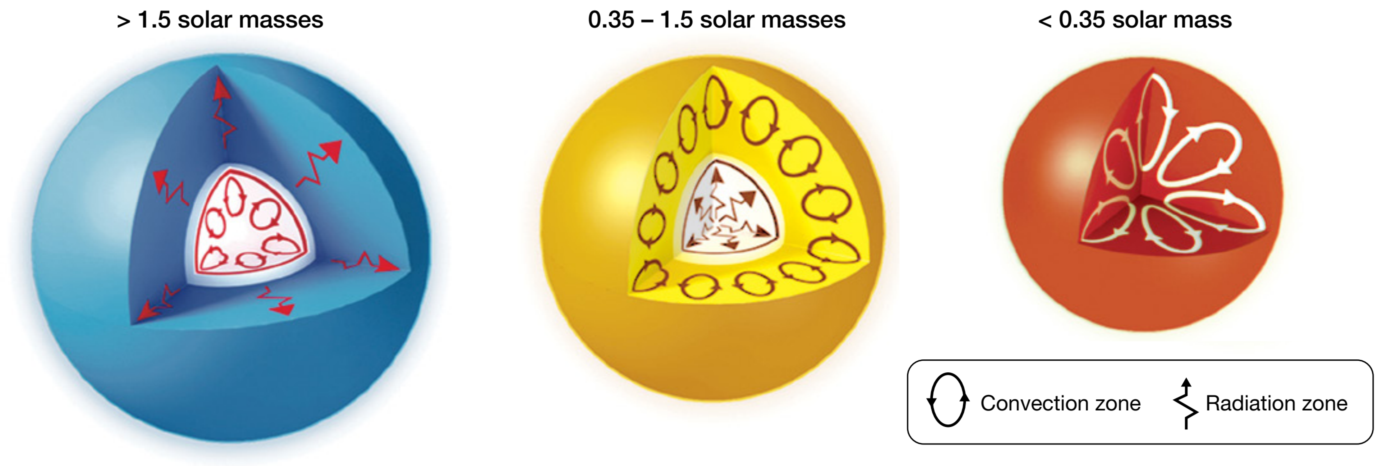
"Younger stars act out," he says. "As they grow up, they settle down and their explosions become less frequent and violent, and more predictable."

We know this is true for our Sun, and it's a good thing, too. But even with the decline, most stars stay active throughout their lives. The vast majority of recorded stellar activity involves flares. (Astronomers have only indirectly observed a few extra-solar CMEs, and these are controversial.) The variety and plenitude of flare activity revealed in the past several years is astonishing, from the multifarious outbursts of small, cold, and young "flare stars," to the rare and seemingly random eruptions on big, hot giants, to periodic bursts on stars very similar to the Sun. We have also learned that while the cause of most flares is intrinsic to the star itself, a companion star or a Jupiter-size planet in a close orbit can also induce such flashes.

GREGG DINDERMAN AND TERRI DUBÉ / *S&T*, SOURCES: NASA, ESA, AND Z. LEVY (STSCI); CHESTER HARMAN; A. J. RUSHBY ET AL. / *ASTROBIOLOGY* 2013



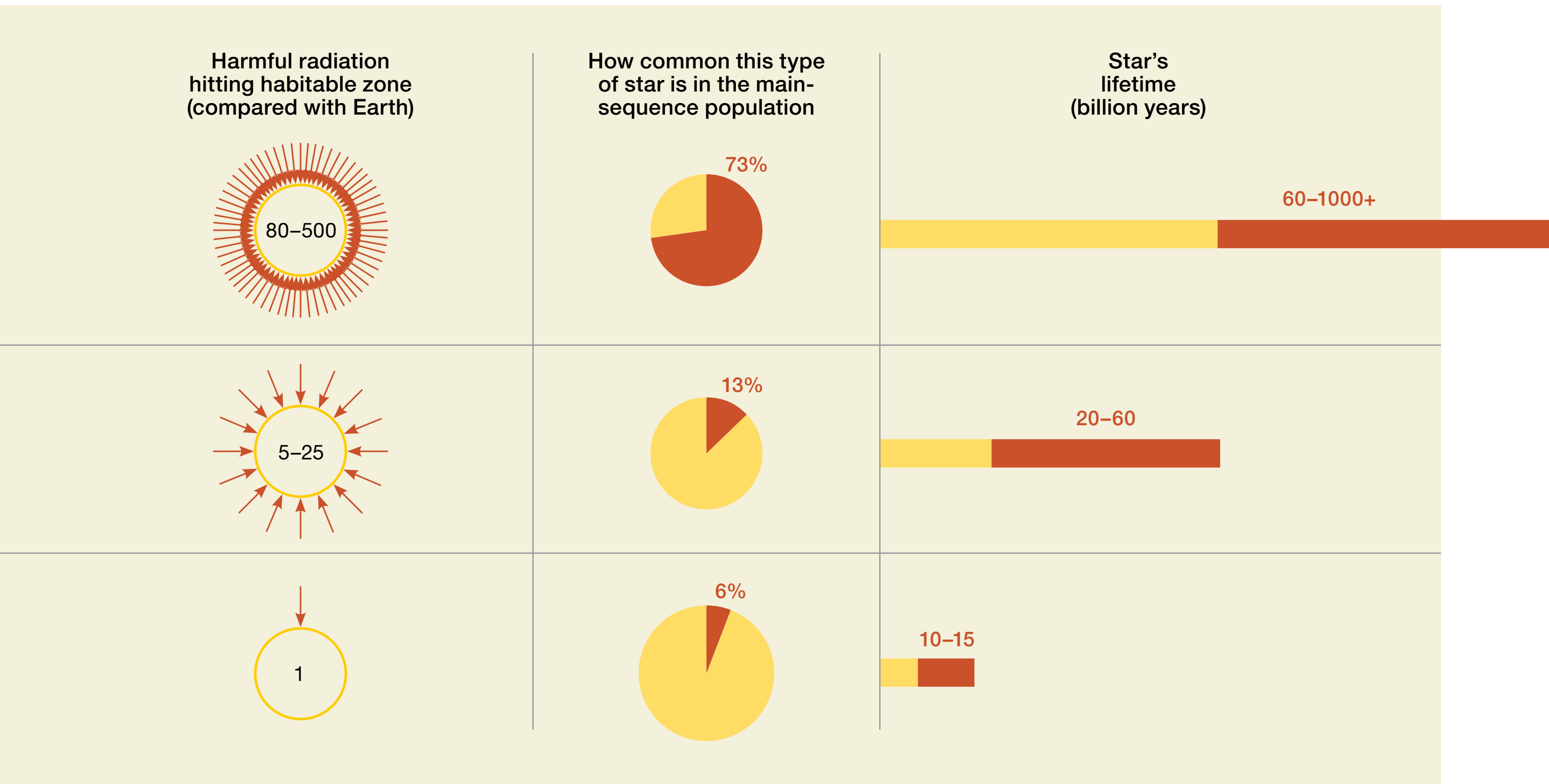
▶ HABITABLE ZONES The smallest stars, *M* dwarfs, are much more common and live much longer than stars like the Sun (a *G*-type dwarf). Because smaller stars put out less heat than larger ones, an Earth-like planet would need to be much closer to the star to sustain liquid surface water. This sweet-spot orbit is called the habitable zone. *M* dwarfs emit lots of extreme ultraviolet and X-ray radiation, which might be dangerous to life. A star's habitable zone will move as the star ages and changes — for more on that, see the upcoming January issue.



▲ **INTERIORS** Two kinds of heat transfer happen in stellar interiors: convection and radiation. In convection, hot gas rises and cool gas sinks, like water boiling. In radiation, heat travels outward more haphazardly. Convection drags a star's magnetic field up from the interior to the star's surface, where we can detect it. The convective zones of the largest stars — with spectral types *O*, *B*, and *A* — lie trapped under radiative zones, which may be why we generally don't see magnetic fields on these stars. Middle-mass stars — the *F*, *G*, and *K* dwarfs, as well as the largest *M* dwarfs — have an outer convective zone, and the smallest *M* dwarfs are fully convective, so their magnetic fields make it to the surface.

Amidst all the new research on stellar activity, the most dramatic observations are indisputably of events called *superflares*. Superflares are explosions with up to 10,000 times the energy of a typical solar flare (*S&T:* Nov. 2015, p. 22) and might pair with powerful CMEs. For scale, the legendary Carrington Event of 1859, one of the largest geomagnetic storms ever observed, was accompanied by a flare that was only 100 times bigger than normal. And it turns out that such outbursts are happening constantly across the galaxy. In its first four years, the Kepler space telescope recorded 26 superflares on stars with properties similar to our Sun, and NASA's Transiting Exoplanet Survey Satellite (TESS) recorded a similar frequency in its first year of operation.

Any star can have a superflare, but the frequency varies.



The red dwarf Proxima Centauri, for example, gives off about one a year. The star also potentially has three exoplanets. Which begs the obvious question: What effects might this kind of stellar activity have on nearby planets?

Goldilocks and the Flares

A blast of radiation and plasma may sound nasty, but stellar flares aren't all bad. A recent study led by Abygail Waggoner (University of Virginia) indicates that a nascent star's X-ray flares could encourage the formation of organic molecules in protoplanetary disks. Some scientists have even theorized that a flare or CME could have sparked *abiogenesis*, the origin of life, on Earth. So it seems that activity early on in a star's existence could be good, maybe even necessary, for life.

But if the host star is extremely active, life might never have a chance to take hold and evolve. This is because flares and CMEs can destroy complex molecules and erode planetary atmospheres.

As every home cook knows, you need more than the right ingredients and equipment to bake a cake — a portion of luck is also vital to the endeavor, because so many things can go wrong. "An exoplanet can be in the habitable zone without being habitable," Airapetian says. "It could have the right composition, a nice magnetic field, and a regular orbit the right distance from its host star, and still end up a barren rock."

It goes without saying that astronomers don't want to waste time looking for signs of life on a world where the host star's nature precludes it. So the question of which stars are the best targets is of utmost importance, especially for the recently launched James Webb Space Telescope. JWST will examine exoplanet atmospheres for signs of life (*S&T:* May 2021, p. 34), and most of the planetary systems it's set to study in its first year of observations orbit red dwarfs.

The reason for this is simple. "The majority of the stars in the Milky Way are red dwarfs," says Ward Howard (University of Colorado, Boulder). "These are the smallest, coolest stars in the main sequence, so orbiting planets are easier to see around them." In fact, most planets discovered so far that might be able to sustain liquid surface water orbit *M* dwarfs. "But these stars are also very active," he adds.

Howard led a large survey to study superflares from red dwarf stars in the TESS catalog. He found that a significant portion of those thought to be good candidates for hosting temperate rocky planets frequently emit flares large enough to erode those planets' atmospheres. In their youth, red dwarf stars such as Trappist-1 would likely have fallen into this category. The Trappist-1 system, one of JWST's targets, is a red dwarf system with seven rocky planets circling extremely close together. A few are even in the liquid-water zone, which for a red dwarf lies at a distance from the star that's roughly one-tenth the size of Mercury's orbit. But Trappist-1 still flares regularly today, and it was likely even more active in the past, constantly bombarding its planets with radiation and charged particles.

70%

Fraction of potentially habitable planets found around *M* dwarfs

10% to 50%

Estimated fraction of *M* dwarfs with Earth-size planets in their habitable zones

20%

Fraction of *M* dwarfs that might flare often enough to drive prebiotic photochemistry on rocky planets within their habitable zones

A certain kind and amount of ultraviolet radiation is good for life; recent studies suggest that UV photochemistry on the early Earth was vital to the creation of prebiotic molecules. High-energy X-rays, on the other hand, are bad for life. Our Sun gives off a fair amount of X-rays, but Earth's atmosphere blocks them. Unfortunately, that doesn't help us beyond Earth: Solar X-rays would pose significant risk to colonies on worlds like the Moon or Mars, which do not have a decent atmosphere. Without some kind of shielding, astronauts will be vulnerable to solar particles and X-rays, which would pass through their bodies like thousands of minuscule burning threads, causing severe injury. It stands to reason that exoplanets with very active host stars, especially those giving off powerful X-rays, would need to have fairly thick atmospheres, or life there wouldn't stand a chance.

That's a problem, though. "With flare stars, red dwarfs, and other stars known to put out lots of superflares, there is evidence these are accompanied by CMEs," says Airapetian. "This would blast off the atmosphere of a nearby planet in a very short period of time."

Earth's magnetic field deflects the majority of the charged particles that stream towards us. Still, when plasma clouds from the Sun reach Earth, they cause geomagnetic storms and aurorae that can disrupt satellites and telecommunications activities. In a worst-case scenario, charged particles could interact with Earth's magnetic field to produce powerful electromagnetic fluctuations that temporarily shut down power grids all over the planet. And not all worlds — like Venus, for example — have global magnetic fields for protection. So it's a given that any technology on a Trappist-1 planet would have a hard time. But even an exoplanet with a robust magnetic field and an orbit that pushes the outer limits of the habitable zone might not be able to retain its atmosphere if it's around a red dwarf.

Chemistry 101

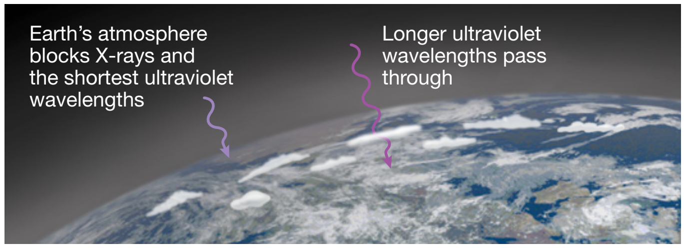
Prebiotic chemistry happens naturally without life's involvement but might have contributed to the origin of life. For example, prebiotic processes create amino acids, the building blocks of proteins.

Some astronomers hold out hope, suggesting that the magnetic fields of some red dwarfs might be strong enough to confine CMEs to the star's corona, making the neighborhood a bit more hospitable, but this has not yet been confirmed. Others have posited that it might be possible for a world to grow an atmosphere later in a red dwarf's life, if the star calms down enough for, say, gases spewed out by volcanism to build up on the planet. If it were sufficiently thick, this atmosphere could provide any budding life on the surface protection from flares.

So maybe if several fortuitous circumstances align, it might actually be possible to have a habitable planet around a red dwarf. And since most of the stars out there in the galaxy are red dwarfs, it's just a matter of getting lucky with our targets, right?

Unfortunately, recent observations and modeling suggest that even many old, "inactive" red dwarfs may be too energetic for nearby planets to sustain life-friendly atmospheres. Even if an atmosphere survived, the ultraviolet rays necessary for prebiotic chemistry might not reach the planet's surface. That's because these stars don't put out very much long-wavelength UV radiation, and although they put out a lot of short-wavelength UV, the latter doesn't penetrate Earth-like atmospheres. Red dwarfs emit a lot of both during flares, but are these emissions enough for abiogenesis to occur — and not enough to fry the planet?

In short, we don't know for sure whether strong, frequent flares make a world uninhabitable; this is an area of active research. As much as habitable-zone exoplanets like Proxima Centauri b, LHS 1140b, or the worlds orbiting Trappist-1 have caught our imaginations, at this time there are too many unknowns for us to say how their stars' outbursts have affected them.

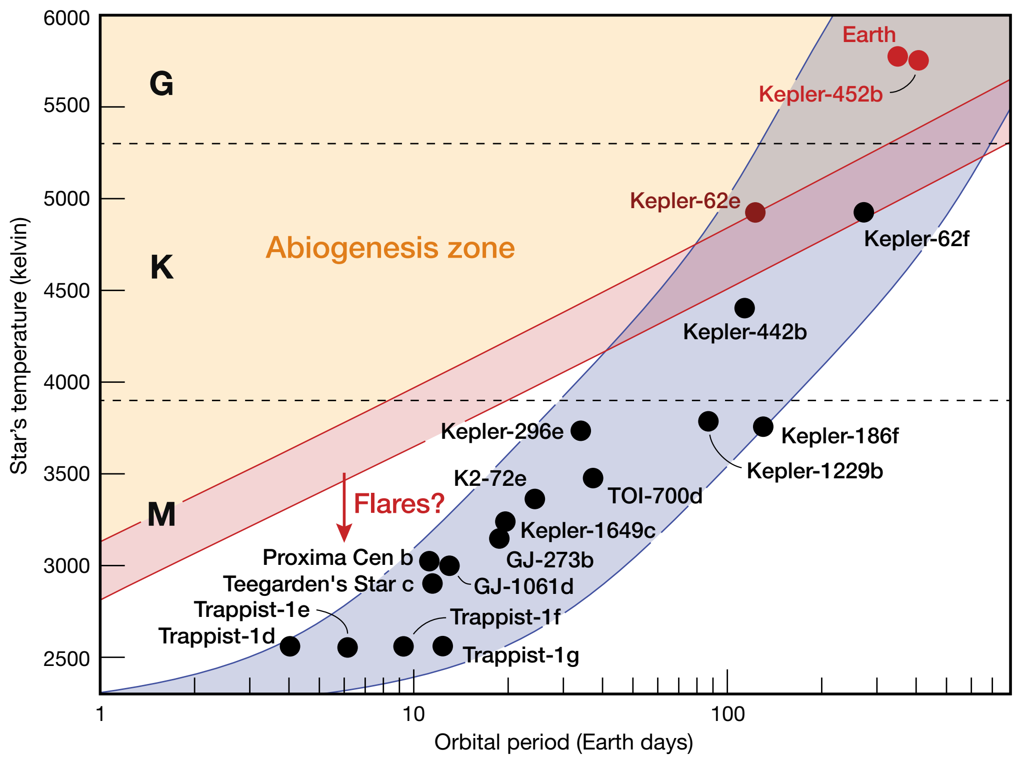


Life from the Stars?

For those who can't bear the thought of all those red dwarf systems out there being barren, there are some creative solutions. Life might endure under several feet of water or underground, for example.

"Another possibility is, if a world is tidally locked, life could begin near the terminator where the light and dark sides meet and some protection exists," Howard says. Planets in a red dwarf's habitable zone will probably be tidally locked, with only one hemisphere ever seeing the star. "But the weight of evidence would probably lean against the survival of complex surface life facing a very active star."

Whether life exists on these worlds depends in part on how stellar activity affects chemical reactions in their atmospheres. A 2018 study out of University of Cambridge struck



▶ WHERE LIFE MIGHT ARISE It's not just a star's habitable zone that determines habitability. Scientists suspect that a planet also needs to receive sufficient ultraviolet radiation (specifically, in the 200 to 280 nm range) to trigger chemical reactions that make prebiotic molecules. If so, planets around red dwarfs are in trouble: These stars' abiogenesis zones lie far closer to the star than the habitable zones do. Powerful flares might help bridge the gap. But atmosphere matters, too: Modern Earth's ozone layer blocks these ultraviolet wavelengths, meaning abiogenesis couldn't work the same way on Earth today as it might have billions of years ago. (Red region is the uncertainty range from lab experiments.)

WAVELENGTHS: GREGG DINDERMAN / S&T; ABIOGENESIS: GREGG DINDERMAN / S&T, SOURCE: PAUL RIMMER a hopeful tone, suggesting that flares might be able to create complex molecules on red dwarf planets. The researchers delineated an *abiogenesis zone* around stars of different stellar types, based on the distance at which UV rays emitted by the star were strong enough to trigger the creation of prebiotic molecules on orbiting worlds. This zone can overlap with the liquid-water habitable zone; Earth, perhaps unsurprisingly, falls into both.

The study's results suggest that Sun-like stars will provide the best opportunities for the chemistry that life needs, but planets around slightly smaller stars called orange dwarfs can also lie within the abiogenesis zone. Red dwarfs could only provide sufficient UV with the help of frequent flares.

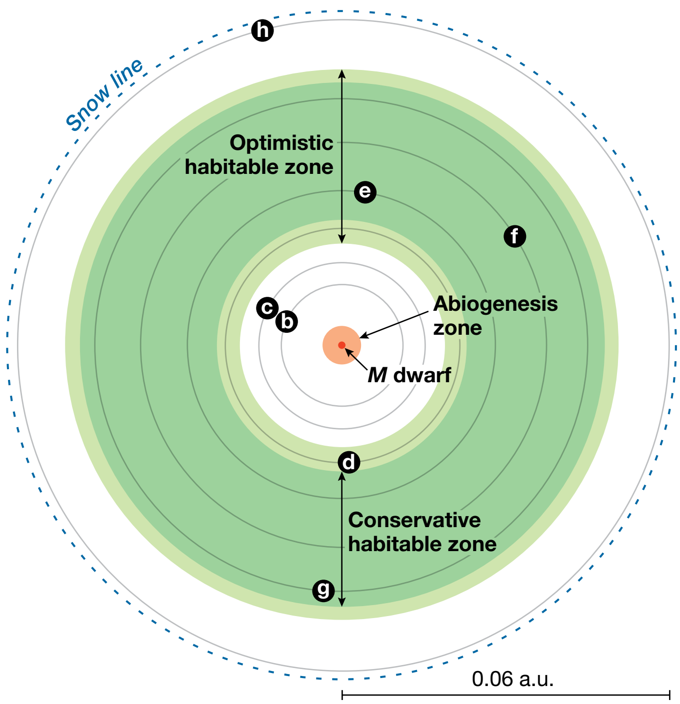
The same University of Cambridge group, led by Paul Rimmer and Didier Queloz, is now in the process of simulating observed flares from the stellar catalog, so as to put constraints on what kinds of light chemistry might be happening on exoplanets around different kinds of stars. Their experiment is called FlareLab. It consists of a motorized track with a lamp fixed at one end, and a quartz container mounted on the moving stage. The team chose the lamp to reproduce the spectrum of a flare. (As far as we know, all flares have similar spectra, though the intensity varies over time.)

Scientists place samples of simple molecules that might exist on the surface of a rocky planet in the container. They turn the lamp on, and the motorized stage moves the sample back and forth along the track. As the container approaches the lamp it receives more photons, so by moving the container towards and away from the lamp, scientists can simulate the way a flare's intensity changes over time.

"The goal is to see if a flare-like light source can trigger the formation of simple sugars," says team member Samantha Thompson (also Cambridge), who designs new instruments and techniques for detecting and characterizing exoplanets. Simple sugars are relevant for prebiotic chemistry because they're stepping stones for making RNA. Researchers can set the FlareLab lamp to simulate the light of a particular star, and the track motion to copy an observed flare of that star. After illumination, the sample is removed and analyzed to see whether the lab-simulated flares were able to make precursors to the building blocks of life.

4

Average number of superflares Trappist-1 unleashes per year



▲ **TRAPPIST-1** At least three of the rocky exoplanets circling the red dwarf Trappist-1 lie in the star's habitable zone (a more generous definition ropes in a fourth world). But the little star puts out such a scant amount of ultraviolet light that none of the exoplanets receives enough radiation to trigger the photochemistry necessary to build up prebiotic molecules — unless the star's flares do the trick.

GREGG DINDERMAN / *S&T*, SOURCE: PLANETARY HABITABILITY LABORATORY / UNIVERSITY OF PUERTO RICO, ARECIBO

Dwarf Doldrums

So which stars will prove the friendliest to life? Most astronomers suspect that it won't be red dwarfs — which would rule out about 75% of our galaxy's stars. Maybe we should instead focus our efforts on Sun-like stars, such as the solar twin Kepler-452 with its habitable-zone planet. Such exoplanets remain hard to study with current technology.

Let's also not forget orange dwarfs like Kepler-62, which lies about 1,200 light-years away and hosts five worlds, two of them in the habitable zone. Orange dwarf stars are in between red dwarfs and Sun-like stars in size and temperature. They have a generous habitable zone, are a little less active than red dwarfs, live longer than Sun-like stars, and are twice as common as Sun-like stars, too. Astronomers have already found a few potentially habitable planets around these stars, which could prove especially promising targets for the next generation of instruments.

Life as we know it is finicky: It needs things like liquid water, organic compounds, and energy, and it needs them consistently and in just the right amounts. On Earth, the energy often comes from our star's light, but stars aren't predictable or benign. They are prone to burst, flare, and, under the right conditions, explode. As we cast our nets farther and farther out into the cosmos, looking for Earth 2.0, the impact of stellar activity on exoplanets has moved to the fore of astrobiological research. In the coming years, scientists will see what frequent flares and CMEs do to exoplanets. Do they enable life? Preclude it? Just maybe, there's a balance.

■ **ARWEN RIMMER** is a writer and musician based in Cambridge, England. She's married to astronomer Paul Rimmer, whose work appears in this article.

1 **EVENING:** Kick the month off by looking southward in the early evening hours to see the waxing gibbous Moon hanging 2½° below Jupiter. Turn to page 46 for more on this and other events listed here.

6 **EVENING:** The Moon, one day shy of full, poses between the Hyades and the Pleiades. Face east-southeast to take in this sight.

7 **EVENING:** The full Moon occults Mars for much of North America. Go to page 49 for details on this much-anticipated event.

9 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 9:08 p.m. PST (see page 50).

10 **EVENING:** The waning gibbous Moon, Castor, and Pollux form a triangle as they rise in the northeast.

12 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 8:57 p.m. EST.

14 **MORNING:** The maximum of the Geminid meteor shower coincides with a waning gibbous Moon. Page 50 lists tips on the best meteor-spotting opportunities.

14 **MORNING:** If you're out looking for Geminids, turn toward the south before sunrise to see the Moon about 4° upper left of Regulus in Leo, the Lion.

18 **MORNING:** The waning crescent Moon accompanies Spica, Virgo's brightest star, as they climb above the southeastern horizon. Roughly 5° separates the pair.

21 **THE LONGEST NIGHT OF THE YEAR** in the Northern Hemisphere. Winter begins at the solstice at 4:48 p.m. EST (1:48 p.m. PST).

24 **DUSK:** Find a clear view toward the southwest to spot the Moon, Venus, and Mercury in a spiffy triangle near the horizon.

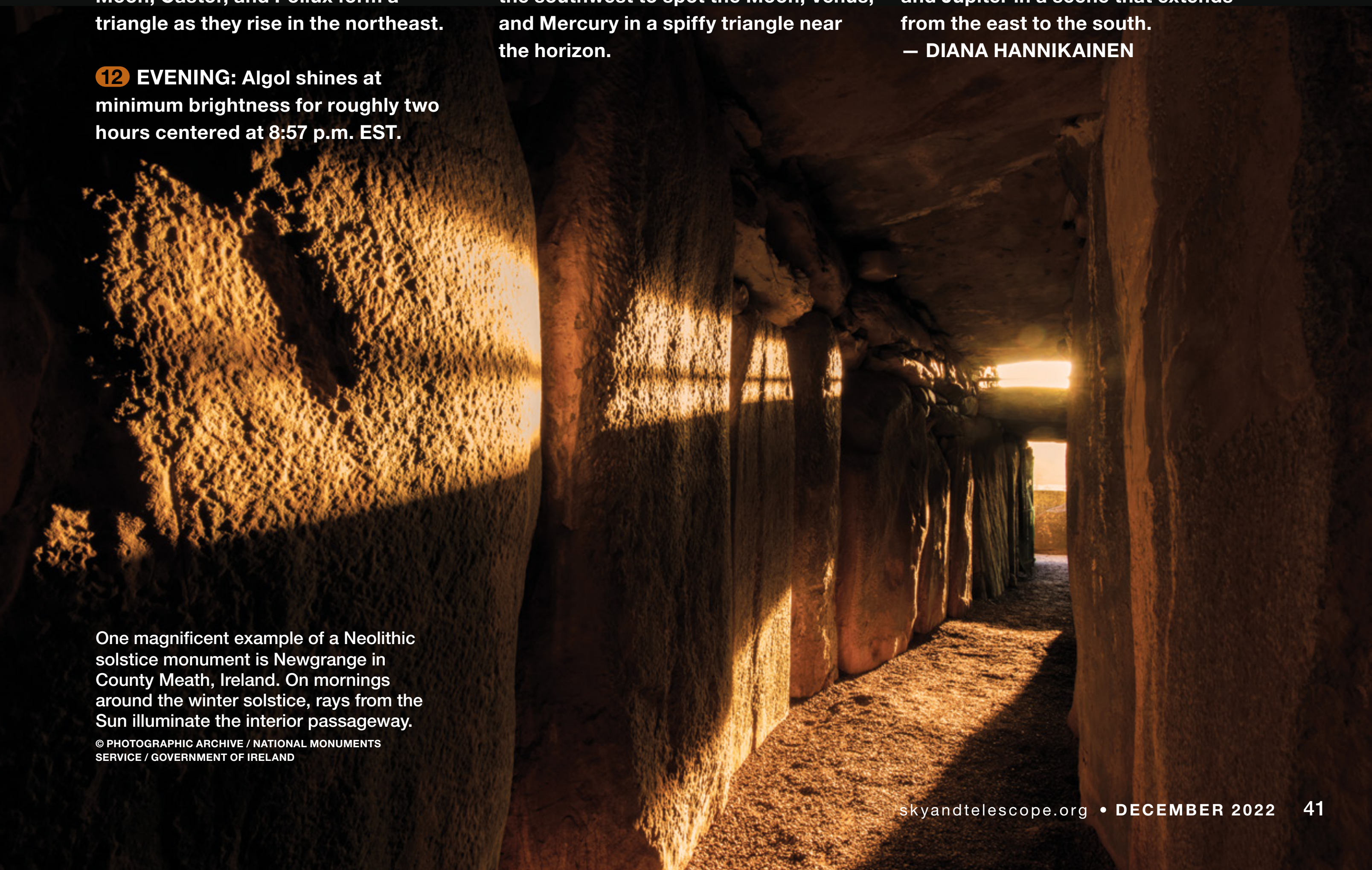
26 **DUSK:** The thin, waxing lunar crescent hangs around 5° left of Saturn. Catch the pair while they're high in the southwest and follow them as they gracefully sink toward the horizon.

28,29 **DUSK:** Mercury and Venus are less than 2° apart. Look for the two worlds very low in the southwest after sunset.

29 **EVENING:** High in the southwest, the first-quarter Moon stands guard around 6½° above left of Jupiter.

29 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 10:52 p.m. PST.

31 **EVENING:** End the year by taking in the sight of the Moon pleasingly poised about halfway between Mars and Jupiter in a scene that extends from the east to the south.
— DIANA HANNIKAINEN



One magnificent example of a Neolithic solstice monument is Newgrange in County Meath, Ireland. On mornings around the winter solstice, rays from the Sun illuminate the interior passageway.
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DECEMBER 2022 OBSERVING
Lunar Almanac
Northern Hemisphere Sky Chart

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

MOON PHASES

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

FULL MOON
December 8
04:08 UT

LAST QUARTER
December 16
08:56 UT

NEW MOON
December 23
10:17 UT

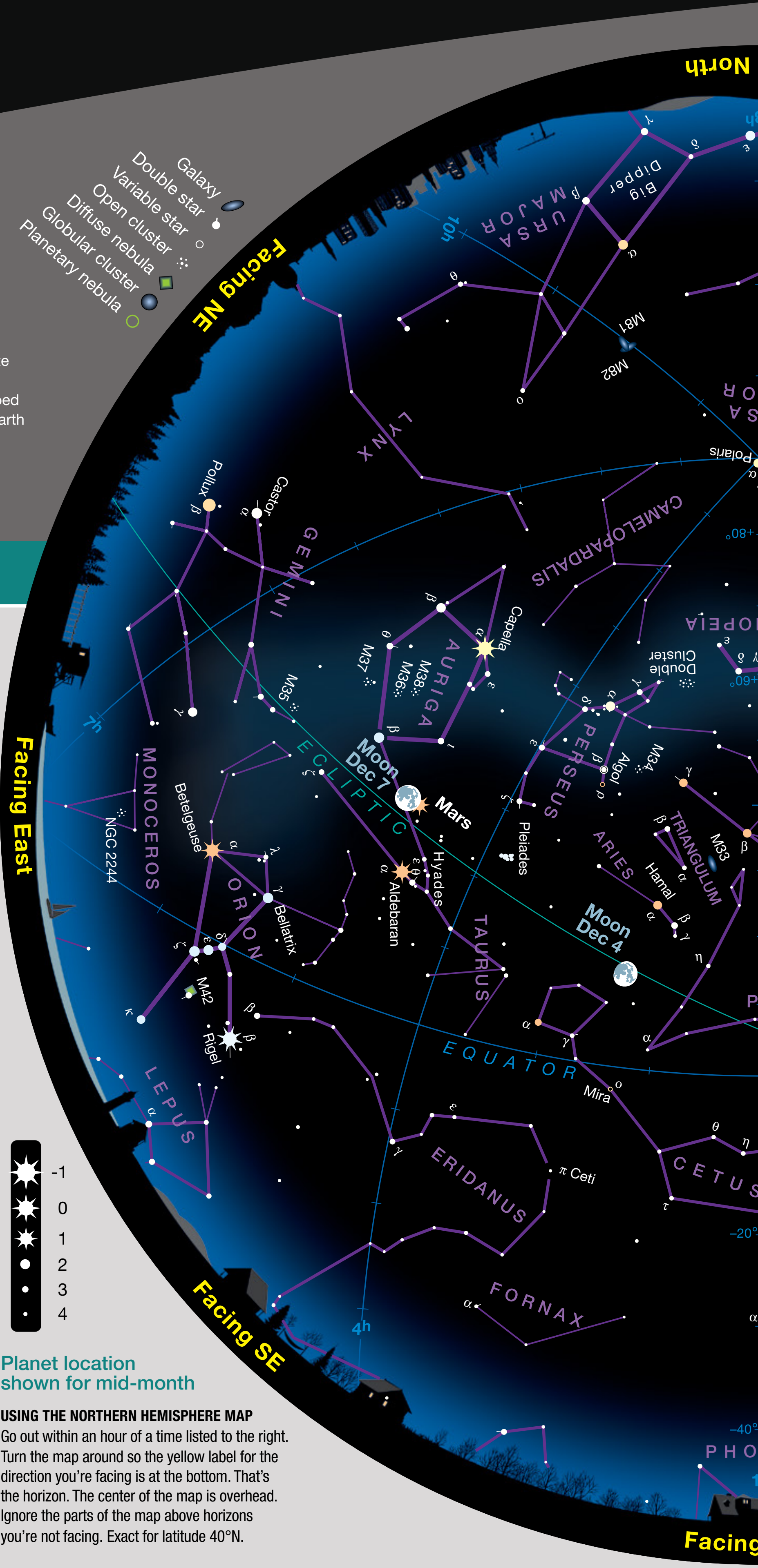
FIRST QUARTER
December 30
01:21 UT

DISTANCES

Apogee	December 12, 0^h UT
405,868 km	Diameter 29′ 26″
Perigee	December 24, 08^h UT
358,270 km	Diameter 33′ 21″

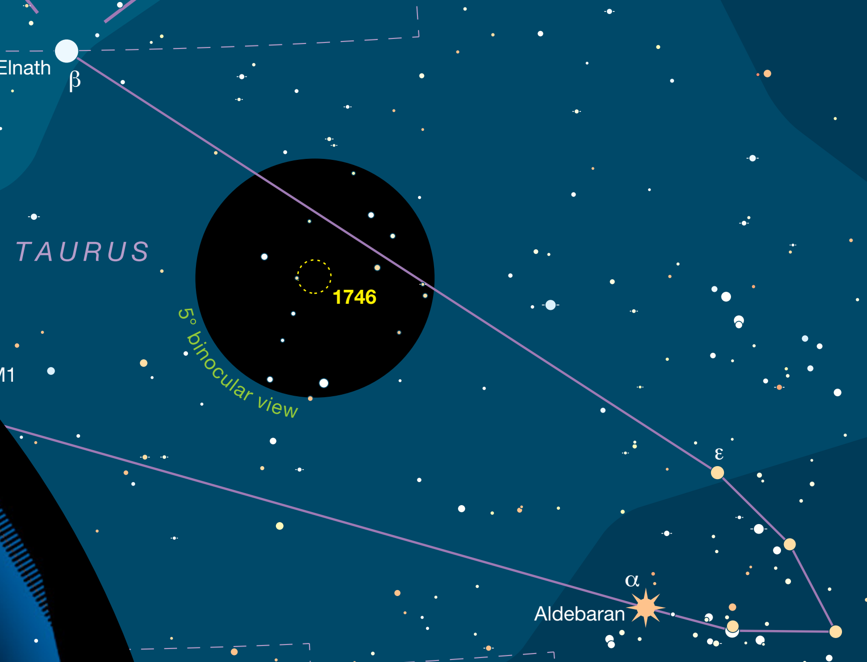
FAVORABLE LIBRATIONS

- Boss Crater — December 1
- Mare Australe — December 8
- Andersson Crater — December 15
- Mare Orientale — December 18



Planet location shown for mid-month

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



Binocular Highlight by Mathew Wedel

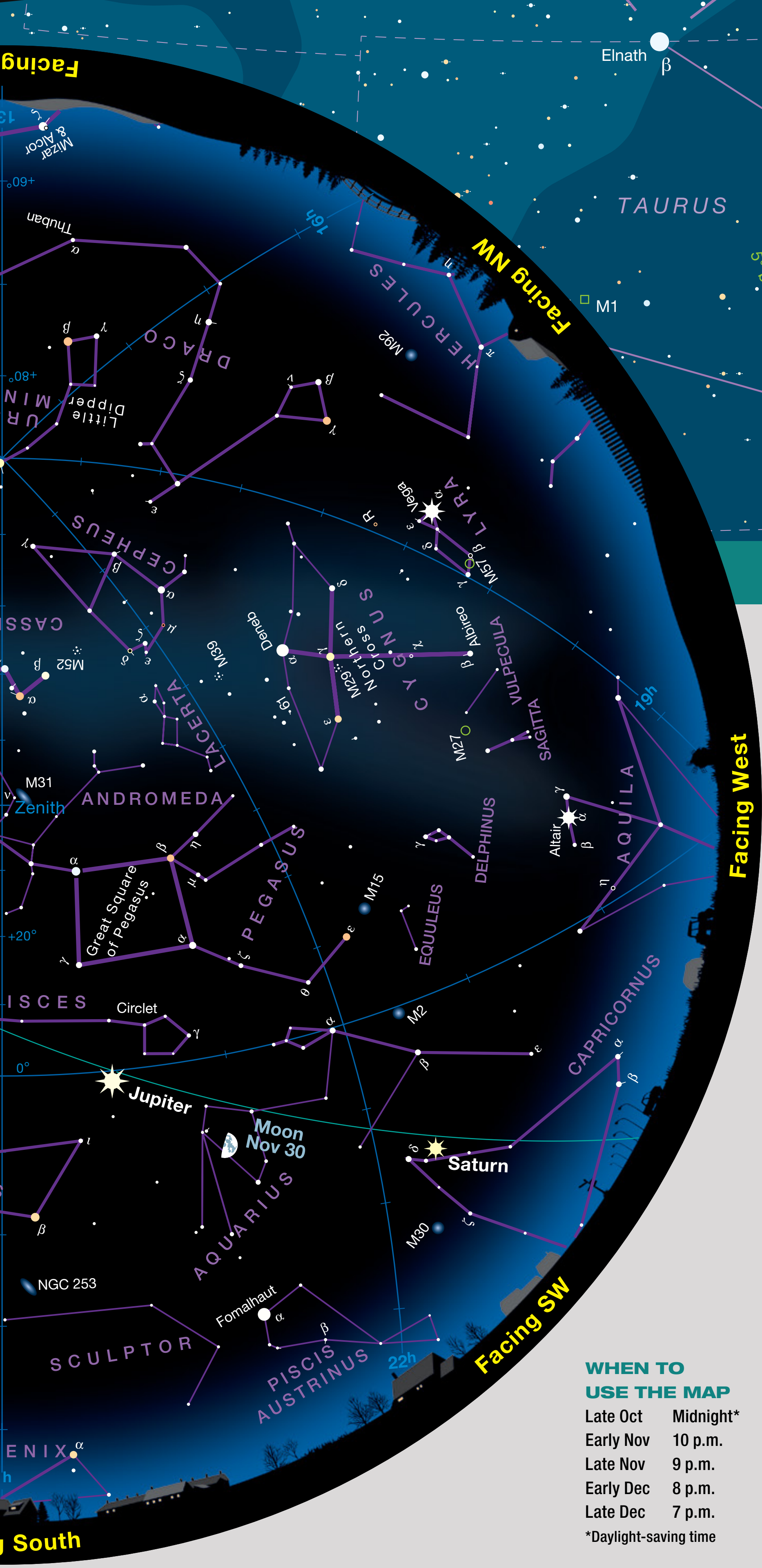
The Cluster That Wasn't

At first glance, the open cluster **NGC 1746** in Taurus, the Bull, seems to have everything going for it. It's big, with a diameter of 40′, and decently bright at 6th magnitude. It's also easy to find, in an otherwise fairly dark stretch of sky some two-thirds of the way from Aldebaran, or Alpha (α) Tauri, to Elnath, or Beta (β) Tauri. About the only downside to this otherwise lovely object is that it probably doesn't exist.

It's not that there's nothing in the region of space where NGC 1746 is plotted on star charts. On the contrary, there are too many things. The open clusters NGC 1750 and NGC 1758 are visually superimposed on each other in the southeastern quadrant of the region reserved for NGC 1746. Photometric studies by professional astronomers have confirmed the reality of NGC 1750 and NGC 1758. Those two genuine clusters, plus a scattering of 7th-magnitude field stars, create the impression of a larger, rather ragged cluster — the illusory NGC 1746.

But don't let the tangled backstory and doubtful status of NGC 1746 keep you from exploring this fascinating region. We're looking out in almost exactly the opposite direction from the center of the Milky Way, observing the galaxy's distant spiral arms. Most deep-sky objects in this area lie on the far side of the Taurus molecular cloud, a complex web of dark nebulae where new stars are being born. And the region of NGC 1746 is a delight in binoculars of all sizes, with arcs and chains of 7th- and 8th-magnitude stars converging haphazardly, like the center of a medieval city lit by lanterns. The best stories involve at least one fantastic element — NGC 1746 doesn't have to be real to draw you into a rewarding journey into the cosmos.

■ **MATT WEDEL** is always charmed when one celestial object turns out to have others within — it's like getting free stuff!

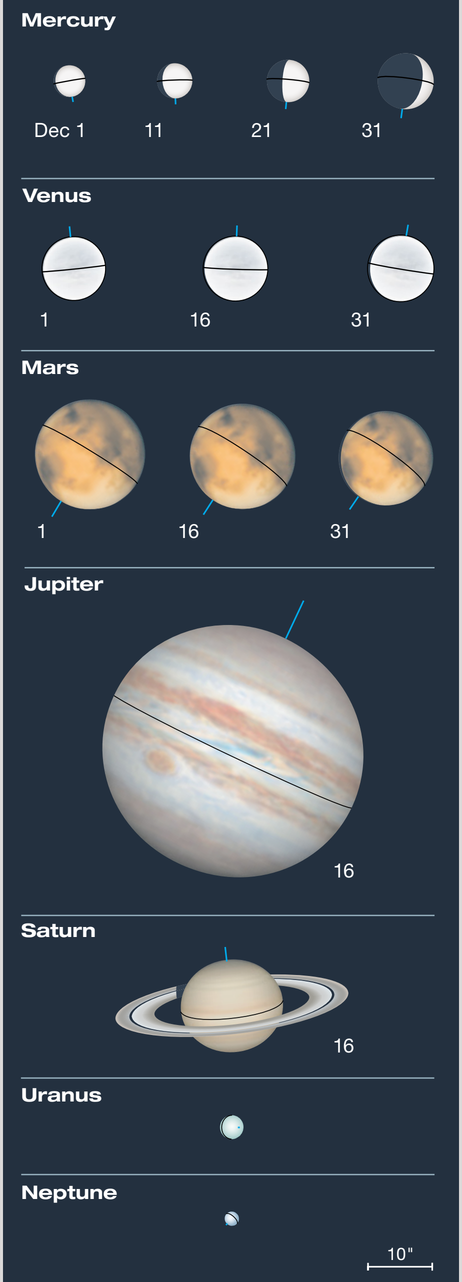


WHEN TO USE THE MAP

Late Oct	Midnight*
Early Nov	10 p.m.
Late Nov	9 p.m.
Early Dec	8 p.m.
Late Dec	7 p.m.

*Daylight-saving time

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dusk from the 10th to the 31st • **Venus** visible at dusk all month • **Mars** rises before sunset and is visible to dawn • **Jupiter** transits in the early evening and sets after midnight • **Saturn** visible at dusk and sets in the evening.



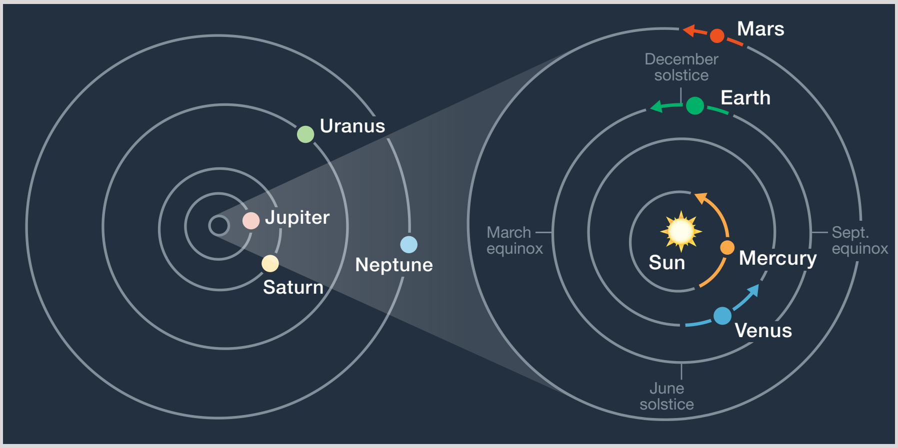
▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

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

December Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$16^h\ 26.8^m$	−21° 43′	—	−26.8	32′ 26″	—	0.986
	31	$18^h\ 39.0^m$	−23° 08′	—	−26.8	32′ 32″	—	0.983
Mercury	1	$17^h\ 19.1^m$	−25° 07′	12° Ev	−0.6	4.9″	94%	1.359
	11	$18^h\ 25.3^m$	−25° 38′	17° Ev	−0.6	5.5″	85%	1.224
	21	$19^h\ 22.5^m$	−23° 48′	20° Ev	−0.6	6.6″	63%	1.017
	31	$19^h\ 42.3^m$	−20° 48′	15° Ev	+0.8	8.7″	21%	0.770
Venus	1	$17^h\ 08.5^m$	−23° 17′	10° Ev	−3.9	9.9″	99%	1.680
	11	$18^h\ 03.2^m$	−24° 12′	12° Ev	−3.9	10.0″	98%	1.660
	21	$18^h\ 58.2^m$	−23° 52′	15° Ev	−3.9	10.2″	97%	1.637
	31	$19^h\ 52.3^m$	−22° 19′	17° Ev	−3.9	10.4″	96%	1.610
Mars	1	$5^h\ 09.5^m$	+24° 56′	170° Mo	−1.8	17.2″	100%	0.544
	16	$4^h\ 44.5^m$	+24° 52′	169° Ev	−1.7	16.5″	100%	0.567
	31	$4^h\ 26.9^m$	+24° 33′	150° Ev	−1.2	14.8″	97%	0.633
Jupiter	1	$23^h\ 57.0^m$	−1° 53′	110° Ev	−2.6	43.6″	99%	4.525
	31	$0^h\ 04.8^m$	−0° 53′	82° Ev	−2.4	39.5″	99%	4.995
Saturn	1	$21^h\ 29.5^m$	−16° 09′	71° Ev	+0.8	16.4″	100%	10.118
	31	$21^h\ 39.2^m$	−15° 21′	43° Ev	+0.8	15.8″	100%	10.531
Uranus	16	$2^h\ 51.4^m$	+16° 03′	142° Ev	+5.7	3.7″	100%	18.892
Neptune	16	$23^h\ 33.9^m$	−4° 08′	89° Ev	+7.9	2.3″	100%	29.919

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**.



Extra Taurus Treasures

The constellation is more than just a couple of clusters and a bright star.

Mention Taurus to most stargazers and they'll immediately think of the Pleiades and Hyades star clusters, and Aldebaran, the 1st-magnitude orange star that marks the Bull's eye. So wondrous is this constellation that even though I've already devoted two columns to it, there's more to discuss!

Aldebaran and the Hyades together form the tilted V that outlines the Bull's face, while the Pleiades are located on his shoulder. But can we trace out the entire form of the beast? Actually, we can't. Traditionally, only the front half of Taurus is outlined with stars. One explanation for this is that the back half of Taurus is underwater. The story is that Zeus, king of the gods, assumed the form of a bull who carried the maiden Europa off across the waves.

In addition to the Bull's face, stars mark his horns, too. The more northerly horn is tipped with 1.7-magnitude Beta (β) Tauri, also called Elnath (a name derived from the Arabic for "the butting one"). Although Elnath officially belongs to Taurus, it's also used to complete the famous pentagon shape of Auriga, the Charioteer. So luminous is the winter sky, however, that Elnath struggles to stand out from the crowd. Indeed, just over the border in Orion we find three more stars that have essentially the same magnitude as Elnath: Bellatrix (the star indicating the Hunter's western shoulder) along with Alnilam and Alnitak (the two brightest Belt stars). The four are so similarly bright that you likely won't be able to detect any differences among them.

▲ **CHARGING BULL** Taurus looks to be in some trouble as he charges headfirst at Orion, who's poised with his upraised club. Thankfully, in the night sky, both constellations are more likely to delight stargazers than provoke concern.

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

But at least Elnath outshines its counterpart on the tip of the Bull's southern horn, Zeta (ζ) Tauri. Elnath is noticeably brighter than Zeta, but the latter is much closer to the ecliptic and therefore engages in many more and closer conjunctions with the Moon and planets. And Zeta has another claim to fame. In the summer of AD 1054, a point of light only about 1° to the northwest dramatically outshone it. Brighter than the planet Venus, the "guest star" was observed in broad daylight by Chinese astronomers for 23 days. Today we know this luminary as the sky's most famous supernova remnant, M1, the Crab Nebula. Even today, poor Zeta plays second fiddle to the Crab; most telescope users simply regard the star as a convenient jumping-off point for the nebula.

This month, the brightest light in Taurus isn't a supernova or even Aldebaran, but rather it's another guest: the planet Mars. As described on page 48, the Red Planet reaches opposition on December 8th and spends the entire month drifting westward across Taurus. At its peak this month, Mars is 12 times brighter than Aldebaran, though the two share a similar ruddy hue. And, in March 2023, the planet will be neatly positioned between the tips of the Bull's horns.

Let's close with a couple of rarely mentioned stars in southern Taurus that form a line leading from Gamma (γ) Tauri (the tip of the Hyades V) straight to the head of Cetus, the Whale. The first star, about 6° southwest of Gamma, is Lambda (λ) Tauri — one of the brightest eclipsing variable stars. It varies modestly from magnitude 3.4 to 3.9 over a period of 3.95 days — a variability first noticed in 1848 by British astronomer Joseph Baxendell. Continue the line toward Cetus and you'll find Xi (ξ) and Omicron (ο) Tauri. These two shine respectively at magnitudes 3.8 and 3.6 and are a little less than 1° apart, making them a wonderful naked-eye double.

■ With this installment, **FRED SCHAAF** completes 30 years of writing columns to accompany this magazine's central star chart.

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

A Dusk Holiday Delight

The Moon, Mercury, and Venus gather on Christmas Eve.

THURSDAY, DECEMBER 1

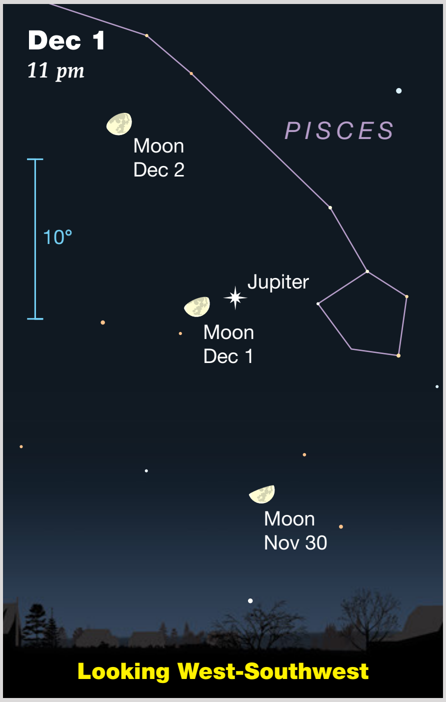
The **Moon** has a busy month, and it gets to work on Day 1 by sidling up to **Jupiter**, approaching to within 2½° at its closest. What time that occurs depends on where you are. For observers on the West Coast, it's conveniently early, at around 9 p.m. PST. On the East Coast, however, prime time will be just after midnight when the night of December 1st transitions to the morning of the 2nd. Regardless of the hour, Jupiter and the waxing gibbous Moon will be nice and close whenever you look.

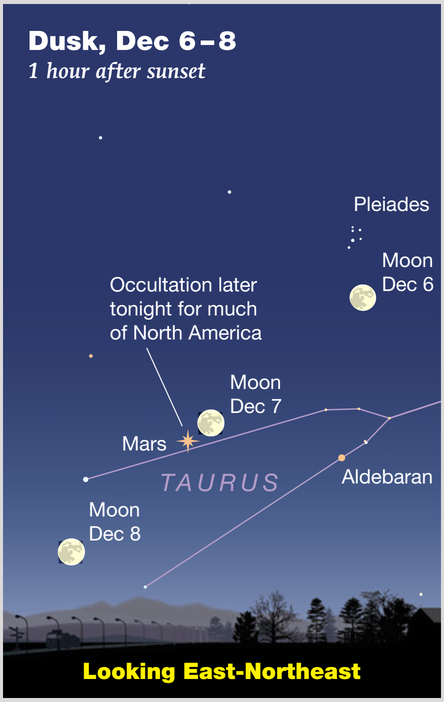
One advantage of this conjunction happening on the 1st of the month is that there's enough time left in December for a second meet-up on the 28th, when the Moon returns to the same general region of the ecliptic. That pairing won't be quite as appealing, though, as the waxing lunar crescent doesn't get closer than about 5½° to the planet as the pair set late in the evening. Still, given the season's typically inclement weather, a backup conjunction is nice to have.

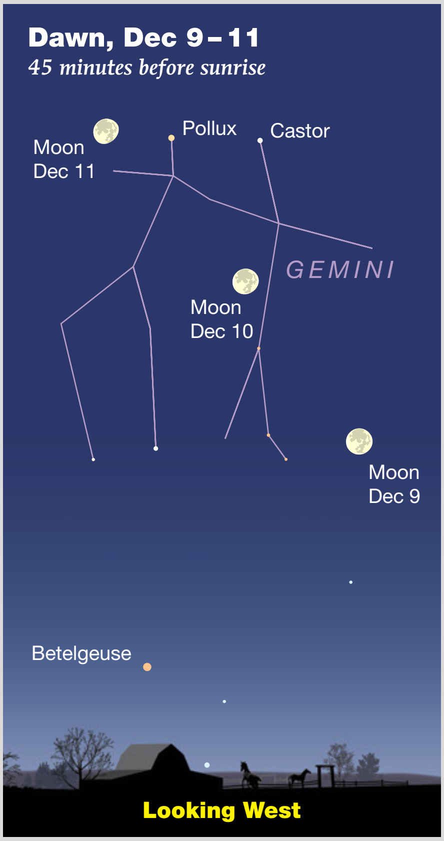
WEDNESDAY, DECEMBER 7

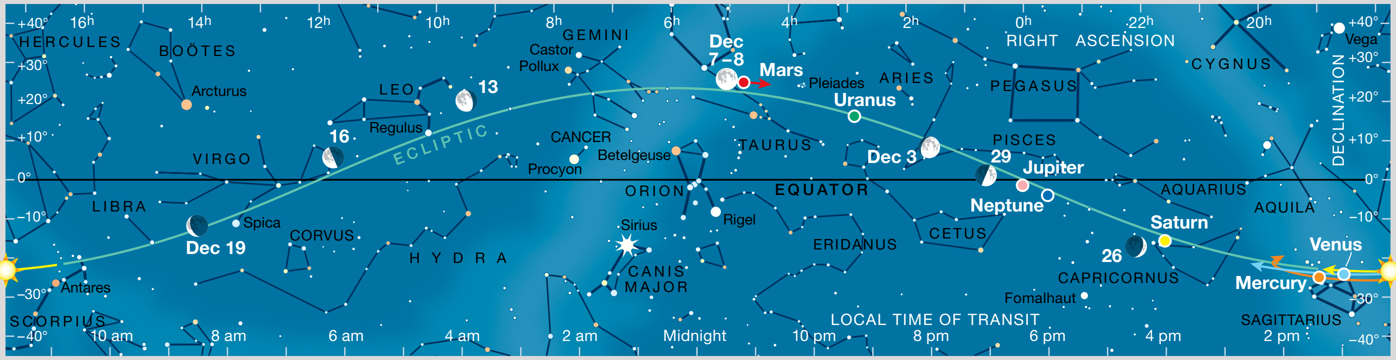
Of all the pairings this year between planets and the **Moon**, tonight's encounter with **Mars** is arguably the best. Three things make it extra special. First, the Moon is full at 11:08 p.m. EST. Second, Mars is at opposition less than two hours later and gleams at its brightest this apparition at magnitude –1.8. Third, they get close — *really* close. In fact, for much of North America, the Moon actually eclipses the Red Planet.

The show starts as soon as twilight fades sufficiently so that you can spot Mars, just left of the Moon. (Use binoculars if you want to get an early start.) Over the course of the next few hours, the gap between the two will shrink and shrink in a fascinating display of celestial mechanics as both objects reach "opposition." After the Moon overtakes Mars, the separation between the twosome will start to increase. Because this event is covered extensively in the pages that follow, here I'll simply alert you to the fact that this is happening and that it's something you definitely don't want to miss!





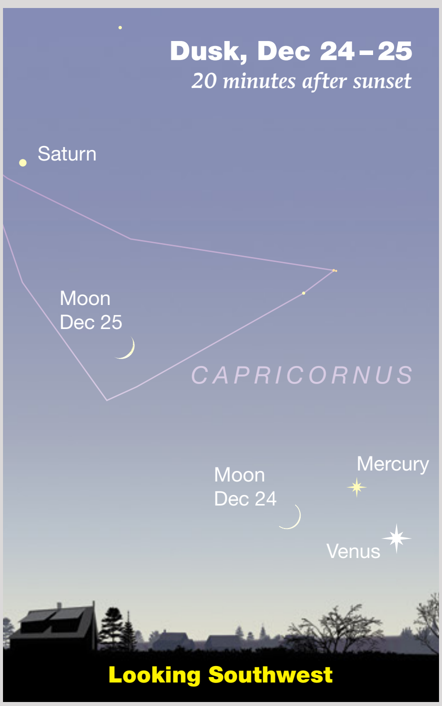




▲ The Sun and planets are positioned for mid-December; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit" tells when (in Local Mean Time) objects cross the meridian — that is, when they appear due south and at their highest — at mid-month. Transits occur an hour later on the 1st, and an hour earlier at month's end.

SATURDAY, DECEMBER 10

As the **Moon** rises this evening, it's part of a right triangle that includes Gemini's bright, stellar pair of **Castor** and **Pollux**. As the trio clears the east-northeastern horizon, the waning gibbous is about 3° to the right of Pollux. It's a pretty enough sight, but the payoff occurs later. The Moon advances toward Pollux throughout the night, and just as dawn begins to break on the morning of the 11th, the configuration will be a tidy three-in-a-row line high above the western horizon. You could stay up all night and watch events unfold, but I suspect most skywatchers will simply catch the moonrise conjunction, and then check back again in the morning.



SATURDAY, DECEMBER 24

If you're looking to add a bit of celestial sparkle to your Christmas Eve celebrations, the universe (or, at least, the solar system) abides. Cast your gaze toward the southwest just as twilight begins to fade to see the heavenly trio of **Venus**, **Mercury**, and the earthlit crescent **Moon** arranged in a sweet isosceles triangle. The Moon and Venus form the triangle's base, which spans a little less than 7°, while Mercury resides at the triangle's peak, roughly 4° from Venus and 4½° from the lunar crescent. And there *is* a lot of sparkle here. Mercury is enjoying a favorable evening apparition and shines gamely at magnitude –0.4. Venus is at the start of an evening appearance that will last through the middle of summer, and tonight it dominates the scene, gleaming at magnitude –3.9. Last, but certainly not least, is the 4%-illuminated, 1.5-day-old crescent Moon.

Shift your gaze a little higher in the sky to enjoy some extra holiday cheer courtesy of a 90°-long string of lights that includes (from south to northwest) Fomalhaut, Saturn, Altair, and Vega. The quartet are similarly bright — only a touch more than a full magnitude distinguishes the brightest (Vega) from the faintest (Fomalhaut) light in the string.

◀ 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.

WEDNESDAY, DECEMBER 28

Just four days after the Christmas Eve show, the scene has changed dramatically. At dusk, the **Moon** has climbed higher and now sits about 8° below right of **Jupiter**. (It'll be closer late in the evening and again at dusk on the 29th.) The more notable change, however, is in the positions of **Mercury** and **Venus**. After reaching greatest elongation on the 21st, Mercury has well and truly begun its plunge toward the horizon and will be in conjunction with the Sun on January 7th. The little planet has also lost some of its luster, now glowing at magnitude +0.2. Venus, meanwhile, is holding steady at magnitude –3.9 and has climbed a tiny bit (about 1°) higher. On this evening, the two innermost planets pass like slow-motion ships in the twilight. Look to the west-southwest to see the pair nearly side-by-side, with a bit more than 1½° between them. The caveat here is that you'll need an unobstructed view, preferably over water or a flat field, since they're only about 6° up half an hour after sunset.

■ For Consulting Editor **GARY SERONIK**, any season with interesting conjunctions is a festive one.

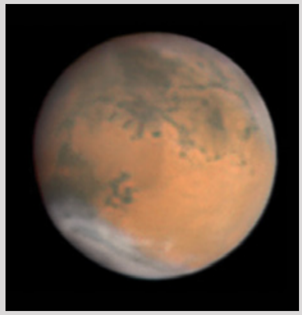
A Transitional Mars Opposition

The Red Planet offers a double dose of December observing pleasure.

Mars lovers have been looking forward to this moment for more than two years. With 26 months between oppositions, it's wonderful to have the Red Planet home for the holidays. Mars dazzles in Taurus at magnitude –1.8, outshining even Sirius, the night sky's brightest star. After a day of hectic holiday shopping and icy roads, the planet's emberlike glow invites us to slow down and savor the tranquility of a winter night.

This opposition, occurring on December 8th (at 5:36 UT), is neither *perihelic* (close) nor *aphelic* (far), but a transitional one smack in the middle. Closest approach to Earth occurs a week earlier, on December 1st at 2:18 UT (November 30th, 9:18 p.m. EST), when the planet will be just shy of 81.5 million kilometers (50.6 million miles) distant and a plump 17.2″ across. While that's 5.4″ smaller than it was during its excellent 2020 perihelic opposition, Mars climbs 19° higher in the sky this time. At latitude 40° north it passes just 15° south of the zenith when it culminates at midnight. Since altitude is one of the best balms for unsteady seeing, we can expect some great telescopic views of the planet this go around.

In December, the Martian South Pole is slightly tipped in our direction, increasing from 3.8° to 8.8° during the month. Since it will be late summer in the southern hemisphere, little will remain of the South Polar Cap. We're more likely to see the planet's northern limb fringed in white from the expansive North Polar Hood (NPH), especially early in the month. The NPH is a system of clouds that forms over the North Polar Region beginning in late summer and persisting through winter. With the start of spring in Mars's northern hemisphere on December 26th, the NPH should begin to dissipate by month's end. Sharp eyes may spot the North Polar Cap poking out from under the clouds before the year is out. Finally, observers should be on the lookout for a return of the rare Edom Promontorium flares, as noted in the October issue, page 58.

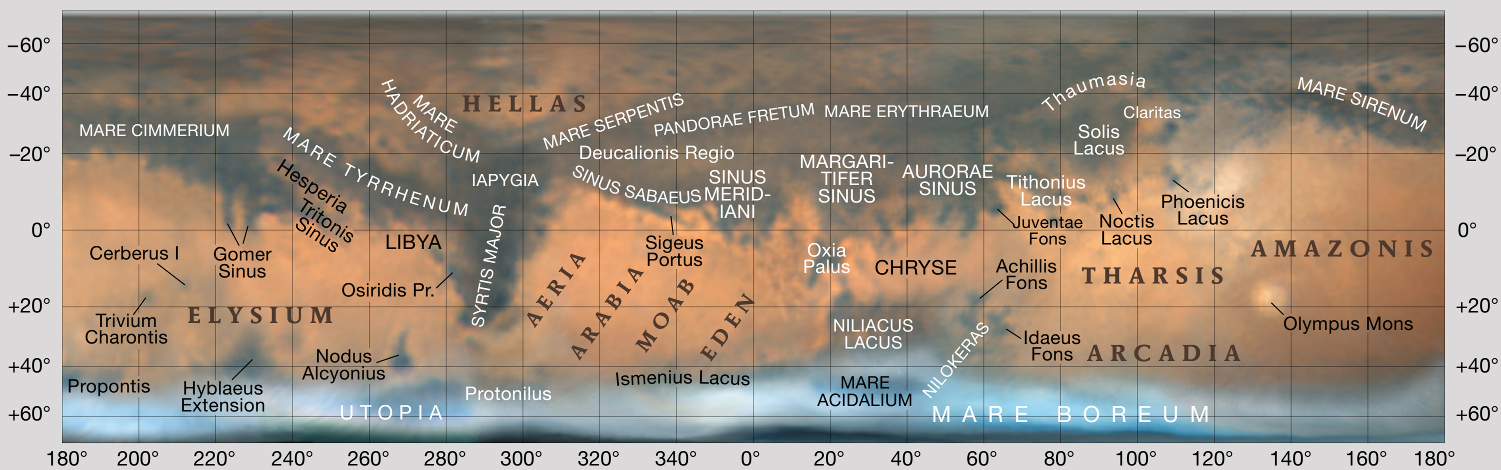


◀ The December 2007 Mars opposition was similar to the current one, with an extensive cap of clouds that shrouded the planet's north polar region, captured in this image from December 7, 2007. At the time, the Martian disk had a diameter of 15.5″ — somewhat smaller than the 17.2″ the planet will attain this December. (South is up.)

Viewing fine detail on Mars means using the highest magnification that seeing conditions will allow and a set of color planetary filters. A red or orange filter increases the contrast of dark albedo features while at the same time reducing glare. A blue or violet filter enhances atmospheric haze and clouds. Aesthetically, however, you will probably find the unfiltered view the most appealing of all.

To identify what you see at your eyepiece, or to plan an observing session, use our online Mars Profiler at **https://is.gd/marsprofiler**.

MARS IMAGE: DAMIAN PEACH; MARS MAP: DAMIAN PEACH / GREGG DINDERMAN / *S&T*



The Moon Occults Mars

AS THOUGH THE FULL MOON were jealous of all the attention Mars receives this month, it briefly removes the Red Planet from the sky. On the night of December 7–8, much of North America, northern Mexico, Greenland, Iceland, northern Africa, and most of Europe get to enjoy a remarkable occultation as the Moon passes in front of Mars. The occultation occurs during the evening hours in the U.S. and promises to be a spectacular and widely observed event. Mars is so bright it should be plainly visible to the naked eye, pinned to the lunar limb just before it vanishes from view, and again later when it returns. Unlike a star, which disappears in a wink, it will take many seconds for the Moon to cover Mars — more than a minute as viewed from Dallas, Texas!

For further details, including times of disappearance and reappearance for many cities, go to **https://is.gd/marsoccultation2022**.

▲ The Moon and Mars appear to almost touch moments before the occultation in this simulation of the event for Fargo, North Dakota, on December 7th at 9:01 p.m. local time.

STELLARIUM

The Moon Meets Mars

Location	Time Zone	Closest	Sep	PA	Alt
New Orleans, LA	CST	9:11 p.m.	3′	141°	54°
Huntsville, AL	CST	9:23 p.m.	1′	148°	59°
Miami, FL	EST	10:16 p.m.	11′	161°	64°
Jacksonville, FL	EST	10:23 p.m.	7′	158°	64°
Atlanta, GA	EST	10:26 p.m.	3′	151°	62°
Columbia, SC	EST	10:31 p.m.	4′	159°	66°
Knoxville, TN	EST	10:31 p.m.	1′	154°	63°
Charlotte, NC	EST	10:36 p.m.	3′	160°	66°
Virginia Beach, VA	EST	10:46 p.m.	4′	170°	69°
Washington, DC	EST	10:46 p.m.	2′	166°	69°
Philadelphia, PA	EST	10:51 p.m.	1′	172°	70°
New York, NY	EST	10:56 p.m.	1′	173°	71°
Boston, MA	EST	11:01 p.m.	1′	180°	71°
San Juan, Puerto Rico	AST	11:51 p.m.	23′	192°	82°
Hamilton, Bermuda	AST	12:06 a.m.*	11′	199°	83°

* Calendar date is December 8th.

A Moon and Mars Close Call

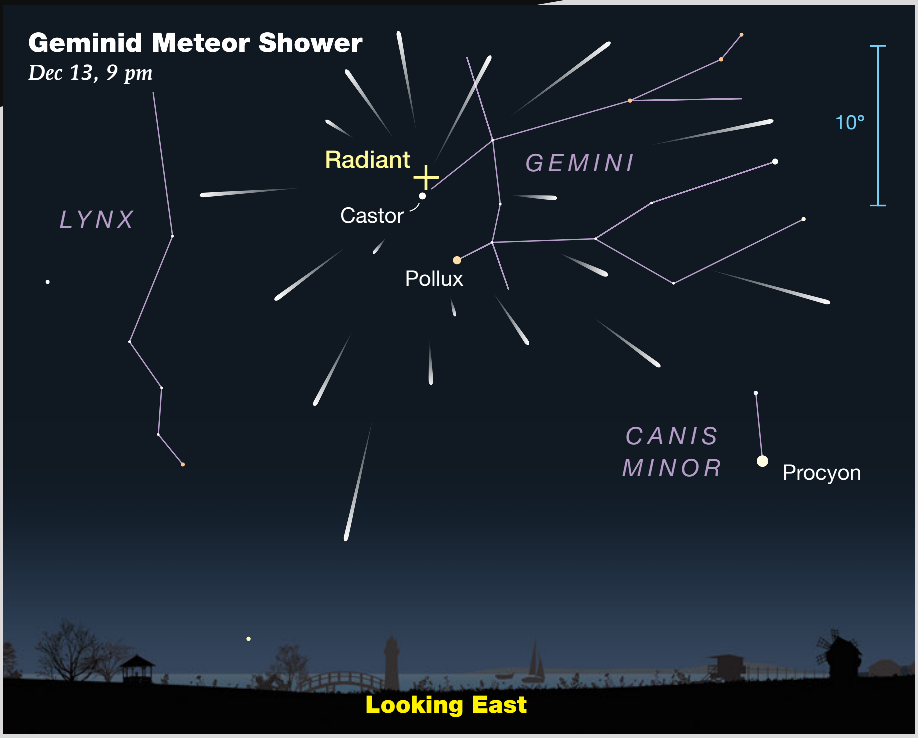
While many locations will enjoy the sight of the full Moon occulting Mars, a swath of the southeastern U.S., including the Atlantic seaboard, lies outside of the occultation zone and instead will be treated to the stunning and rare sight of the planet skimming along the lower edge of the lunar disk. The last time a similar event occurred was during the early morning hours of July 17, 2003. The December 7–8 encounter will instead happen in “prime time” with potentially a much larger viewing audience.

In the table below-left, circumstances are provided for 15 locations. From downtown Boston, for example, where the southern limit of the occultation tracks just 30 km to the north, the separation between the Moon and planet is less than 1′ at 11:01 p.m. EST. In the table, PA indicates the position angle of Mars relative to the Moon’s disk (measured clockwise from the top of the Moon), and Alt is the altitude of the Moon above the horizon.

How often does the Moon eclipse Mars? On a worldwide basis, simulations turn up 61 occultations of the Red Planet between 2010 and 2040. But if we confine our search to a specific location and only include instances when the Sun is below the horizon, such an event occurs on average once every 14 years.

The next favorable occultation of Mars for North America will take place on January 14, 2025, at around 4h UT. The Moon will be a waning gibbous, about 6 hours past full. Mars comes to opposition just two days later.

—JOE RAO



Geminids Add Seasonal Sparkle

WHILE THE COLD CAN sting fingers and face alike, December is one of the best months for meteor watching. The annual Geminid shower is the most productive of the year, with more than 100 meteors per hour under perfect conditions. Unfortunately, a 70%-illuminated waning gibbous Moon will make conditions something less than perfect on the peak night of December 13–14. Lucky for us, the Geminids are fairly active before midnight. With nightfall starting shortly after 6 p.m. local standard time and the Moon rising about 9:30 p.m., we'll have three good hours of moonless skies.

The shower's peak occurs about 13h UT (8 a.m. EST) on December 14th. That means activity will still be good the following night (December 14–15), when the Moon rises an hour later.

On a separate note, the Moon occults 3.5-magnitude Eta (η) Leonis soon after moonrise on the night of the 13th. This will be viewable for observers living in the eastern U.S. and elsewhere. For details visit **https://is.gd/etaleonis2022**.

To maximize comfort on winter nights, slip chemical handwarmers into your mittens and boots to keep your fingers and toes from freezing. Once prepped for battle, you can ease into your reclining chair and blissfully watch the meteors fly by.

Minima of Algol

Nov.	UT	Dec.	UT
2	22:31	1	14:41
5	19:20	4	11:30
8	16:09	7	8:19
11	12:58	10	5:08
14	9:47	13	1:57
17	6:36	15	22:46
20	3:25	18	19:35
23	0:14	21	16:25
25	21:03	24	13:14
28	17:52	27	10:03
		30	6:52

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**.

Action at Jupiter

AS DECEMBER GETS UNDERWAY, Jupiter is approaching the meridian, where it's most favorably placed for telescopic viewing in the early evening. At its highest, the planet has an altitude of 48° for observers at mid-northern latitudes. On the 1st, Jupiter gleams at magnitude –2.6 and its disk spans nearly 43.6″, slightly less than its 49.8″ peak when it was at opposition in late September.

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

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

November 1: 4:40, 14:36; **2**: 0:32, 10:27, 20:23; **3**: 6:19, 16:14; **4**: 2:10, 12:06, 22:01; **5**: 7:57, 17:53; **6**: 3:48, 13:44, 23:40; **7**: 9:35, 19:31; **8**: 5:27, 15:22; **9**: 1:18, 11:14, 21:09; **10**: 7:05, 17:01; **11**: 2:57, 12:52, 22:48; **12**: 8:44, 18:39; **13**: 4:35, 14:31; **14**: 0:26, 10:22, 20:18; **15**: 6:14, 16:09; **16**: 2:05, 12:01, 21:56; **17**: 7:52, 17:48; **18**: 3:44, 13:39, 23:35; **19**: 9:31, 19:26; **20**: 5:22, 15:18; **21**: 1:14, 11:09, 21:05; **22**: 7:01, 16:56; **23**: 2:52, 12:48, 22:44; **24**: 8:39, 18:35; **25**: 4:31, 14:27; **26**: 0:22, 10:18, 20:14; **27**: 6:10, 16:05; **28**: 2:01, 11:57, 21:52; **29**: 7:48, 17:44; **30**: 3:40, 13:35, 23:31

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

19: 4:28, 14:24; **20**: 0:20, 10:16, 20:11; **21**: 6:07, 16:03; **22**: 1:59, 11:55, 21:50; **23**: 7:46, 17:42; **24**: 3:38, 13:34, 23:29; **25**: 9:25, 19:21; **26**: 5:17, 15:13; **27**: 1:09, 11:04, 21:00; **28**: 6:56, 16:52; **29**: 2:48, 12:43, 22:39; **30**: 8:35, 18:31; **31**: 4:27, 14:22

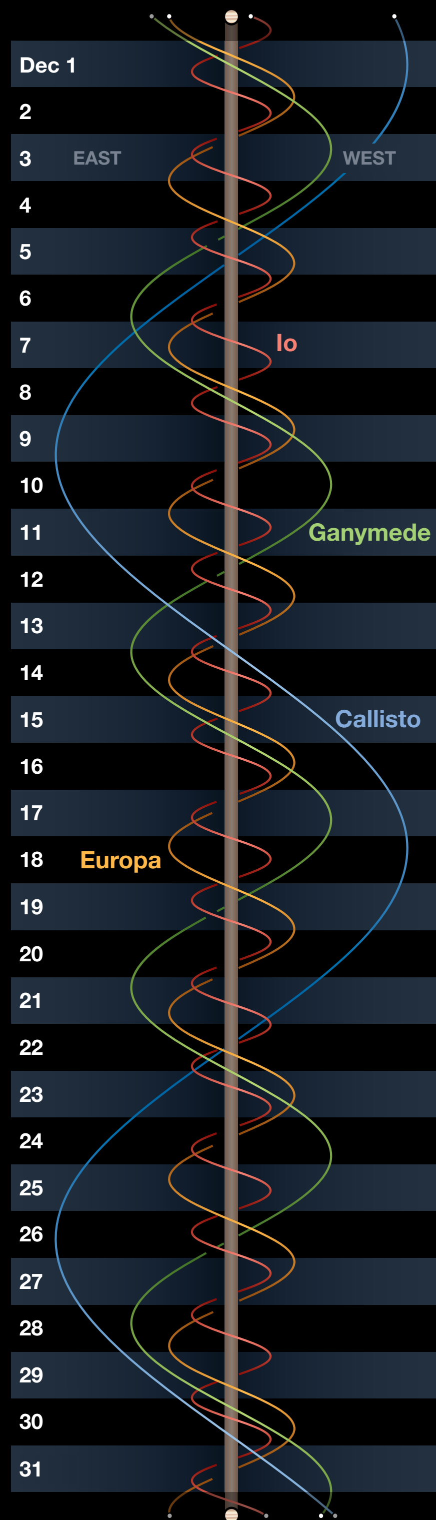
These times assume that the spot will be centered at System II longitude 30° on December 1st. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 30° and 1²/₃ minutes later for each degree more than 30°.

Phenomena of Jupiter's Moons, December 2022

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

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

Jupiter's Moons



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

Layer Upon Layer Upon Layer

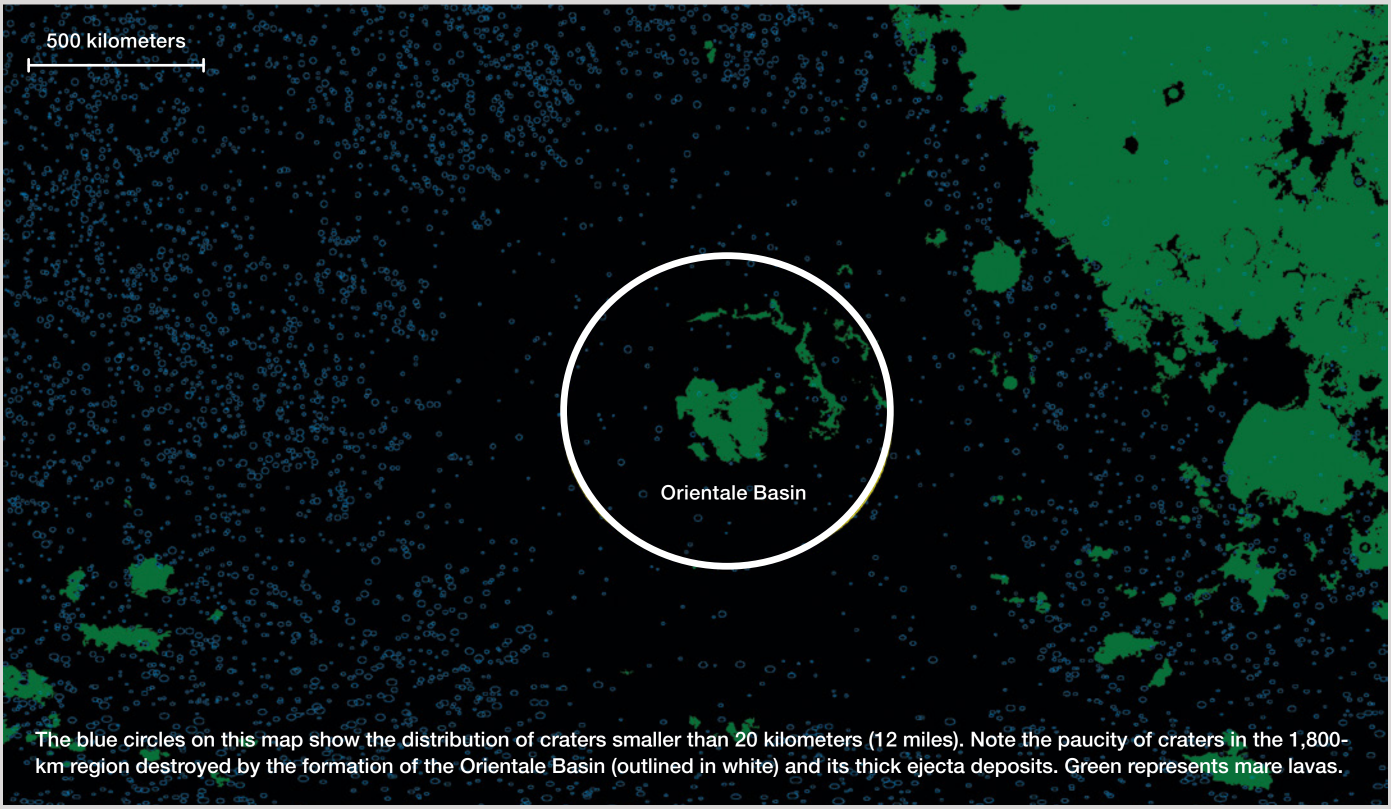
Follow the clues leading back to the formation of two large lunar basins.

Like every other object in the solar system, the Moon has been battered by innumerable impacts of rocky debris. All told, its surface bears 1.3 million impact craters larger than 1 kilometer (0.6 miles) across. Each of these collisions instantaneously excavated a crater while fracturing, melting, and vaporizing the target rocks and distributing ejecta both near and far. And while most observers focus their attention on dramatic craters, they often overlook the much more extensive and morphologically varied ejecta. These impacts excavated a crater's worth of material ranging from a fine powder to mountain-sized boulders and strewing it across the lunar surface to create a wide variety of features and textures.

Observers of the fresh, 93-km-wide crater **Copernicus** often concentrate on its mountainous rim, stair-step terraces, and flattish floor containing a cluster of central peaks. But consider the surrounding area. Ejecta from Copernicus that shot nearly vertically upward fell around the crater, building about half of the kilometer-high mountainous rim, with uplifted target rocks making up the rest. The debris pile is thickest at the rim and decreases to virtually nothing about one crater radius away. Beyond that is scattered, rough terrain made up of discontinuous hills and ridges of ejecta. Even farther out, individual clumps of hill-sized rocks bombarded the surface, digging out clusters and chains of secondary craters, each one a few percent of the diameter of the primary crater. Tracing along an alignment of secondary craters to the north are bright rays made mostly of the fragments of previously buried rocks that were brought to the surface by the formation of these secondaries. Such rays typically extend 10 to 20 times the radius of the primary crater.

You can scale up the formation of Copernicus to understand large impact basins and their far-reaching effects. Clearly, debris from large craters and basins must cover immense swaths of the lunar surface. Only mare lava flows, which are younger than nearly all impact basins, are mostly free of ejecta layers.

The best examples of the effects of basin ejecta is at the 930-km-wide



The blue circles on this map show the distribution of craters smaller than 20 kilometers (12 miles). Note the paucity of craters in the 1,800-km region destroyed by the formation of the Orientale Basin (outlined in white) and its thick ejecta deposits. Green represents mare lavas.

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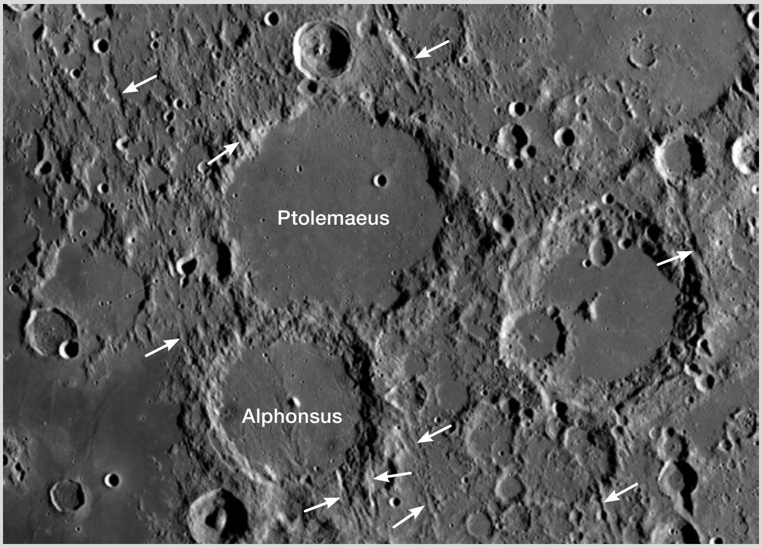

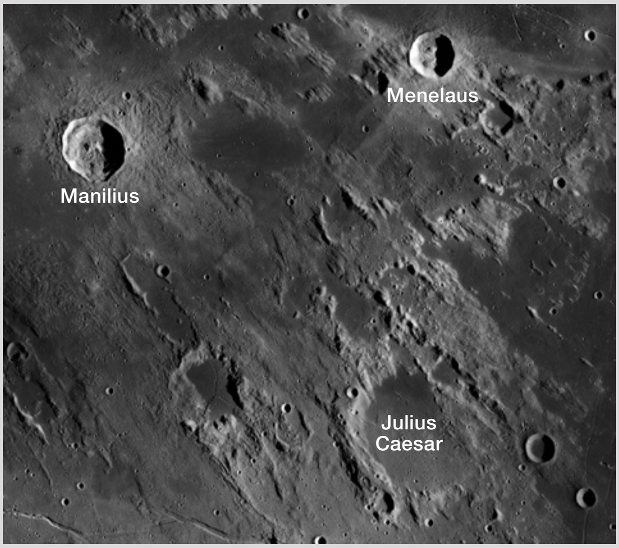

▲ *Left:* Long grooves in the highlands near Ptolemaeus and Alphonsus are informally known as the Imbrium Sculpture. *Right:* The area north of crater Julius Caesar contains several mare-filled secondary crater chains that point back to the Imbrium Basin to the northeast.

Orientale Basin, the youngest large basin on the Moon. Orientale is mostly out of view on the Moon's western limb but can be seen under favorable libration conditions, such as those presented in the morning hours of December 17th. But even under good conditions, Orientale is extremely foreshortened as seen from Earth, so spacecraft images are required to understand the feature and its surroundings. Vertical views of such relatively fresh ejecta help you recognize similar deposits near the Imbrium Basin and other basins on the nearside.

The map at left dramatically shows the widespread effects of ejecta deposits around Orientale: Very few craters exist in an annulus extending one basin radius beyond Orientale's rim. Most craters in that zone were completely buried by Orientale ejecta, while others, such as the 160-km-wide crater **Lagrange,** were heavily damaged by flows of ejecta. Yes, some ejecta flowed across the landscape, smoothing rough spots and filling in depressions.

Now focus your attention on the 1,300-km-diameter Imbrium Basin (containing **Mare Imbrium**) and its surroundings. First, notice that other than the partial rim remnants of **Montes Carpatus** to the south and **Montes Apenninus** to the southeast, Imbrium is largely surrounded by mare lavas, and most of its nearby ejecta deposits are buried. The 28-km-long, oval crater **Marco Polo** and a few other severely damaged crater ruins are seen on the back slopes of the Apennines. To the southeast are small patches of lava, such as **Lacus Odii,** that probably fill the floors of older, destroyed craters. Continuing southeast near the 90-km-crater **Julius Caesar** are numerous, elongated mare deposits that fill two or three overlapping craters with demolished walls. These are secondary crater chains radial to the Imbrium Basin. The chain craters' sizes range from 20 to 40 km across, and like Copernicus' secondaries, are a few percent of their primary's diameter. Look closely and you may also notice several ridges and smoothed, faintly gouged terrain radial to Imbrium, where ejecta scoured the lunar surface.

About 750 km to the southwest of Mare Imbrium, the rims of **Ptolemaeus**, **Alphonsus**, and nearby highlands are cut by rough, linear grooves 20 to 80 km long. The geologist G. K. Gilbert called these radial gashes the Imbrium Sculpture and correctly interpreted them as gouges produced by chunks of Imbrium ejecta hundreds of meters wide that plowed across the landscape at high speeds.

Notice also that Ptolemaeus and other nearby craters have smooth floors that are lighter than mare material. Similar smooth, light deposits — long ago dubbed the *light plains* — are found in and between craters in virtually every part of the lunar highlands. For a long time, geologists thought the fill and plains — which must have flowed in order to appear so smooth — were a different type of volcanic material than mare lavas. But scientists now interpret most of the plains as impact-basin ejecta, specifically from Imbrium and Orientale, the two youngest big basins.

Some evidence of this interpetation is found in the rock samples collected during NASA's Apollo 16 mission, which landed on smooth, light plains. The samples are *brecciated* — broken up by the intense energy of a basin-forming impact 4.3 billion years ago. Additionally, mapping the distribution of light plains reveals many linear patches radial to the Orientale and Imbrium basins. Orientale's smooth plains extend four times its radius. If that's typical, then the existence of up to 74 basins means that there must be layers upon layers of impact ejecta on the lunar surface. Indeed, the 2,400-km-wide South Pole–Aitken Basin alone may have deposited a layer of ejecta to cover more than 80% of the Moon and launched even more material toward Earth and beyond.

■ Contributing Editor **CHUCK WOOD** is continually fascinated by the violent processes that shape the lunar surface.

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Composition Tips for Astrophotographers

There's more to a great shot than just getting the exposure right.

Photographer Edward Weston famously once said that "Good composition is merely the strongest way of seeing." As astrophotographers, it's easy for us to become obsessed with the technical aspects of the pursuit. But too much pixel peeping leads to the classic problem of not seeing the forest for the trees. At some point, you need to step back and consider how you go about composing your photos.

Three closely related factors determine how compelling your images end up being: scale, framing, and cropping. Master these and you'll be on your way to creating your best work.

The Goldilocks Zoom

The size of your camera's sensor in conjunction with the focal length of its lens determine its field of view. Careful planning will help confirm the combination you plan to use is a good match for what you want to photograph. A full-frame camera and ultra-wide lens may be perfect for capturing the majestic arch of the Milky Way, but a crop-sensor body and long telephoto optics are a better match for framing individual deep-sky objects. Your target needs to cover enough pixels on the sensor to record sufficient detail while still allowing some breathing room around the edges to prevent the overall composition from feeling claustrophobic. Getting the scaling just right is key to a successful image.

I use desktop planetarium software to pre-visualize the best combination of equipment for a specific target. My go-to application is *SkySafari*, but many other

▲ This nocturnal landscape demonstrates the many benefits of careful composition. The initial framing was done according to the "rule of thirds," which suggests placing the horizon about one-third from the bottom of the frame, and the Milky Way to the right of center. This layout balances the visual weight of the trees on the left with the rocky beach on the right, while adding symmetry with the reflections of the Milky Way in the tide pool below.

ALL IMAGES COURTESY OF THE AUTHOR

programs allow you to superimpose a field-of-view box that shows what a specific camera and lens combination will yield. If your gear selection is limited to just one setup, you can still use this technique to find imaging subjects that are a good match. A quality zoom lens is handy for fine-tuning the image scale to match your target.

Frame and Fortune

Most camera sensors are rectangular (with aspect ratios like 3:2 or 4:3), so you'll need to decide whether to frame your shot horizontally or vertically. How you plan to display the final image will heavily influence your choice. Social-media platforms like Instagram and TikTok are optimized for the tall and narrow screens found on mobile phones. Conversely, landscape-style images look better on wide-screen monitors and video-centric platforms like YouTube. Often it makes sense to shoot both orientations to future proof your composition and provide maximum flexibility. (More on this later.)

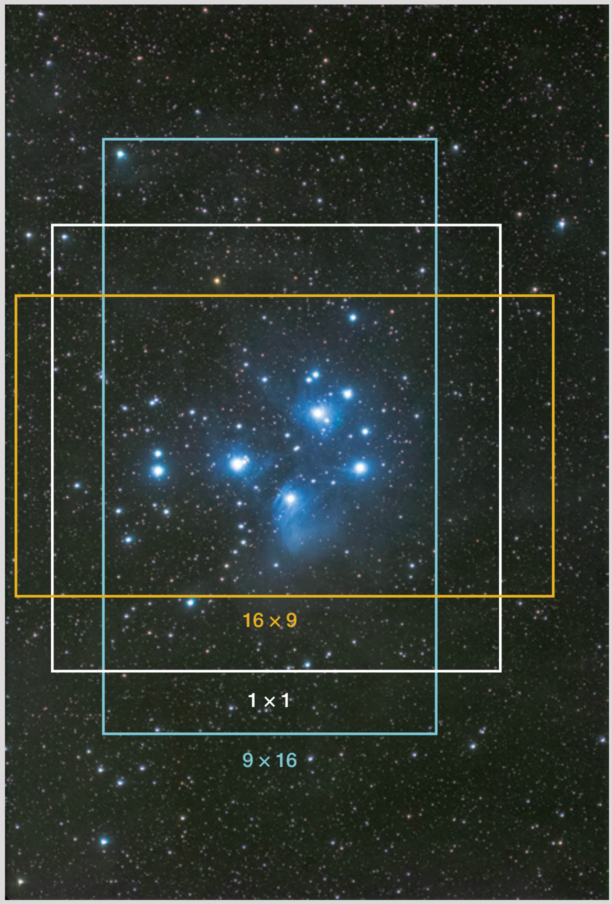
Wide-field nightscapes that include foreground objects require you to determine where to place the dividing line between the horizon and the sky. Resist the urge to split the difference and place this transition in the middle of the frame. Instead, use the well-known *rule of thirds* to strengthen your composition. Imagine a tic-tac-toe grid projected on the scene — the lines and their intersection points offer the strongest placements in the field. Positioning the horizon line one-third of the way from the top or bottom of the frame will result in a more powerful composition, allowing either the sky or landscape to dominate the image.

Of course, as with any rule, there are exceptions. Full-disk portraits of the Moon look just fine when centered in the frame as long as you leave a little space around the edges. However, filling the frame could make sense if you want to show specific details, such as individual craters along the terminator. The trick is to make sure that your decisions are all intentional and that you take the time to consider other options.

▲ This image pair hints at some of the many possible decisions you can make when framing your images. I think galaxies look better when they're placed at about a 45° angle relative to the frame (rather than straight up and down or perfectly horizontal). The author took this three-minute exposure of the Andromeda Galaxy with a Canon EOS 70D camera at ISO 1600 and a Canon EF70-200mm f4L USM telephoto lens.

Although a north-up orientation is a popular choice, closeups of deep-sky objects often benefit from rotating the camera for a better fit. And since there's no up or down in space, you can use some artistic license when framing your targets. Be aware, however, that there are some compositional archetypes in the field of astrophotography. While an argument could be made for inverting your image of the North America Nebula in Cygnus, it would look rather odd since it would clash with the orientation we're accustomed to seeing. Similarly, the Horsehead Nebula in Orion just doesn't look right if oriented north-south. Comets and edge-on galaxies often benefit from a diagonal composition. Beyond simple aesthetics, this may allow zooming in to capture more details without exceeding the boundaries of the image frame.

If you find the field of view is too tight, you also have the option of



▶ You never know how your astro images will be used, so you want to make sure that your initial framing supports a wide range of potential crops. Here, some alternate layouts have been superimposed on the original image. Vertical or square cropping would work well for posting on Instagram, while a horizontal layout will be necessary when using the image on Facebook or in a YouTube video.

using the more advanced technique of mosaicking by shooting multiple, slightly overlapping frames to stitch together during post-processing. Programs like *Lightroom* or *Photoshop* have become remarkably good at compositing images with no visible seams, assuming that you allow about a 30% overlap between frames. I often shoot a three-by-three matrix of nine overlapping exposures to allow for maximum flexibility while increasing the overall resolution.

▲ Rules are made to be broken — and that includes the "rule of thirds." For full-disk shots of the Sun or Moon, it may be better to create a more symmetrical composition by placing the object in the center of the frame, as long as you allow a bit of breathing room around the edges to keep the composition from feeling too claustrophobic.

Border Patrol

Once you're satisfied with the overall dimensions of your image, it's a good idea to do some border patrol — a careful inspection along the edges of your image. Are there any distractions such as a tree branch intruding into the frame, or a bright star cut in half? You have two opportunities to take care of these problems. The first occurs in the field by ensuring you've optimized the framing and orientation of the shot.

The second chance is by cropping the composition in post-processing. Your image will be stronger if you tighten the crop slightly to eliminate any trespassing objects. However, getting things right under the stars will ensure that you only have to perform minimal cropping later, thereby preserving the maximum field of your camera's sensor. For wide-field, nightscape shots you also want to check that the horizon is perfectly level. Rotating the crop a bit to straighten things out will greatly improve your final result.

▲ Match your equipment to the subject. In the left frame, a 50-mm lens on a crop-sensor camera barely resolves the Lagoon and Trifid nebulae (M8 and M20, respectively) amid a sea of stars. Recording detail in these deep-sky targets requires at least a 300-mm lens (right frame).

Bumper Crops

Back in the film days, life was simple. If you were viewing color slides or picking up 4-by-6 prints from the local drugstore, the capture and delivery formats matched. Today, things are different. Your digital camera's sensor may share the traditional 3:2 aspect ratio of 35-mm film, but modern playback devices do not. As noted earlier, smartphones, tablets, TV sets, computer monitors, and print media accommodate a wide variety of shapes and sizes. That's why it helps to build in a little wiggle room to accommodate how your images will be presented.

For example, suppose you want to post your work on Instagram. That platform is currently optimized for tall, portrait-orientation images with a narrow 9-by-16 format. Even vertical images from most cameras will need to be cropped to display properly. If you didn't leave enough extra space when framing your initial capture, you might be forced to trim away important parts of your image.

Conversely, if you decided to start a YouTube channel to show off your work, you'll need the exact opposite dimensions, namely, a 16-by-9 format. If you want optimal images for a variety of display formats, it's a good idea to shoot both vertical and horizontal compositions and leave some room around the edges. Even photographic paper comes in a variety of sizes, so if you're planning on printing your images, you'll likely face situations in which cropping will be required.

None of the compositional tools I've described here will transform a poorly exposed image into an award winner, but they will add polish and help your images stand out from the crowd. It's often the little things that matter most.

■ **TONY PUERZER** is a retired professional photographer and avid amateur astrophotographer who always strives to make better compositions.

The Clouds of Andromeda

A familiar object presents surprising new sights, if you view it carefully with the right equipment.

◀ **SHIMMERING SIGHT** My 30-inch scope reveals glorious detail in and around the Andromeda Galaxy. Particularly striking to me is the Andromeda Shelf, the nebulosity that loops around M110. While the paddlelike extensions at either end of the galaxy follow the warp of the twisted spiral arms, they're also aligned with the galactic cirrus that streams along the galaxy itself. It's not clear to me if the paddles are part of Andromeda, the cirrus, or both.

ALL DRAWINGS BY THE AUTHOR

Look long enough with a wide-angle telescope into the darkest skies and you may see something astounding: The sky background varies ever so slightly. This isn't your imagination — it's *galactic cirrus*. Comprising dust and gas that's thrown far outside of the galactic plane by supernova explosions, galactic cirrus reflects the integrated light of the galaxy like a ghostly apparition.

We can trace the first (recorded) mention of galactic cirrus to William Herschel, who concluded that, visually, the sky "ground" varied. He compiled a table of 52 "Nebulosities that have not been published before" in the *Philosophical Transactions of the Royal Society of London* in 1811, which includes areas of galactic cirrus. But it's only more recently that the subject has been studied in greater detail, starting in the 1960s when American astronomer Beverly Turner Lynds cataloged clouds and nebulae that she identified on Palomar Observatory glass survey plates. Several amateur astronomers were also intrigued by the topic and started imaging galactic cirrus, including Steve Mandel for his Unexplored Nebula Project.

I find it stunning to stumble upon unexpected nebulosity — I've identified and drawn more than 120 fields of galactic cirrus clouds, mainly in the northern spring sky. And now I'd like to turn to a familiar target: Amazingly, a thin veil of Milky Way galactic cirrus encircles M31, the **Andromeda Galaxy**. It might even be possible that the clouds extend some 14° southeastward to **M33**, the Triangulum Galaxy. I discovered these clouds visually with my homemade telescopes equipped with wide fields of view at maximum exit pupil.

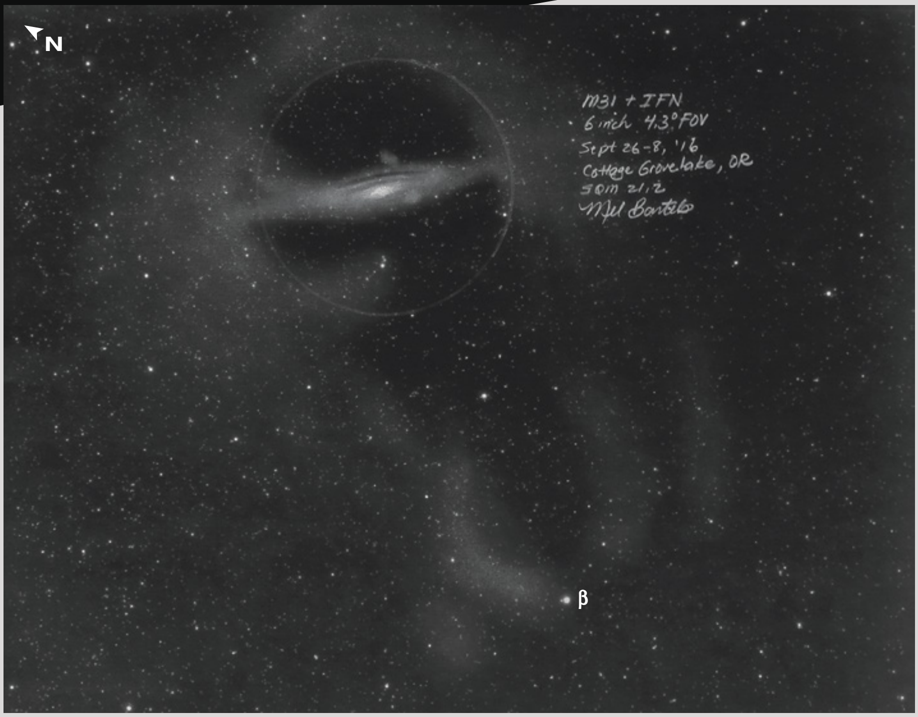
The Andromeda Galaxy and Neighbors

In 2013, during first light with my 6-inch f/2.8 Newtonian with a true field of view of 4.2° (for details see *S&T:* Sept. 2014, p. 72), I pointed the scope at the Andromeda Galaxy. Taking in the entire object, I noted a warping of the spiral arms, which appear to reach out towards its southern satellite galaxy, **M32**. A collision some 800 million years ago between M32 and Andromeda may have caused the warp, which I like to call the Andromeda Twist. Scanning back and forth across the galaxy with my 30-inch f/2.7 (with a field of 1°), the distortion of the spiral arms on both sides of the nucleus was striking.

With the 6-inch, I also became aware of indistinct nebulosity that envelops Andromeda and then curves around **M110**, the brightest and largest of Andromeda's satellite galaxies. I particularly enjoy showing fellow stargazers the Andromeda Shelf, as I call this nebulosity, in my wide-field telescopes — to an experienced observer in dark skies, the Shelf is rather bright.

Focusing on the satellites, M32 looks small and featureless in the 30-inch. This galaxy is stuffed with 400 million stars yet is only 6,000 light-years across. Unlike the main galaxy, M32 has no accompanying globular clusters that would be accessible in large amateur scopes. And astronomers are still debating whether M32 is in front of or behind the Andromeda Galaxy.

In contrast, M110 shows faint dust lanes, and its elongated nucleus is at a different angle to the fainter extensions. M110 is warped, too! Through



◀ **COSMIC PADDLES** With my 6-inch reflector the paddles extend the Andromeda Galaxy from its regular visual length of 3° to 5°. Photometrically, the galaxy measures some 3.2° degrees across. Of Herschel's 52 nebulous regions that he tabulated in his 1811 article, I've identified numbers 7, 8, 9, and 10 as clouds of Andromeda, which extend from M110 to Beta (β) Andromedae (labeled). Region number 8 is probably the bright cirrus left of the star.

the 30-inch it reminds me of what the Andromeda Galaxy looked like with the 4-inch telescope that my parents bought me for a grade-school science project on the Moon.

The nearly face-on M33, the smallest spiral in our Local Group of galaxies, is a notorious test of sky conditions and of our eyes. But unlike the Andromeda Galaxy, in dark skies M33 becomes breathtaking as aperture increases.

Andromeda's Nebulosities

All those years ago with my 4-inch I felt transported to the stars from my Portland, Oregon, backyard (which I darkened by simply switching off the porch light!). I first saw the Andromeda Galaxy as an oval with a starlike nucleus that, when I looked directly at it, turned fuzzy. This "is it fuzzy?" versus "is it starlike?" dichotomy persists even with my large scopes 55 years later.

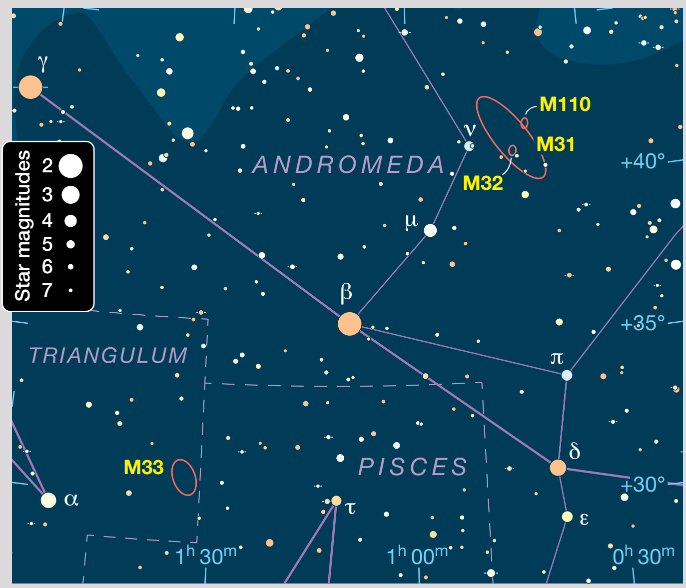
To observe the Andromeda Galaxy's clouds, you'll need transparent skies (a reading of at least 21 on a Sky Quality Meter, or Bortle 3); use lower-power, wide-angle eyepieces yielding a maximum exit pupil; and then look for faintly indistinct, glowing regions. Shake the nebulosity loose by moving your eye about the field every few seconds and by gently jiggling the scope occasionally.

In my 6-inch, I see the clouds as broad regions, while in my 25-inch f/2.6 (1.1° field) they appear as continuous streaks and daggers of similar sizes. But with my 30-inch, a wonderful new realm of detail comes into view — the clouds break up into puffs. Why? It's likely that the darker areas between the puffs are large enough in apparent size that the 30-inch can detect them. I estimate them to be roughly 5° to 10° in apparent length in the eyepiece.

I also note a fainter and thinner third spiral arm just outside the more dramatic second arm, as I've drawn in my sketch on page 57. In particular, the spiral arms display beautiful daggers and frills along their edges that I'd not seen before in my smaller scopes. These are difficult to pin down — it's like accounting for individual crests in the surf. Unexpectedly, I also find that I can trace the spiral arms in close to the nucleus.

Maybe what stands out most are the hues and colors. Patches near the nucleus look yellowish, while the surrounding Milky Way stars fill in the field of view in myriad colors. This all makes me wonder what views a larger, wide-field, very fast telescope of 40 inches or greater might provide.

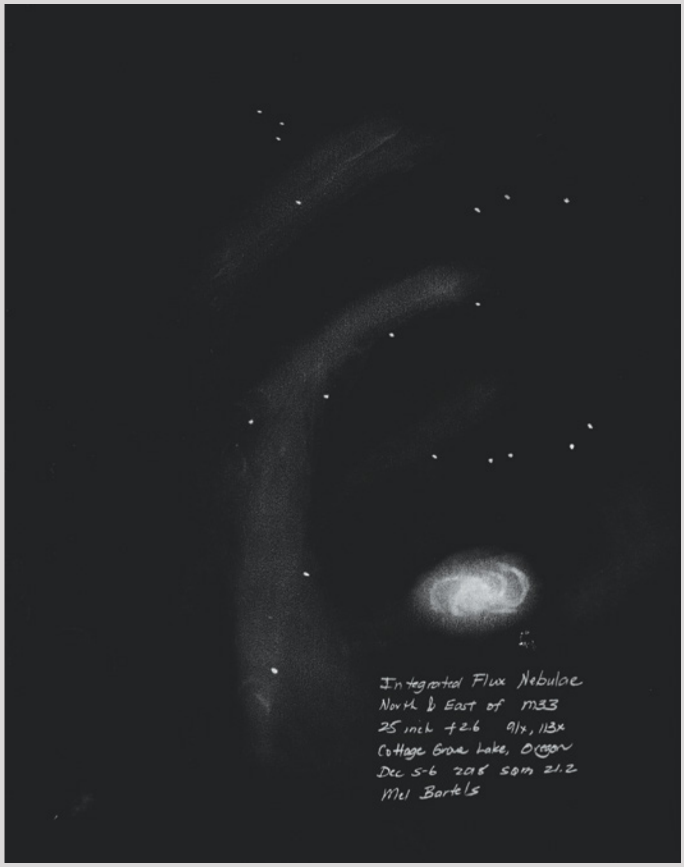
If at first you don't succeed, keep trying. The initial view is always the most difficult to feel confident in. Subsequent views build on visual memory, often making objects easier to see and adding more detail — sometimes even making them accessible in smaller scopes.



Observing and Sketching Tips

I use three exit pupils in my wide-angle viewing: a slightly oversized pupil (8 mm) that's surprisingly effective; a pupil matched to my eye (6.7 mm) that reveals more detail, but at the cost of reduced field size;

▲ **PECULIAR SATELLITE** The dwarf elliptical galaxy M110 surprisingly contains young stars and dust lanes that I can just detect in my 30-inch. On the other hand, I can see the nucleus much more readily.



▲ **HERSCHEL'S CLOUDS** The galactic cirrus (which I also refer to as *integrated flux nebulae* in my notes) that curves around M33, the Triangulum Galaxy, is likely Herschel's region number 11.

and, finally, a slightly undersized pupil (5.4 mm) that reveals finer detail but with a noticeably zoomed-in, narrower field. At higher magnifications, dozens of globular clusters, open clusters, star associations, and some individual stars within the Andromeda Galaxy come into view (see, e.g., Bob King's article in the December 2021 issue, page 57).

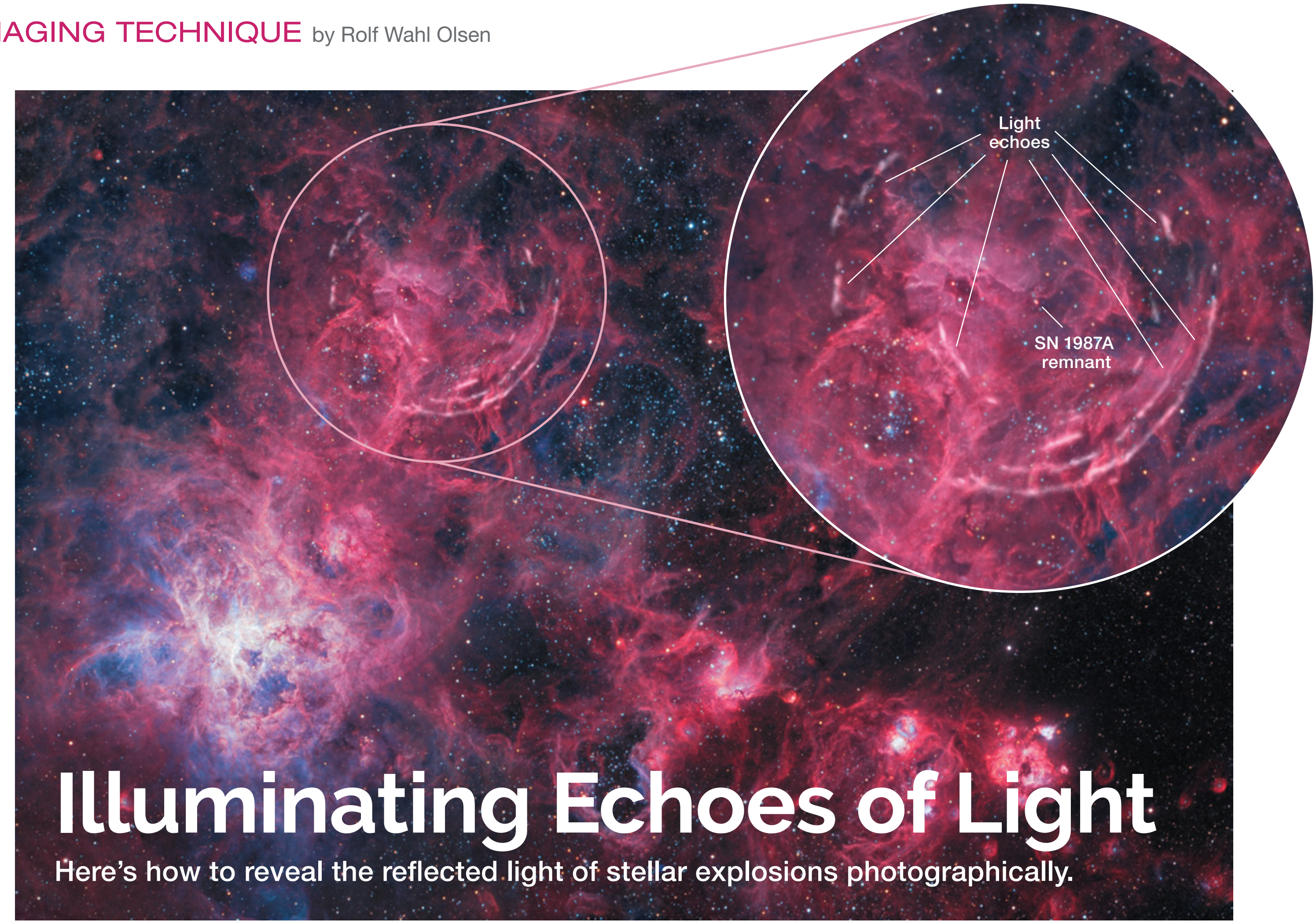
The factor that contributes most to detecting these clouds in the eyepiece is the combination of a large apparent field and a large exit pupil (limited by the eye's maximum pupil). Multiplying the two gives the light flux that flows into the eye — this is known as *étendue*. Maximizing étendue for a range of real field sizes calls for a series of fast telescopes of various apertures. Just as Caroline and William Herschel built a variety of telescopes and adjusted their observing tactics to best match their targets, I, too, use a sequence of telescopes, adjusting my telescope designs to better suit my observing and drawing methods.

To preserve dark adaptation and to spend as much time as possible at the eyepiece, I make a series of pen-on-white-paper markings accompanied by brief notes under very dim red light. To begin the final charcoal drawings (on white paper), I trace in the brighter stars using a software-generated printout of the field, since in this case I'm concentrating on the nebulosity, not the stars. Then I finish the drawing based on my observing notes and ink sketches.

There are always gaps and questions that require subsequent observations to address. My goal is the object and its context, not an arbitrary circular field of view. At some point I call the drawing done, scan it in as a high-resolution black-and-white graphic, and invert it. I then lower the contrast until the background begins to turn gray, bringing out a nice range of tonalities, hinting at the view through the eyepiece. I also find that photographing the drawing in natural lighting with my smartphone gives good results, though gradients can be an issue.

I can't resist returning to the Andromeda Galaxy each time I build a telescope, seeing something new and beautiful every time. I would love to observe Andromeda sideswiping the Milky Way several billions of years from now. In the meantime, I continue to observe from a distance of 2.5 million light-years, looking to encounter the sublime night after night.

■ After retiring a couple of years ago, **MEL BARTELS** moved to just outside a small town in Central Oregon, where he enjoys the truly dark skies that prevail there. Go to Mel's webpage for more on galactic cirrus: **https://is.gd/mel_bartels**.



Illuminating Echoes of Light

Here's how to reveal the reflected light of stellar explosions photographically.

The night sky often seems like a stable, unchanging tapestry of stars, nebulae, and distant galaxies. Occasionally some transient phenomenon like an eclipse or a bright comet graces our skies, reminding us that our vista is not entirely static. But some transient events play out over decades or even centuries, and, despite their ethereal nature, have an extraordinarily violent origin. These are light echoes, the glow of bygone novae or supernovae reflecting off interstellar dust and reaching us from afar long after the cataclysm was first visible.

On February 23, 1987, a star approximately 163,000 light-years away in the Large Magellanic Cloud (LMC) reached the end of its life and quickly became the brightest supernova visible in nearly 400 years, peaking at an apparent magnitude of 2.9 (*S&T:* Feb. 2017, p. 36). As the first supernova discovered that year, it was designated SN 1987A. This was the closest one observed since Kepler's Supernova in 1604. The progenitor star of the LMC explosion turned out to be the unassuming, 12th-magnitude star Sanduleak –69 202, a blue supergiant that astronomers determined ended its existence as a Type II, core-collapse supernova that produced a neutron star. It was the first time modern astronomers were able to study one in detail, and their observations have provided significant insight into the deaths of such stars.

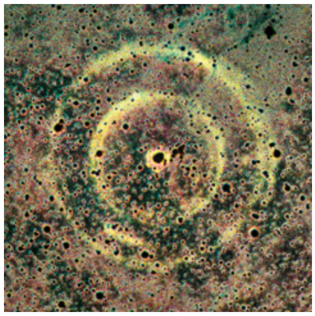
▲ **HIDDEN LIGHT** Supernova SN 1987A exploded in a region loaded with dust and gas near the Tarantula Nebula (NGC 2070), permitting amateur Rolf Olsen to record its faint light echo fully 33 years after the initial event. The above image is thought to be the first amateur detection of the echoes. It was made using images taken eight years apart and added to a deep narrowband color image of the region.

Late Reflections

In 1987, I was just an 11-year-old boy with a keen interest in astronomy growing up in Denmark, where SN 1987A was permanently below the horizon. I've always wished that I could have seen this remarkable event with my own eyes.

But two things occurred that enabled me to "see" the light of this event. In 2003 I relocated to New Zealand and its excellent view of the Southern Hemisphere skies. There I ventured into the world of astrophotography and concentrated on taking extremely deep images of this night sky (*S&T:* Feb. 2022, p. 60). Using the incredible sensitivity of my CCD detector, I found that recording the light from this historical supernova is now entirely possible! Thanks to a phenomenon known as *light echoes*, we are still able to witness the light from a supernova even long after it has passed.

Light echoes are analogous to audio echoes produced when sound waves reflect off of solid objects. With a large enough distance between the origin of the sound and the observer, the sound from the event arrives noticeably later. In 1940 the prolific Swiss astronomer Fritz Zwicky proposed the existence of supernovae light echoes when he suggested that light from historical supernovae could still be seen as faint echoes long after the initial explosion. Light echoes are produced when the initial flash from a bright source, such as a supernova, expands outward in all directions. Some of this light is reflected off of dust clouds in interstellar space. A small part of that reflected light is directed towards Earth and can be seen years or even decades later as faint arcs of light surrounding the site of the original explosion.



◀ **LIGHT RIPPLE** The light from SN 1987A faded as it expanded through the surrounding nebulous field, requiring innovative processing techniques to monitor its progress. This image shows the result of placing a negative of the region recorded before the supernova exploded over a positive photograph recorded in June 1989. The result highlights anything that appears in only one of the frames.

A Long Gap between Observations

While photographing the Tarantula Nebula (NGC 2070) in the LMC a few years ago, I recalled having some image data of the same target recorded eight years earlier. This rekindled my fascination with SN 1987A, and I decided to test to see if light echoes from the supernova might be visible with my modest amateur equipment.

Astronomers had detected echoes of this famous explosion previously at large observatories. The first to do so was Michael Rosa on February 13, 1988, with the European Southern Observatory's 3.6-meter telescope. Later, astrophotography pioneer David Malin produced a spectacular color image of these faint, luminous shells in 1989 while working at the Anglo-Australian Observatory (now the Australian Astronomical Observatory). But to my knowledge, no amateur detection had ever been noted. I considered the possibility that, more than three decades later, the echoes may no longer be visible, but I decided to compare my 2020 observations with the data taken eight years earlier anyway.

A Surprising Result

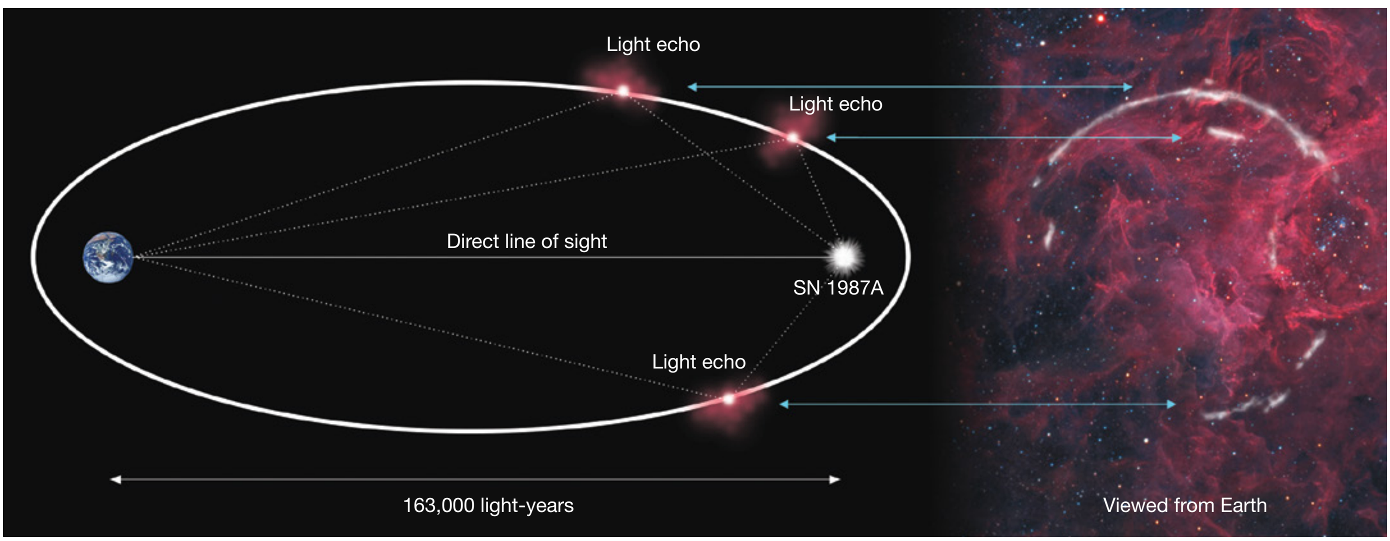
Inspiration for this project came in part from a technique I had applied in 2011 to make the first amateur detection of the circumstellar disc around the relatively nearby star Beta Pictoris (*S&T:* Aug. 2013, p. 72). In that case, the challenge was to eliminate the overwhelming glare from the star itself in order to reveal its faint, edge-on debris disk. To do so, I photographed both Beta and a similar reference star under the same conditions. The two images were then aligned, and the reference star image was subtracted from the target image to eliminate the glare of Beta Pictoris, revealing the star's dusty disk.

I achieved the detection of light echoes from SN 1987A in a similar way, this time by using two images of the same target recorded eight years apart.

Although the instruments used to record the two data sets were slightly different (I used a 10-inch f/5 Newtonian telescope in 2012 and a 12.5-inch f/4 Newtonian reflector in 2020), the difference in resolution was minor. I was still using same QSI683 CCD camera and Astrodon LRGB filters. Exposure times in both cases were just over one hour through the luminance filter, which blocks near-infrared light.

To create this image, I first aligned the 2012 image exactly to the 2020 image, using star alignment in *PixInsight*, though any astronomical image-processing software that can align star-field images will work. Afterwards, the two images were

▼ **ECHO GEOMETRY** The initial flash from SN 1987A arrived first, via direct line of sight. Light scattered from intervening dust clouds reaches Earth later along different paths. All the reflected light rays that arrive at Earth together will have travelled exactly the same distance. The possible light paths between SN 1987A and Earth correspond to reflections on an ellipsoid, with Earth and the supernova at its focal points.



SN 1987A: A-AO / DAVID MALIN

background subtracted (consecutively recorded images are subtracted from each other) to ensure the best possible comparison and to (hopefully) allow the detection of any differences between the two images, such as faint arcs from the light echoes. This didn't reveal anything of note.

I then subtracted the 2020 image from the 2012 image using the ***PixelMath*** process in *PixInsight*, in order to reveal any brightness difference that might have occurred over the eight years. At first, all I was presented with was a bland, gray image, but when I stretched the result, I was surprised to see very large and prominent arcs — the light echoes I sought!

These features appear as concentric light and dark arcs centered on the precise location of SN 1987A. The light and dark tones are simply an artifact of the order in which the images are subtracted. However, the spaces between the light-and-dark arcs clearly reveal how much the echoes have expanded during the intervening eight years between the two sets of images. The result shows what is possibly the first amateur detection of light echoes from SN 1987A — fully 33 years after the event.

To present the light echoes in the beautiful context of the sprawling clouds of the LMC, I then acquired a substantial amount of narrowband image data in 2021 and used that to create a deep, colorful picture of the region's complex gas clouds. The broadband light echoes were then composited onto this to achieve the result seen on page 60.

The full-size image is a mosaic of two deep fields centered near the bright Tarantula Nebula in the LMC. The field is filled with numerous bright, colorful nebulae and star clusters. At the LMC's distance of 163,000 light-years, the field of view seen here spans a massive 2,917 by 2,000 light-years. At this large scale, the nebulosity seems to feature many bubble-shaped voids of different sizes. These are formed by the radiation pressure from young star-forming regions and shock waves from ancient supernovae. The small but comparatively recent remnant of SN 1987A is also visible as a tiny pink dot at the focal point of the light-echo arcs.

◀ **INNOVATIVE AMATEUR** Author Rolf Olsen and his 12-inch astrograph

I acquired all the image data from my observatory in outer suburban Auckland, New Zealand. I used my 12½-inch telescope to acquire the wider, narrowband context photo of the Tarantula Nebula and surrounding area in early 2021. This is a deep, bi-color image comprising 7 hours and 15 minutes worth of exposures through hydrogen-alpha and oxygen III filters, totaling 14.5 hours.

Superluminal Illusion

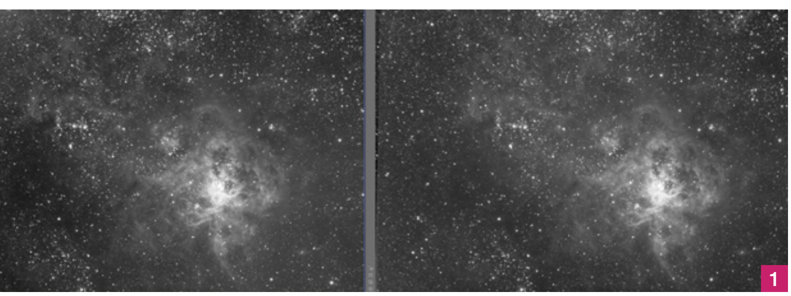
The light echoes from the supernova appear to be moving outwards faster than the speed of light, something that is physically impossible but often observed in phenomena that move close to our line of sight. This effect is most often associated with relativistic jets of matter ejected from active galactic nuclei — for example, the jet emitted by the supermassive black hole in the center of elliptical galaxy Messier 87 in Virgo.

Using the formula $s = d \times v$, we can calculate the angular speed of motion of the light echoes across the sky, as apparent speed (s) equals distance to object (d) times angular velocity (v).

Between 2012 and 2020, the brightest arc had expanded outwards by approximately 47 pixels. With an image resolution of 0.764 arcseconds per pixel, this corresponds to a movement of 4.49 arcseconds per year (47 × 0.764 ÷ 8). At the distance of the LMC, this equates to around 28 light-years in 8 years — 3½ times the speed of light! So how is that possible?

This apparent superluminal speed is in fact an optical illusion and doesn't represent the actual speed of the outward travelling sphere of light, which is, of course, moving at 299,792

▼▶ **PIXEL MATH** Subtracting one image from another in order to generate a difference image is easy to do in any astronomical image-processing software. *1:* Begin by opening the two images and aligning them together. 2: Next, use the *PixelMath* function to subtract one image from the other (seen here in *PixInsight*). The result will most likely look gray until you stretch the data (3). Anything not found in both images will appear either black or white. Stars appear as black spots with white halos due to the difference in star sizes between the two pictures.



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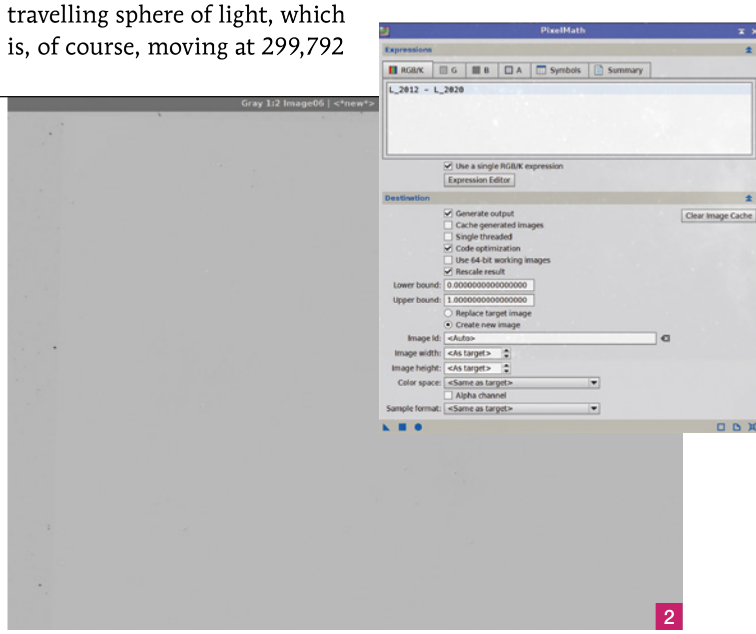


2

kilometers per second. This interpretation fails to consider that when measuring the apparent motion of distant objects across the sky, they aren't often moving perpendicular to our line of sight. The light bouncing off dust clouds at various distances has travelled farther than the light coming directly from the supernova itself, but the dust clouds aren't located at the same distance as the explosion — a simple trick of perspective that produces the faster-than-light illusion. A similar phenomenon is seen in the expanding light echo surrounding V838 Monoceros, which underwent a nova outburst in 2002.

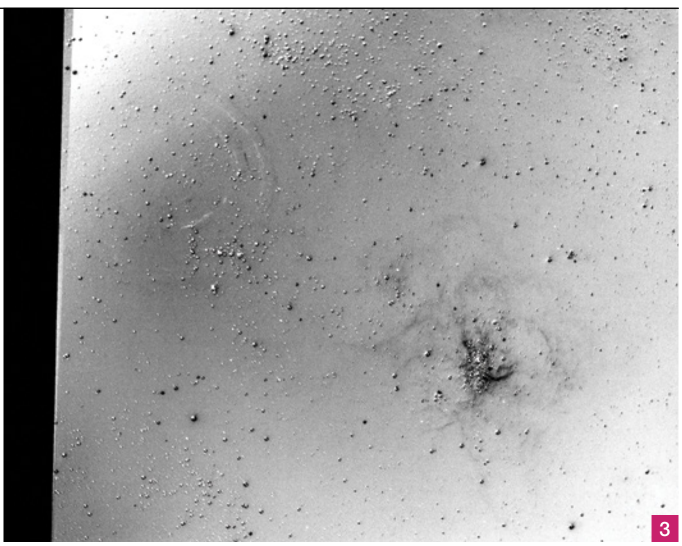
Other Applications

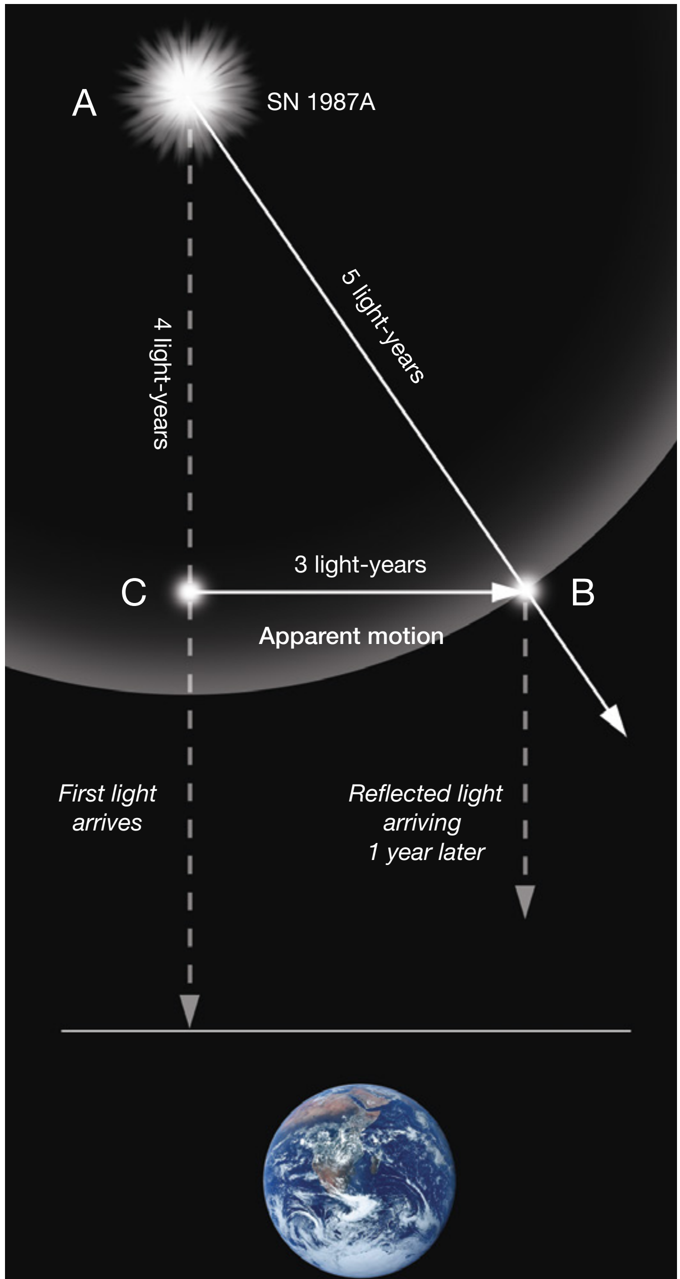
Astronomers have used this same imaging technique to discover several light echoes in the LMC from previously unknown ancient supernovae. It's even possible to acquire spectra of these light echoes to study the type of supernova, centuries after the direct light would have first reached Earth. These discoveries were a byproduct of the SuperMACHO Microlensing Survey, which looks for evidence of dark matter using the same image-subtraction technique to detect transient distortions in the light of individual stars.

Such light echoes are also helpful for measuring the structure of the interstellar medium, because the dust and gas in space are cold and dark. When a supernova explodes, its expanding flash illuminates the surrounding clouds, providing astronomers with a three-dimensional "scan" of otherwise invisible structures between us and the dying star.

This subtraction technique can also be used in search of light echoes from novae and supernovae in Northern Hemisphere skies. While most are extremely faint and require large instruments to record, photographing them may be an interesting project for imagers with fast astrographs, sensitive cameras, and datasets spread over multiple years. Who knows what might turn up?

■ **ROLF WAHL OLSEN** images the night sky from his backyard observatory in the outskirts of Auckland, New Zealand.

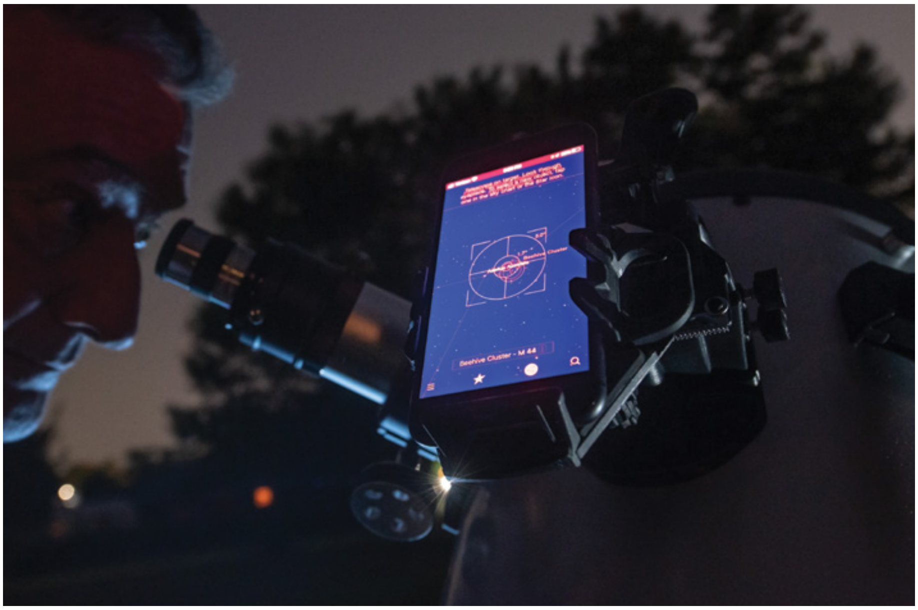




SUPERLUMINAL ILLUSION The flash from SN 1987A is an expanding sphere that illuminates interstellar dust clouds as it travels outwards. Though it appears to move faster than the speed of light, the light paths are illustrated here using a Pythagorean triangle of 3, 4, and 5 light-years, respectively. The initial flash (A) is observed at Earth coming along the direct line of sight (C). When the flash is scattered by interstellar dust (B), some of that light is reflected towards us along a slightly different line of sight. The light path from point A to B is only one light-year longer than the direct line of sight, but its proximity to us gives the false appearance of having traveled 3 light-years in one year, or three times the speed of light.

Celestron's StarSense Explorer 10-inch Dobsonian

This scope offers good optics and one of the easiest sky-alignment routines to date.



▲ Celestron's StarSense Explorer 10-inch Dob comes with a spring-clamped dock to accommodate a wide range of smartphones. The phone's onboard camera is used with the *StarSense Explorer* app to precisely navigate to a multitude of celestial sights.

ALL PHOTOS BY THE AUTHOR

StarSense Explorer 10" Smartphone App-Enabled Dobsonian Telescope

U.S. Price: $1,099.95
celestron.com

What We Like

Reliable, accurate pointing

Easy daytime Go To alignment

What We Don't Like

Azimuth tension hard to adjust

Red-dot finder awkward to use

AMATEUR ASTRONOMERS HAVE increasingly turned to smartphone planetarium apps as their sky guides at the telescope. Since smartphones always know the local time and geographical location, the apps are immediately in tune with what's visible overhead each night. But a new app and hardware from Celestron call on another, more recent feature in order to directly link its telescopes with the night sky.

Celestron's StarSense Explorer telescope series uses the phone's camera to image the sky. It then quickly analyzes the star field to determine exactly where the telescope is pointing (a process known as *plate solving*). Celestron has been perfecting this technology for about a decade; early StarSense devices used a built-in camera with a wide-angle lens to help automate the Go To alignment routine (*S&T:* Mar. 2013, p. 62).

Since then, the StarSense Explorer system has grown in leaps and bounds. It now needs only its docking mechanism to attach your phone to the telescope and Celestron's *StarSense Explorer* app to make your smartphone "smart" about what's overhead and where it's to be found (*S&T:* Aug. 2020, p. 64).

The company now offers this powerful system with two Dobsonian telescope models, each having generous aperture. I borrowed a StarSense Explorer 10-inch Smartphone App-Enabled Dobsonian Telescope to see just how far the technology has evolved.

Out of the Box

The StarSense Explorer 10-inch Dobsonian is the first fairly large Dob Celestron has produced in many years, and it includes a number of well-thought-out features that make its use in the field easy and intuitive. The scope arrived in two boxes, one containing the optical tube assembly (OTA) and StarSense dock, and the other the Dobsonian mount base. Some assembly is required — the 12-kilogram (26-pound) rocker box took about 45 minutes to assemble with the provided tools.

The base has three rubber feet that raise the base 3.8 centimeters (1½ inches) off the ground. Once assembled, the rocker box is pretty solid, with smooth motions in both axes. An included metal eyepiece rack attaches to one of the side boards and accommodates one 2-inch and three 1¼-inch eyepieces. (See page 72 for a clever improvement to this rack.)

The scope's 18-cm-diameter altitude bearings come attached to the tube and ride on two plastic "altitude bearing cylinders" located on the inside of the rocker-box side boards. Each bearing accepts an included threaded knob, though be sure to install the "altitude tensioning knob" on the focuser side of the tube as the other knob is simply cosmetic. I often found myself adjusting the tension to compensate for balance issues that arose when using eyepieces of different weights.

The OTA is a 10-inch f/4.7 Newtonian reflector shipped with "Pyrex-equivalent" primary and secondary mirrors in place. The scope required only a slight tweak in collimation to bring the optics into alignment. The 112-cm-long rolled-steel tube is reinforced with cast aluminum rings at both ends, the bottom one being integrated with the primary mirror cell. The 13-kg OTA also sports a 2-inch, Crayford-style focuser that comes with a 2-inch extension tube to bring eyepieces to focus. A 1¼-inch adapter is included as is a 1¼-inch, 25-mm Plössl eyepiece yielding 48× with this instrument. The eyepiece is 112 cm above the ground when the scope is pointed at the zenith.

The mirror cell leaves much of the back of the mirror exposed, which helps allow the mirror to reach thermal equilibrium. Celestron offers an optional USB-powered cooling fan for $24.95 to speed the process. Three knurled knobs on the mirror cell align the primary, and three smaller knurled knobs lock the mirror cell in place. A small plastic "panning knob" protrudes from the upper tube below the focuser and serves as a convenient handhold for both moving the scope while observing and, along with a second handle on top of the tube between the altitude bearings, for removing the OTA from the rocker box.

A small, unit-power red-dot finder is included, but given the high pointing accuracy of the StarSense system, it's really only needed if you choose to observe without using the smartphone app. The finder is awkwardly located on the opposite side of the OTA from the focuser, so using it means walking around to the other side of the scope, but I expect most owners of this scope will rarely need it anyway.

The azimuth movement of the StarSense 10-inch Dob is typical of mass-produced Dobsonians: The rocker box rotates around a central bolt that secures it to the ground board. Finessing the azimuth tension requires accessing this bolt — a not-so-simple task that, thankfully, isn't needed often. Adjusting the tension requires two wrenches, one on the bolt head on the underside of the ground board, and another for the nut on top. A captive bolt, perhaps a carriage bolt, on the ground board with a knob on top instead of the nut would be much easier to work in the field.

◀ Both the tube assembly and the Dobsonian rocker box have convenient handles, making it an easy task to carry both sections in a single trip. Note the panning handle near the front aperture of the OTA.

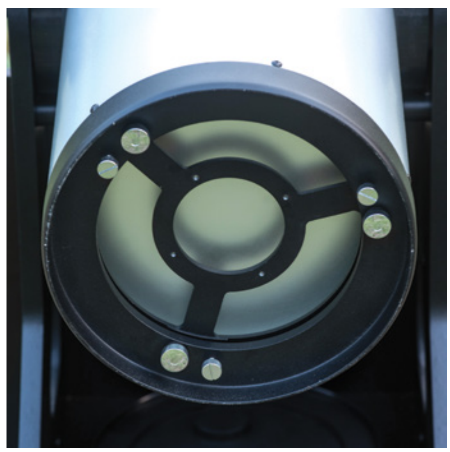
Optical Performance

The StarSense Explorer system is impressive, and it certainly helped that the views through the scope are pleasing. A 10-inch aperture provides a lot of resolving power — lunar and planetary details appeared sharp at high powers when the seeing cooperated, and even

▼ This view of the front of the telescope shows the red-dot finder, StarSense Explorer dock, and 2-inch focuser. Note that the smartphone dock takes the location adjacent to the eyepiece usually reserved for a finderscope.

▼ The scope's 2-inch focuser is a smooth-operating, Crayford-style model with a drawtube extension and a 1¼-inch eyepiece adapter. A 25-mm Plössl eyepiece is also included.

▼ The primary mirror cell is open in the back, exposing the rear surface of the mirror, which helps it reach ambient temperature. Both the primary and secondary mirrors are made of what Celestron describes as "Pyrex-equivalent" glass.



deep-sky objects started to reveal small-scale detail. Using a Tele Vue Nagler 12-mm eyepiece (100×), globular clusters M13 and M22 were easily resolved into myriad stars all the way to their cores. Bright galaxies M81 and M82 began to look like individual galaxies rather than the vague, amorphous glows presented through smaller apertures.

The f/4.7 parabolic mirror is a focal ratio that is long enough that coma isn't very noticeable except at the extreme edge of the field of view. Star images on either side of focus were identical as I racked through focus.

◀ *Top:* Each of the 18-cm-diameter plastic altitude bearings on the OTA has a tension-adjustment knob on a threaded bolt, surrounded by a smooth plastic bushing that drops into slots on top of the rocker box. *Bottom:* Two plastic knobs mounted inside on both sides of the rocker box uprights form the bearing surfaces for smooth altitude motion.

The Ease of StarSense

The StarSense Explorer 10-inch Dobsonian is a good telescope, but what sets it apart from the pack is its clever StarSense dock. This plastic smartphone cradle attaches to a mounting foot near the focuser, where a finder is typically located. The dock contains a rectangular mirror that faces skyward at a 45° angle from your smartphone's camera. The phone is held in place with a spring-loaded clamp, and its position is adjustable in three axes to allow the phone's camera to take in the maximum area of sky. The dock itself attaches to the scope with a tapered dovetail and is secured with two locking thumbscrews to ensure repeatable alignment. A removable cover protects the mirror when the dock is not in use.

After assembling the telescope and aligning the red-dot finder, I downloaded the *StarSense Explorer* app from the iOS App Store for my iPhone 8. (Android users can get the app from the Google Play site.)

When first opened, the unique unlock code on a provided card needs to be input. (You can install the app on up to five devices with the same code.) Next, the app tells you to "center camera over mirror," which is done by adjusting the knobs on the dock until you can see as much sky as possible on your phone's screen. When satisfied with the view, tap Next to enter the pointing alignment mode. Forget about a typical multi-star alignment, or even the single-star alignment routine originally required with the first StarSense Explorer scopes we reviewed in 2020. Simply aim the scope at a distant terrestrial object (such as a treetop or building) and center it in the eyepiece. You then drag the app's on-screen crosshairs until they're on top of your target and tap Done. That's it — you're ready to observe! This initial alignment can conveniently be performed any time, day or night. The alignment doesn't need to be done again unless you change the position of the phone in the dock, or switch smartphones.

You'll need a fairly large, unobstructed swath of sky overhead for the app to get its bearings. Buildings or trees blocking large portions of the sky can prevent *StarSense Explorer* from successfully plate solving. It also needs to be rather dark before the app can recognize stars in the images recorded with the phone's camera. StarSense was able to recognize fields with bright stars overhead by the start of nautical twilight, but not much earlier. Likewise, searching for an object that may be washed out by a bright Moon sometimes triggered an onscreen warning about moonlight.

Pointing the telescope skyward after alignment brings up a pleasing graphical view of the sky, similar to the one in the *SkySafari* planetarium app. (Simulation Curriculum, the same company behind *SkySafari*, developed the Celestron app.) *StarSense Explorer* contains the entire Messier and Caldwell catalogs in the app's "common objects lists," plus thousands of objects in the Abell, Barnard, Sharpless, NGC, PGC, IC, and UGC catalogs.

Tapping the star on the bottom of the app screen opens a list of "tonight's best objects" and tells you if the object is "city viewable" or "dark sky viewable." Each object in the list is also circled in blue on the sky chart. Tapping on an entry in the list brings up plenty of other information, and for many objects there's a calmly narrated audio description. Tap on the "locate" icon and within moments a message pops up

▲ *Left:* A tapered dovetail interface attaches the StarSense Explorer dock securely to the permanently attached mounting foot on the 10-inch StarSense Explorer Dob. *Right:* The author's iPhone 8 is mounted with its lens aimed into the dock's mirror. Three precision rack-and-pinion motions in the dock allow the precise positioning of a wide range of smartphones.

telling you the new target location has been found, and a line of arrows directing you to your target's position appears on the sky map. Just push the telescope in the direction of the onscreen arrows, and as you get closer to the target the arrows shrink while the screen zooms in, allowing increased precision with a tighter field overlaid with crosshairs and circles representing 5° and 1.7°. When you've reached your target, the crosshairs turn green, and the app tells you to look through the eyepiece. And just as it states, the target object was visible in the central ⅓ of the field.

Moving the scope to the opposite part of the sky automatically makes the app re-do the plate solve, which it often did in just a few seconds. You then choose your target, and the on-screen arrows appear again to guide you.

Your phone doesn't need an Internet connection for StarSense Explorer to work. However, given that the app is constantly taking photos, you'll want to make sure your phone battery is fully charged at the start of the night. On my first night out with the scope, my 30%-charged iPhone 8 battery didn't last long. Fortunately, the dock leaves the phone charging port easily accessible if you need to plug in an auxiliary external battery. Celestron recommends plugging your phone into a portable power source (such as its own PowerTank Lithium LT) to ensure you don't drain its battery before you're ready to pack it in for the night.

A Winning Combination

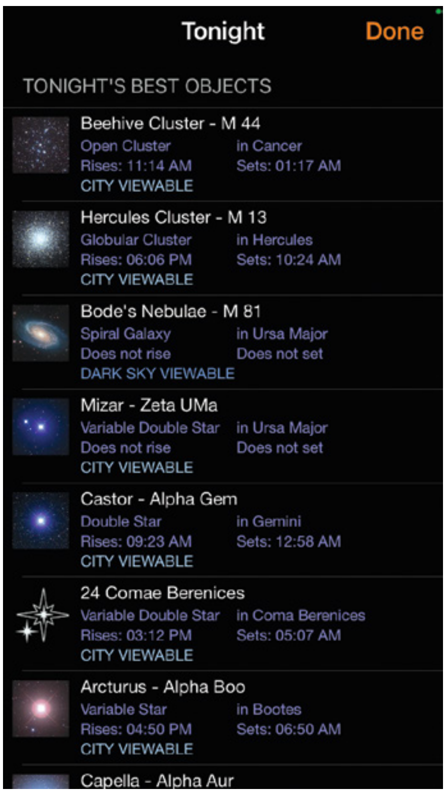
While using the StarSense Explorer 10-inch Dobsonian, I couldn't help but feel the scope represented a new era in amateur astronomy. This app-powered system is easy to set up, accurate, and affordable. Consider what all of this might mean for beginners who can now easily find their way around the sky. StarSense Explorer creates a direct connection between the observer, the telescope, and the sky overhead.

For more seasoned observers in the market for a mid-sized Dobsonian, the StarSense fulfills that role quite nicely. The scope offers 10 inches of aperture but is still portable enough and sufficiently lightweight for a single user to easily set up and enjoy. Mated with the technology of StarSense, Celestron has created a reliable system that doesn't require any additional accessories besides the phone you already own.

I knew if I used the StarSense Dob long enough, something entirely predictable would happen. One night, as I was gazing into the core of M13, my phone rang. I let the caller leave a message while I continued to enjoy the view.

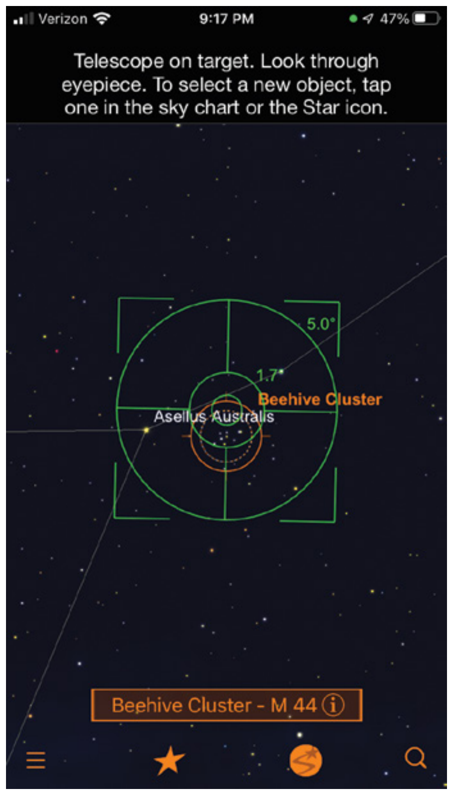
■ Longtime amateur **JOHNNY HORNE** isn't sure he needs another telescope, but a newer phone would be nice.

▼ Tapping the star icon at the bottom of the main screen brings up a list of the best objects currently visible. Among the basic information for each object is a note on whether it's visible from the city or only from a dark-sky location.



▼ After you choose a target, the app displays a series of arrows leading to the selected object. Simply push the scope in the direction of the arrows, and the view will zoom into your target as you approach the field.

▼ The app alerts you when you've found your target and to look through the eyepiece. You can also click on the object name at the bottom of the screen to bring up additional information and audio content.



◀ COOLING ADD-ON

Player One Astronomy announces an accessory cooling unit for its line of high-speed cameras. Retailing for $49.00, the ACS (Active Cooling System) connects to the rear plate of certain Player One solar or planetary imaging cameras. The device contains a heat sink and a magnetic levitation fan that together help to lower the temperature of the camera's sensor. This reduces the thermal noise generated in its solar cameras as well as some of the company's planetary cameras when used for deep-sky images requiring long exposures. The device connects to the rear of your camera's housing with four long M 2.5 x 40 screws that replace four on the rear of the camera housing. The ACS is powered through a 2.1-mm, center-positive 12-volt, 3-amp DC power port (power supply not included), and a dial on the side adjusts the fan speed. A 5.5-to-2.1-mm splitter cable and 30-mm-square thermal pad are included with purchase. Be sure to check that your camera model has passive cooling before ordering.

Player One Astronomy
Room 522, Bldg. 1, maslong Bldg., 168 Yuxin Road, Suzhou, China
player-one-astronomy.com

◀ 6-INCH ASTROGRAPH

Meade now offers a compact astrograph system for budding imagers. The Meade 6″ f/4.1 LX85 Astrograph Reflector Telescope ($1,999.99) is a scope-and-mount combination that's designed for both visual observing and astrophotography. The OTA is a 6-inch Newtonian reflector having a BK-7 glass parabolic primary mirror with a focal length of 610 mm. The scope includes a 2-inch, dual-speed, Crayford-style focuser with linear bearings. The mount is Meade's LX85 German Equatorial Go To model operated with its AudioStar hand controller, with more than 30,000 objects in its database. Each purchase includes a 26-mm Super Plössl eyepiece, a 2-to-1¼-inch eyepiece adapter with brass compression rings, 2-inch eyepiece extension tube, 8 × 50 finderscope, dual mounting rings, and 9-pound counterweight. A 12V DC power source (not included) is required.

Meade
89 Hangar Way, Watsonville, CA 95076
800-626-3233; meade.com

◀ 2024 ECLIPSE BOOK

Umbraphile Gordon Telepun has published his e-book *Eclipse Day 2024 and More! How to Enjoy, Observe, and Photograph A Total Solar Eclipse* ($7.99). This comprehensive guide to the upcoming North American total solar eclipse takes a different approach than others. Its 28 chapters follow the progression of the eclipse throughout the day, with important science and visual phenomena occurring at each of these points in the order they occur. This interactive e-book is filled with hundreds of color photographs and illustrations as well as embedded videos and audio files. *Eclipse Day 2024 and More!* is available from the Apple and Google bookstores or as a PDF download from the author's website. A companion *Solar Eclipse Timer* app ($1.99) is available on the Android Play and Apple App stores.

Eclipse Day 2024 and More!
solareclipsetimer.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.*

Soul of a New Machine

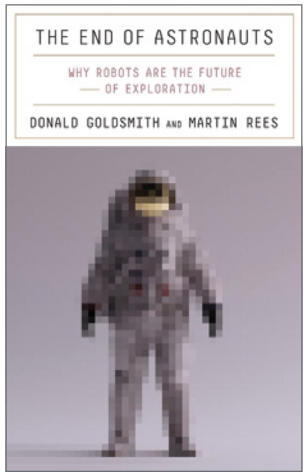
THE END OF ASTRONAUTS: *Why Robots Are the Future of Exploration*

Donald Goldsmith and Martin Rees
The Belknap Press of Harvard University Press, 2022
185 pages, ISBN 9780674257726
US$25.95, hardcover

"THE ARGUMENTS IN this book point to one striking conclusion," write the authors of *The End of Astronauts*. "We do not need astronauts as space explorers." Their reasoning for using robots over people is rational, sane, and authoritative — what you'd expect from the U.K.'s Astronomer Royal (Rees) and a well-respected astrophysicist-author (Goldsmith). So it's worth hearing them out, even if your initial reaction to the title is, "No more astronauts? What are you thinking?"

Goldsmith and Rees answer that question methodically. For starters, they claim that machines' abilities are rapidly converging on ours. In the coming decades, they write, "robots and artificial intelligence will grow vastly more capable, closing the gap with human capabilities and surpassing them in ever more domains." (Curiously, elsewhere in the book they conclude, "Although our robots will continue to increase their artificial intelligence, no one knows when, if ever, they can match us humans . . ." Such uncertainty, though understandable, undermines their case.)

Another reason for androids over humanoids: Using inanimate explorers lessens the chance that we'll inadvertently contaminate another world. Even people-less missions carry risks if we're not careful. The authors cite the fate of Israel's Beresheet spacecraft, which failed on approach and crashed into the Moon — along with a few thousand tardigrades it held. What if those micro-animals, one of Earth's hardiest organisms, somehow established themselves?



The authors are succinct when it comes to their two primary reasons to use automatons over us: "We cost far more than robots to maintain, and we expect to return home." Astronaut missions to Mars, at least over the next two decades, will cost roughly 50 times more than if we rely on rovers and other non-human explorers, they estimate. Missions beyond Mars have always used machines, and we've seen spectacular results from Cassini at Saturn, New Horizons at Pluto, and many other mechanical missions.

Safety concerns may loom largest of all. As the authors observe, when it comes to radiation dose, one day in space equals a year on Earth, and myriad other potential dangers threaten our fragile bodies out there. Psychological threats are even harder to gauge. In pondering the human-vs-machine question, we need to consider not only the physical challenges of long journeys, the authors state, "but also the human psyche, in some ways a more difficult proposition." At about six months, a Mars trip is 50 times longer than one to the Moon — and that's just one-way. Until we actually undertake such an extended mission, we can't reliably gauge how astronauts will respond to the increased isolation and monotony, much less to what some have called the "Earth-out-of-view" effect. Robots, of course, couldn't care less.

This brings us to what many will deem the principal argument against the authors' stance: the emotional component. Rees and Goldsmith acknowledge that astronaut missions "make us feel better, more connected, and more engaged in our success as a country, perhaps as a civilization." They admit that the first Moon landing, as well as the Space Shuttle disasters of 1986 and 2003, moved us much more deeply than the success or loss of any automated missions have.

The authors do make an interesting point that younger generations might be more accepting than older ones of robotic missions, given their greater familiarity with virtual reality and corresponding enhanced ability to "project themselves mentally to other worlds without losing sight of where they are." They also remind us that we may soon be entering an era of "technological evolution of intelligent beings." Operating a thousand times faster than Darwinian selection, designing certain robotic elements into people will generate diverse varieties of "post-humans" — developments they consider "entirely likely" within the next few centuries.

Thus, not only may robots be converging on us, but we on them. Yet when it comes to impassioned feedback during exploration, like Apollo 17 astronaut Harrison Schmitt's radioed response the moment he discovered orange soil on the Moon — "It's all over! Orange!" — most would likely agree that never the twain shall meet.

■ Editor in Chief **PETER TYSON** admits a bias toward hoping one day to hear the reaction of the first human being to step onto the surface of Mars.

The No-Dew Eyepiece Rack

Prevent your eyepieces from prematurely dewing.

AT A RECENT STAR PARTY, Lauren Wingert (*S&T*: July 2021, p. 72) asked me, "What's the most useless part of a conventional Dobsonian telescope?" I wondered if that was a trick question, especially when she answered it for me: "The eyepiece rack!"

The eyepiece rack? Seems pretty useful to me. But I only take my classic Dob out for a few minutes in the driveway when I want to grab a quick look at something. Otherwise, I set up one of my trackballs, which don't have eyepiece racks.

The reason for Lauren's question became apparent within minutes after we set up on a green, well-watered lawn. Dew! Any eyepieces on a rack would dew up in synchrony with the telescope tube, long before the internal mirrors.

Except for the ones on Lauren's eyepiece rack, which was not, in fact, even evident once I began to look for it. What I saw instead was a smooth panel that folded down over the eyepieces — a panel that was already collecting dew on the upper surface. Lauren swung it upward, and I saw four pristine lenses peering up at me, nary a molecule of moisture on any of them.

▶ The parts are simplicity itself: a plastic tray, a wire, two shoulder washers, and two hinges.

The panel is a repurposed disposable food serving tray. Lauren says, "The hardest part of this whole project was sorting through the hundreds of options for one the right size and shape."

Once she found the ideal tray, she bolted a couple of small cable clamps to its underside and ran a stiff wire through them, wrapping the wire ends around screws that went into the edges of the altitude rocker boards. The tray pivots up and down on the cable-clamp hinges, resting at an angle against the eyepieces and providing shielding all the way down to their bases when lowered.

3D-printed shoulder washers on the sides prevent the tray from binding on the rocker boards and keep it from sliding left or right. The whole works looks like a commercial aftermarket add-on, not a home-built one-off.

Lauren's design might be considered the deluxe model. I tried a low-tech version of it on my own scope, taping a flap of neoprene foam over the eyepieces, and that worked well, too. I also tried the cut-off end of a cereal box, and while that's about as inelegant as you can get and must be lifted completely

▲ *Left:* A simple cover over the eyepieces prevents dew from forming on them. *Right:* The cover lifts up to allow access to the eyepieces.

ALL IMAGES COURTESY OF LAUREN WINGERT

free every time you change out eyepieces, it also keeps the dew off.

What about eyepieces that dew up in the focuser? Will they un-dew under the shield? It takes a while if you're just counting on evaporation, but that can be accelerated by placing chemical hand-warmers next to the dewy eyepiece. They'll warm it up nicely, and when you put it back into service it'll stay dew-free for quite a while.

Lauren came up with a different system for her 13-inch Zip Dob. She sets the telescope's ground ring on a low table in order to bring the focuser up to a convenient observing height, so she built a drawer under the tabletop to house her eyepieces and filters. They stay warm and dry inside the drawer, their combined thermal mass providing all the heat necessary to un-dew a wet eyepiece when it's placed in with the others. If they ever do become overwhelmed, a chemical hand-warmer would work fine in the drawer, too.

Keeping eyepieces dry has been the bane of observers since the dawn of telescopes over 400 years ago. Lauren has tackled that problem head-on with two of the best solutions I've seen yet.

■ Contributing Editor **JERRY OLTION** had been using a hair dryer to un-dew his eyepieces, but he's now thinking preemptively.

▲ A drawer beneath the observing table keeps Lauren's eyepieces warm and dry when she's using her Zip Dob.

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What Is a Dobsonian?

YOU DON'T HAVE TO spend much time hanging around astronomy enthusiasts before you hear someone mention a "Dobsonian" or "Dob." They're easily one of the most popular kinds of telescopes, and for good reasons. The best examples combine gosh-wow views of the night sky with remarkable ease of use. But what exactly is a Dob, and how is it different from other scopes?

The Dobsonian is named after its inventor, the late John Dobson. A colorful character and gifted tinkerer, Dobson spent many years as a Vedantan monk in a California monastery before cofounding the San Francisco Sidewalk Astronomers in 1968. Having taken a vow of poverty, Dobson learned to do a lot with very little and figured out how to make a big instrument on a (frayed) shoe-string budget. Ironically, Dobson wasn't much interested in telescopes, commenting "telescopes are a means to an end for me." What really animated him was a desire to show the universe in all its glory to the public. To do that, he needed a portable, low-cost instrument with plenty of light-gathering power. The result was the telescope that eventually came to bear his name.

So, what makes a Dob a *Dob?* At its core, a Dobsonian is simply a Newtonian reflector on a particular kind of alt-azimuth mount. As noted in this department last month, an alt-az mount is easy to use — especially for beginners — because it has intuitive up-and-down and side-to-side motions. But two important features distinguish a Dobsonian from other alt-az mounts. First, its bearings are *huge*, which helps give the scope exceptional stability and freedom from vibration. That's important since a mount that shakes and jiggles at the slightest touch is frustrating to use — and the bigger and heavier a scope is, the more prone it is to this problem. Second, the motions of a classic Dob are controlled by friction alone. Instead of being assembled from gears and machined metal, its bearings are typically constructed with plywood, Formica kitchen-countertop material, and pieces of Teflon. There's no need to lock or unlock clamps — simply grab the front of the scope and swing it to whichever part of the sky you wish to explore. A well-made, properly balanced Dobsonian moves smoothly yet stays put where you aim it.

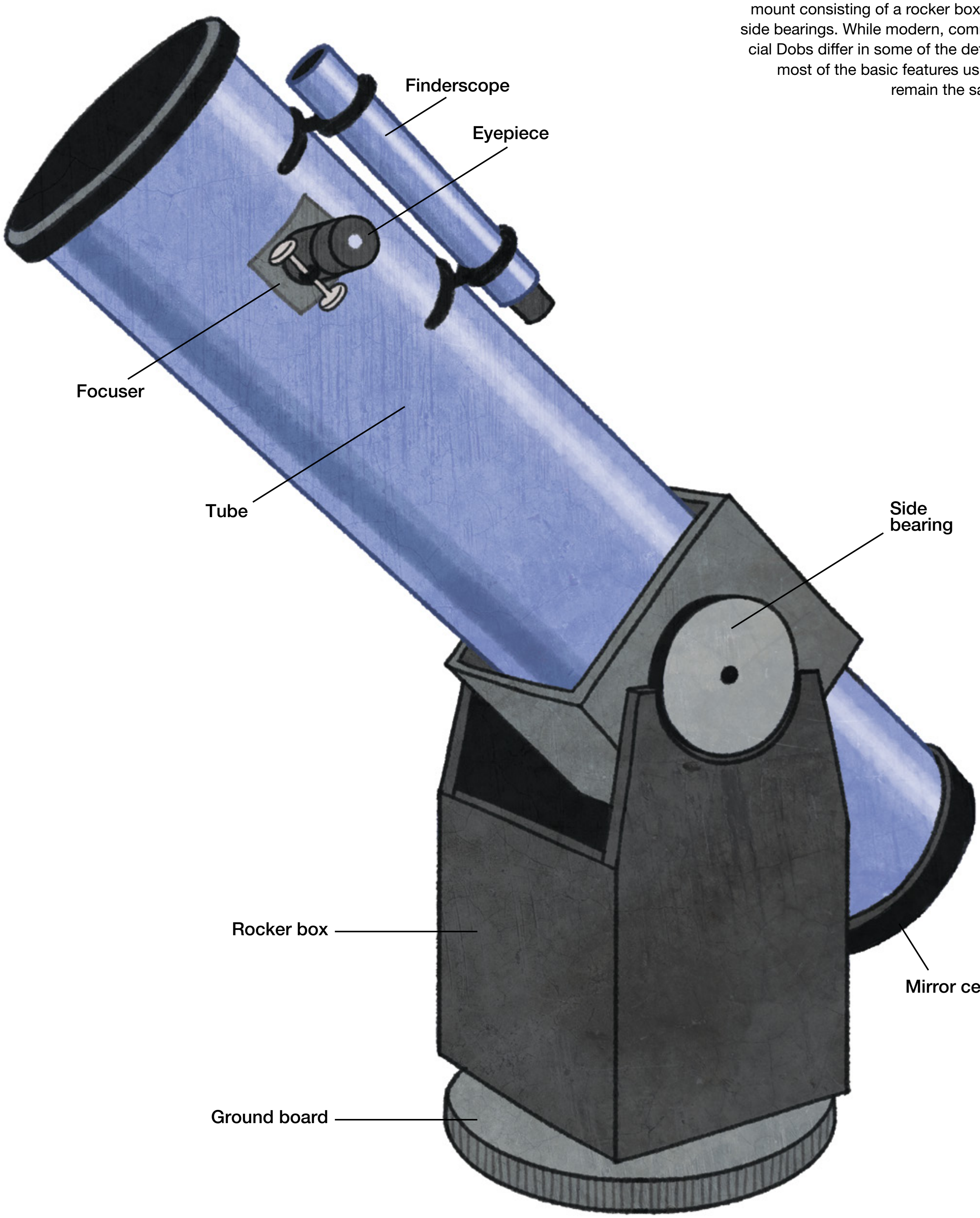
Another important aspect of Dobson's design is that it provides the biggest bang for your telescope buck. That's true whether you decided to make one of your own (yes — plenty of people build telescopes; see *S&T:* April 2020, p. 36) or purchase one from a commercial source. Want a 10-inch scope that doesn't cost a small fortune? Chances are it's a Dobsonian you'll be looking at. How about a 25-inch behemoth for hunting faint deep-sky denizens? A Dob is your only option. (One vendor briefly offered a 50-inch model!) Its budget-friendly nature is to some extent baked into the design, which lends itself to the use of inexpensive materials such as cardboard for the tube and particle-board for the mount.

▲ **STORE-BOUGHT GOODS** Modern, commercially manufactured Dobsonians, like this 8-inch model from Explore Scientific, usually deviate from John Dobson's design, but the best examples retain the original's stability and ease-of-use.

KEN HEWITT-WHITE

The Dob's popularity has led to a proliferation of telescopes that possess only a few of the design's defining features but are nonetheless called Dobsonians. For example, the so-called tabletop version is something that John Dobson likely wouldn't even recognize. (He wasn't a fan of small telescopes in any case.) Other, larger instruments eschew a traditional tube and instead use a series of poles to join the front and back halves of the scope. These "truss-tube" models are highly portable for their size, making them extremely popular with deep-sky observers who want big optics they can transport to remote dark-sky sites. You can even get a Dobsonian that's equipped with a computerized Go To setup and motorized tracking! In the same way that a chihuahua is still a dog even though it's far removed from its wolf ancestor, most of these new-breed Dobsonians share many of the original's desirable attributes.

If you're looking for an affordable first telescope with enough aperture to show lots of objects, a basic 6- to 10-inch, commercially made Dobsonian telescope is an excellent choice. Such instruments are available from several manufacturers and are priced from around $400 upwards. Of course, if you really want the full-on Dobsonian experience, you'll build your own! ■



LEAH TISCIONE / S&T

DOBSONIAN ANATOMY
The classic version of this popular design takes a conventional Newtonian reflector optical tube assembly and places it in a basic, easy-to-build mount consisting of a rocker box and side bearings. While modern, commercial Dobs differ in some of the details, most of the basic features usually remain the same.

△ SANDSTONE MONOLITHS

John Vermette

The Milky Way from Cassiopeia (left) to Scorpius (right) cuts through the strong, green airglow over the wind-worn structures of Grand Staircase-Escalante National Monument in Utah in this panorama from June 6, 2022. Aquila is to the upper right and Cygnus to the upper left.

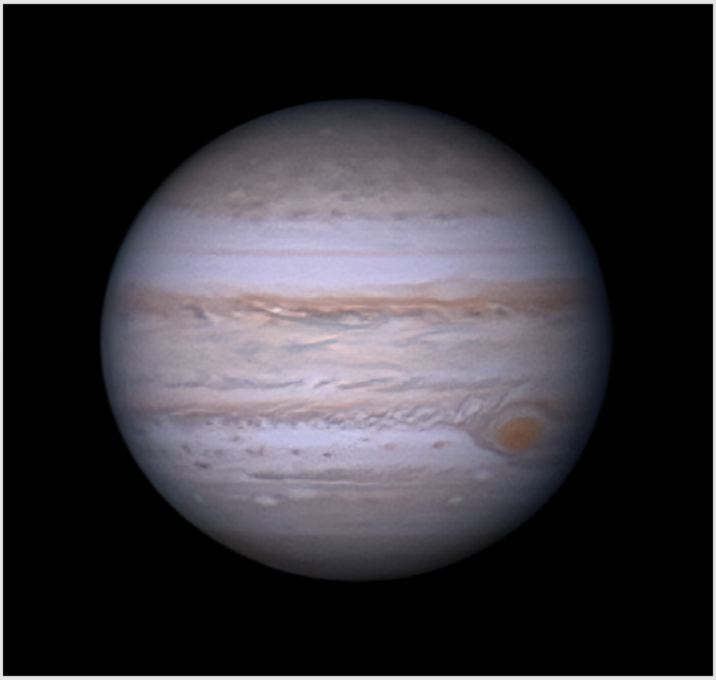
DETAILS: *Canon EOS 6D DSLR camera and Rokinon 24-mm lens. Composite of two exposures totaling 105 seconds at f/1.4, ISO 3200.*

▷ STORMY GIANT

Grant Blair

Jupiter sports a thin North Equatorial Belt and a turbulent South Equatorial Belt in this detailed image from August 4th. Grayish festoons decorate the Equatorial Zone, while several white storms speckle the gas giant's southern hemisphere.

DETAILS: *Meade 12-inch LX200 ACF and ZWO ASI224MC camera. Stack of 29,000 video frames.*



▽ ANDROMEDA AND FRIENDS

Patrick Manley

Dark dust lanes wrap around the bright core of M31, the Andromeda Galaxy. Two of its largest dwarf galaxy companions, M32 (center left) and M110 (bottom), show faint halos of stars connecting them with the gargantuan spiral. North is to the left.

DETAILS: *Celestron 8-inch Rowe-Ackermann Schmidt Astrograph and ZWO ASI2600MC Pro camera. Total exposure: 1.66 hours.*

SOUTHERN BEEHIVE

Dan Crowson

Open cluster NGC 2516 (also known as Caldwell 96) in Carina contains roughly 100 stars. The two 5th-magnitude stars' orange color makes them stand out from the rest of the cluster when seen through a telescope.

DETAILS: *Astrosysteme Austria 500N Newtonian Astrograph and FLI ProLine PL16803 camera. Total exposure: 1.33 hours through LRGB filters.*

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Mindful Stargazing

A former astrophysicist explains why he left the field — and what he gained by doing so.

▲ Next time you're out under a starry sky, the author urges, consider setting all equipment aside for a time and just taking in the vast firmament overhead.

MOOREMEDIA / SHUTTERSTOCK

WHEN I WAS A PROFESSIONAL astronomer, my colleagues and I would often bid for (and sometimes be granted) a few nights of observing time on a big telescope. One December I visited Mauna Kea for such an observing run — it was my first time to Hawai'i. I remember turning up at the summit at dusk, excited that it was beautifully clear and the atmosphere was steady. I entered the control room and sat down under the huge array of computer screens. As it got dark, we commanded the telescope into action in the main dome . . .

The next thing I knew it was dawn. We stumbled outside, bleary-eyed, and watched the Sun slowly rise above the cloud layer below us.

It didn't occur to me until later what I'd done. There I was on Mauna Kea, which, as most *S&T* readers know, has some of the clearest, darkest, stillest night skies in the Northern Hemisphere, and I didn't once look up at the stars. I'd become so engrossed in my research that it hadn't even occurred to me to step outside and look up.

Gradually I realized this was symbolic of where I'd gotten to in my life. For years I had sought to escape the pain of a major family trauma by burying my head in the cosmos, and in doing so I'd numbed myself. After about a decade of professional astrophysics, I decided to re-orient my life so I could focus on my relationships and face the stuff I'd learned to escape from. I took up teaching yoga and mindfulness full-time, and astronomy receded into the distance. Friends kept encouraging me to find ways to bridge my new world with that of my old one, astronomy. It took me some years to see how I could without losing my grounding again.

I now teach what I call "mindful stargazing." This means looking up at the night sky with wide-eyed curiosity and wonder without using technology or trying to understand scientific concepts or theories. It's about slowing down and developing a firsthand knowledge of what it is to "be" in this universe. It's a wonderful antidote to our hectic, anxiety-filled world.

When we go for a casual walk in nature, do we carry along a book or consult an app on botany and try to identify all the plants we're looking at? Some certainly do, and all the power to them, but doing this arguably takes us away from the present-moment experience of simply enjoying the walk. Similarly, when we look up into the night sky, we could — and, among *S&T* readers, often do — grab our telescope or binoculars and begin identifying objects. But the danger is we might forget to just look and be awed.

So how about the next time you're beneath a clear, starry sky, put the tech and science aside for a moment. Let yourself be captivated by the beauty of the heavens. Know that humans throughout our history as a species have looked up and seen the same stars in virtually the same patterns. That can't be said of any view down here on Earth.

When we look up with inquisitiveness and awe, instead of the stars being just objects to study "out there," we start to feel truly part of the cosmos. After all, we're not just observers of the stars but actually made of them.

■ **MARK WESTMOQUETTE** runs mindful stargazing retreats in the UK. He's the author of *Mindful Thoughts for Stargazers* and *The Mindful Universe*.

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