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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

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NASA / ESA / CSA / STSCI / WEBB ERO PRODUCTION TEAM

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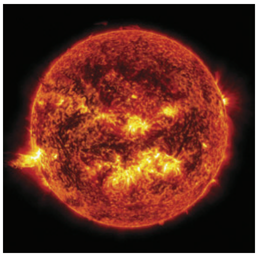
Our Puny Star

THERE'S A PHRASE in our cover story this month that made me snicker: ". . . our Sun is tiny . . ." Anyone reading that phrase might have the same reaction. The Sun is 1.4 million km (870,000 mi) across, wide enough that it would take 109 Earths lined up side by side to span the sphere. Our star's mass totals about 330,000 Earths, and to fill the Sun's volume would require a whopping 1.3 million Earths. How can such a behemoth be considered tiny?

Of course, I took that phrase out of context. The full sentence is: "Yet our Sun is tiny next to other stars within our galaxy." Betelgeuse, for one, the red supergiant in Orion, is about 700 times the size of the Sun and about 15 times more massive. Rigel, across the constellation from Betelgeuse, is even heftier at roughly 20 solar masses.

But as writer Elizabeth Fernandez discusses in her article on page 34, even Betelgeuse and Rigel are diminutive compared with other stars, both confirmed and theoretical. The most massive star astronomers have yet identified, a Wolf-Rayet star in the Tarantula Nebula called R136a1, might have the mass of 200 to 300 Suns. And of stars not yet discovered, particularly those that exist so far only in theory, one look at the bar graph on page 39 will show that the phrase "the Sun is tiny" might be a laughable understatement.



▲ A Solar Dynamics Observatory image of the Sun taken on June 20, 2013

NASA / GODDARD / SDO

The truth is that in our universe size — like distance and time — is relative. Fernandez explores theorized *supermassive stars* that might have tens of thousands to hundreds of thousands of solar masses. (They might even have black holes *within* them, eating them from the inside out!) If they exist, it would be safe to say that, at least when it comes to stars, we haven't seen *big* yet.

Looking at that bar graph made me muse: If only we could observe the most massive star that ever formed in our universe cheek by jowl with the Sun. How would that change our view of things? Voyager's "pale blue dot" image of our world, suspended like a dust mote in the sprawling emptiness, gave us a new vantage on just how insignificant our planet, much less we ourselves, are in the grand scheme of things. Would such a side-by-side comparison of the most massive star and the "tiny" Sun offer the same humbling perspective? Or something else entirely, given we can hardly imagine it?

That's one of the great things about astronomy and science in general: We have so much to discover, learn, and wonder about. How tremendous it is to imagine the possibilities.

Peter

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

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

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Subscription Rates:
U.S. and possessions: $57.73 per year (12 issues)
Canada: $73.18 (including GST)
All other countries: $88.63, by expedited delivery
All prices are in U.S. dollars.

Customer Service: Magazine customer service and change-of-address notices: skyandtelescope@omeda.com
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Outside the U.S. and Canada: 847-559-7369
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All Eyes on Barnard's Star

I just wanted to write and say I really enjoyed "Tracking Barnard's Star" by Howard Banich (*S&T:* May 2024, p. 60). Interestingly enough, at our local astronomy club's last meeting we had a fascinating lecture on the life and accomplishments of Edward Barnard. (He grew up here in Nashville, and our local club is named after him, too.)

So when I got home that night and saw my new *S&T* waiting for me, I was enthused to see the article about Barnard's Star that I had always heard of but knew very little about.

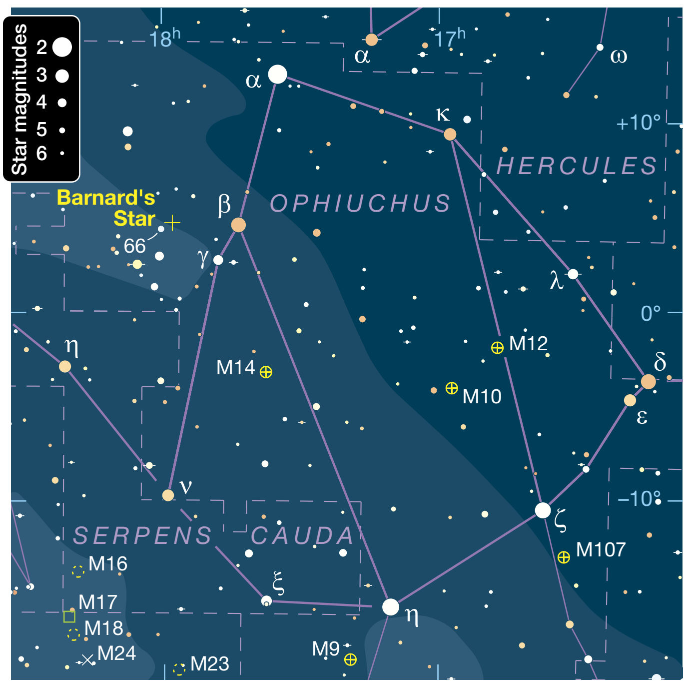
Now, I plan to observe (or maybe image!) Barnard's Star as part of a future observing session. Thanks again for the article!

Brad Hill
Nashville, Tennessee

I appreciate the current editorial direction of *Sky & Telescope*. The recent features "The Story of Wolf 359" by Ken Croswell (*S&T:* May 2024, p. 34) and Howard Banich's article on Barnard's Star unite history, astronomy, and observational possibilities in a way that appeals to your core readership. The piece on Barnard's Star drew my attention particularly because back in 2009–2010, I carried out an observing project to measure both the star's proper motion and parallax.

I reported the project in a paper titled "The Proper Motion and Parallax of Barnard's Star: Errors and Precision in Small-Telescope Astrometry" that I presented at the Society of Astronomical Sciences' 30th Annual Symposium on Telescope Science in 2011. The project started during a summer student workshop when I wondered what was the shortest interval that would allow the student to detect Barnard's Star's proper motion. Could we see it during the three-day workshop? The answer turned out to be *yes* if we were willing to average multiple astronometric determinations of right ascension and declination each night.

The paper describes the techniques involved with an 8-inch f/4 Newtonian telescope and CCD camera. Each night, I shot 60 images when Barnard's Star was near the meridian and averaged them to obtain the star's coordinates for that night. It turns out that this small telescope produced positions good to about 1/25 of an arcsecond each night, and that it was possible — as I demonstrated — to see the movement of Barnard's Star from one night to the next. The path of the star on the sky is not a straight line, of course, but a sine wave with an amplitude determined by the parallax of the star. I was able to collect enough observations to show that the parallax is a bit over half an arcsecond. Amateurs can indeed do good work with small telescopes!



Richard Berry
President of AAVSO
Dallas, Oregon

Tidbit of History

On reading the April issue of *S&T*, I was pleasantly surprised to see a reproduction of a drawing of the Caroline Island encampment of astronomers to observe the May 6, 1883, solar eclipse (*S&T:* Apr. 2024, p. 28). Former Editor Joseph Ashbrook wrote an Astronomical Scrapbook piece (*S&T:* Mar. 1978, p. 211) about this expedition and its findings.

This is of special interest to our club, the Amateur Astronomers Association of Princeton, New Jersey, because the telescope second from the left edge of the drawing, the Hastings-Byrne 6¼-inch refractor, is currently in our observatory in Washington Crossing State Park. I wrote up a history of this telescope in the Gleanings for ATM's article of the March 1979 issue on page 294. I also wrote a Focal Point about it with William Murray entitled "Three Centuries, One Scope" (*S&T:* Dec. 2016, p. 84).

I and several members of my immediate family were fortunate to see the recent total eclipse from a fairground near Urbana, Ohio. On viewing the magnificent solar corona for the fourth time, going back to March 1970, I couldn't help recollecting that Charles S. Hastings studied it with this particular telescope in 1883. The fact that he erroneously attributed the corona to diffraction at the Moon's edge (**https://is.gd/Hastings1883Report**) lends a piquant touch to our current enjoyment of this lens's continuing fine performance at age 145.

John A. Church
Princeton, New Jersey

Eclipse Chasing

I enjoyed reading Alan Whitman's account of his experience with the July 20, 1963, total solar eclipse in "A Teenager's First Eclipse Chase" (*S&T:* Apr. 2024, p. 84). Like him, I was also 16 at the time. I began attending Lane Tech High School in Chicago the year before. The school bulletin announced that there would be a meeting of the Science Society after school that Friday. I decided to attend, a decision that changed my life. At that meeting, I met a group of like-minded students, including an upperclassman named Alan Fries. We decided to form an astronomy club.

It turned out that Al was planning an expedition to observe the July 20, 1963, eclipse, which he invited me to join. We observed the eclipse from Cadillac Mountain in Maine. It was cloudy the morning of the eclipse. Many others relocated to other sites, but Al decided we should stay where we were. We got a lucky break in the clouds shortly before totality. Soon after totality the clouds closed in, and it began to rain. I later heard a news report that said our site was the only one in Maine that saw it.

I have since been lucky enough to observe the 1979 total eclipse from Washington State, the 2017 total eclipse from Idaho, the 2023 annular eclipse from Oregon, and now the April 8th eclipse from Richland Springs, Texas. I had good luck with the total eclipses, but my wife and I weren't quite as lucky with last year's annular eclipse, though we did get a few glimpses of annularity during short periods when the clouds thinned.

We had a great time observing the April 8th eclipse. Our Airbnb hosts and about 10 others joined us to watch the eclipse. Richland Springs is surrounded by sheep farms, so our hostess went to see how sheep would react to the eclipse.

Bob Eramia
Seattle, Washington

I urge *Sky & Telescope*, as one of astronomy's largest voices, to use April's eclipse as a lesson that while experiencing totality is wonderful, amazing, and life-changing with the protected naked eye, it's so much more in every aspect with even a basic set of binoculars. It was an opportunity to open the public up to the power of optics and how looking up with specialized telescopes and aids is spectacular. I saw very few watch parties include optics. The fellow watchers I spoke to said either "I never thought of looking at it through those!" or "Won't I burn out my eyes?" We must do a better job of spreading the joy of optics and the heavens to our neighbors and friends.

Adam Lechner
Brownsville, Wisconsin

Stalwart *S&T*

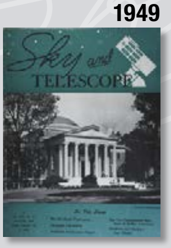
I've been a subscriber for 60 years, from being a young amateur in Philadelphia, to being a professional astronomer, a nuclear engineer, and then back to an amateur again. *Sky & Telescope* is like the stars, always there!

Ed O'Donnell
Mystic, Connecticut

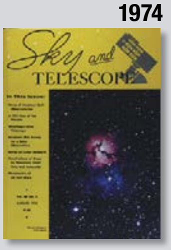
SUBMISSIONS: Write to *Sky & Telescope*, 1374 Massachusetts Ave., 4th Floor, Cambridge, MA 02138, USA, or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1949



1974



1999

◖ August 1949

Sky Survey "July 19th was the date scheduled for the start of a series of some 2,000 photographs of the heavens to be made during the coming four years by the 48-72-inch Schmidt camera on Palomar Mountain. . . . The completed project will be known as the National Geographic Society – Palomar Observatory Sky Atlas, and copies will be made available to other observatories and institutions at cost."

◖ August 1974

Medicine Wheel "At an altitude of 9,640 feet in northernmost Wyoming, on a shoulder of Medicine Mountain above timberline in the Big Horn National Forest, is a structure of stones presumably laid out by early Indians of the Great Plains. Known as the Medicine Wheel, it consists of a rough circle about 80 feet in diameter with 28 'spokes' radiating from a central cairn . . . Six other cairns lie either on the rim of the wheel or outside it.

"John A. Eddy of High Altitude Observatory . . . measured the bearings of lines joining the centers of various cairns. He found alignments to the summer solstice sun, both at rising and setting, and to the rising points of three stars: Aldebaran, Rigel, and Sirius. These stars' heliacal risings (dates of first visibility in dawn after conjunction with the sun) might have been observed by the Indians to mark the summer solstice (Aldebaran), a month later (Rigel), and two months later (Sirius)."

Heavy snows make this curious structure inaccessible except in summer. Eddy believed Native Americans may have had spiritual or aesthetic reasons for placing it on such a remote mountaintop.

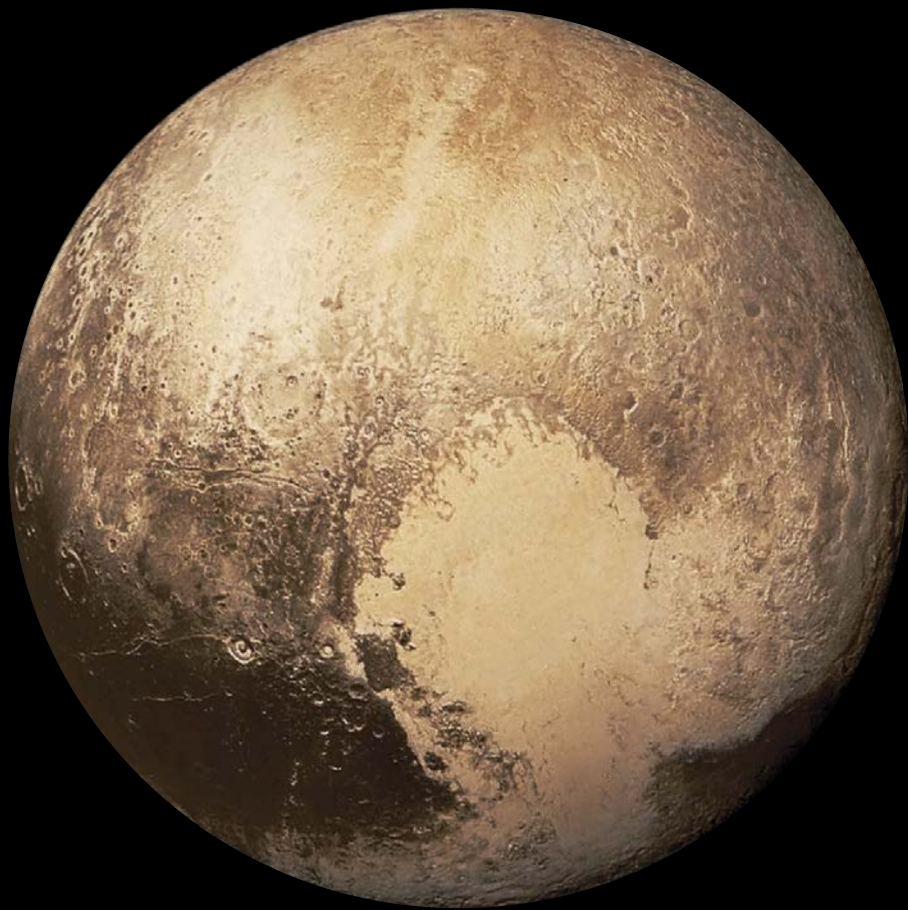
◖ August 1999

Chandra "Revolutions in science are triggered by new instruments more predictably than by new theories. With NASA poised to launch its $1.5 billion Chandra X-ray Observatory . . . a revolution is about to begin in high-energy astronomy. . . .

"Fortunately the field has been on 'fast forward' since 1962, when an experiment aboard a sounding rocket detected the first X-ray signal from beyond the solar system. . . . Chandra is about to beat the traditional 1-arcsecond [resolution] limit of large ground-based telescopes, a breakthrough that took optical astronomy 380 years. . . .

"A key goal for Chandra is to capture images of quasars and clusters of galaxies in the light of the iron atom's K-shell emission-line complex [and] learn much about the massive black holes whose gravitational energy is believed to power active galaxies."

Chandra has far outlasted its original 5-year life expectancy. For example, in 2021 it may have detected an exoplanet in M51, the Whirlpool Galaxy, the first such find outside our Milky Way.



▲ Sputnik Planitia is the nitrogen-ice plains that fills the left lobe of Pluto's "heart."

SOLAR SYSTEM

How Pluto Got Its Heart

SCIENTISTS THINK the western lobe of Pluto's giant heart, Sputnik Planitia, formed billions of years ago when a massive body slammed into Pluto. That ancient impact left behind an icy region as wide as a quarter of the United States and several kilometers lower than surrounding terrain.

Now, Harry Ballantyne (University of Bern, Switzerland) and collaborators have found that a large chunk of the impactor could still exist inside the world. Their research, published April 15th in *Nature Astronomy*, challenges previous conclusions that Pluto hosts a subsurface ocean.

The ocean scenario came about because Pluto's "heart" happens to be at a special location: close to the equator and right on the tidal axis with its large moon Charon. In 2016, several researchers proposed that a large extra mass beneath Sputnik's ice had caused Pluto to change its axis of rotation. Since an impact would have excavated mass, any *excess* mass must come from something else — such as a subsurface ocean (*S&T:* Oct. 2016, p. 14).

▲ This artistic representation shows the huge, slow impact from Pluto's past.

But Ballantyne's team use simulations to account for the slow and shallow impact (as derived from previous work) as well as the material strength of the impactor itself — and the researchers come to a different conclusion. "Immediately, when I ran the simulations, it was different to what one would expect," Ballantyne says.

Based on the simulation, the team concluded that the impactor was roughly one-third Pluto's size, with an icy mantle covering a rocky core. The core — which remained mostly intact — dove in toward Pluto's interior, spreading into a splat at the core-mantle boundary. The impact itself thus created an excess of mass rather than a deficit, eliminating the need for a partially molten interior.

"I think that this is an entirely valid hypothesis," says James Keane (NASA Jet Propulsion Laboratory), who led some of the 2016 research that supported the ocean scenario. However, he notes that more work is needed to test if the impactor had enough mass to rearrange Pluto's rotation.

William McKinnon (Washington University in St. Louis), who wasn't involved in the study, has other qualms. "From my point of view, [the study's findings are] not self-consistent with the evidence we have from Pluto's long history," McKinnon says.

He points to *extensional tectonic features* that break up Pluto's surface, which suggest that a subsurface ocean did exist in the world's warmer past, then slowly expanded as it cooled and froze. "The landscape of Pluto has been slowly rising and therefore splitting apart," McKinnon says.

Ballantyne answers that his impact simulations are not super sensitive to temperature. The important thing, he says, is that conditions remain cold enough so that "everything remains solid." Impacts might just work differently among the small, ultracold bodies in the solar system's outskirts.

■ **JAVIER BARBUZANO**

PLUTO'S HEART: NASA / JHUAPL / SWRI; ARTIST'S ILLUSTRATION OF IMPACT ON PLUTO: UNIVERSITY OF BERN, ILLUSTRATION: THIBAUT ROGER

SOLAR SYSTEM

A Century of Sky, Digitized

DEEP WITHIN the photographic plate stacks at the Harvard College Observatory, curator of astronomical photographs Thom Burns slips a delicate glass plate out of its brown paper sheath. He places it on a large, specialized scanner — custom-built for this purpose — preparing it for digitization, the astronomical markings encoded on its surface soon to be forever preserved in an online database. While there isn't anything unique about this particular glass negative, its pale, filmy surface speckled with dark stars, there is nonetheless cause for tension.

This moment is the culmination of a project that has spanned two decades: Digital Access to a Sky Century @ Harvard, or DASCH. Within the labyrinthian walls and filing cabinets of the Harvard College Observatory's Plate Stacks reside some 600,000 glass plates, collected from 1880 to 1990.

Members of DASCH have now digitized the more than 430,000 plates from which accurate brightness data can be obtained. With more than 400 terabytes of imaging data now at their fingertips, astronomers now have access to a century of sky.

As Burns sets the plate in place and flicks off the lights, the room falls silent. The machine begins its work — red lights flickering as the scanner measures the position and brightness of each tiny region, then shifts the plate over with microscopic precision. The entire process usually takes about 85 seconds, according to the project's operation lead Peter Williams; when the project was underway, the team would complete on average around 200 to 400 plates a day.

The collection is more than just a repository of research data — the early years of photography and the progress of astronomical data collection can be seen through these images. The archive also traces the work of astronomers at the Harvard College Observatory, including that of the women "computers" who stewarded its collection (*S&T:* Dec. 2021, p. 12).

▲ Thom Burns places a glass plate on DASCH's custom-built scanner.

On March 28th, the final plate was scanned into DASCH — finishing one project and paving the way for many others.

■ ARIELLE FROMMER

What's next? Read more about future projects: https://is.gd/DASCH

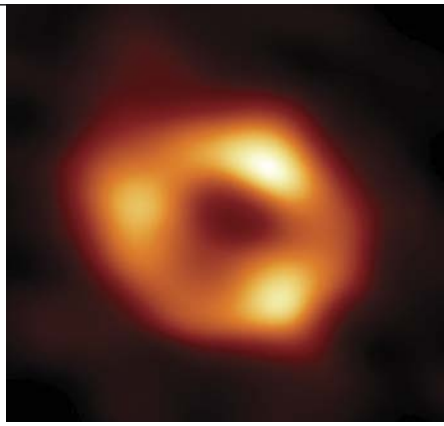
BLACK HOLES

Watch Hotspots Orbit Our Galaxy's Black Hole

OUR RESIDENT SUPERMASSIVE black hole, dubbed Sgr A*, emits bursts of radiation at infrared, X-ray, and radio wavelengths. Such flares were a nuisance to the Event Horizon Telescope (EHT) team in 2017, as they worked to image Sgr A*'s dark silhouette.

Now, Aviad Levis (Caltech) and collaborators, including several members of the EHT team, have utilized some of that 2017 data to examine not the black hole but one of those pesky flares. The results were published April 22nd in *Nature Astronomy*.

The researchers started with the idea that flares come from hotspots within gas flowing around the central maw. Magnetic fields snap-crackle-popping close to the black hole can heat and energize this gas. A hotspot would look different from its surroundings because, while gas flowing into the black hole won't change much over a few hours, hot pockets of gas shear out and fade more quickly. The radio waves' polarization, which tells us at what angle the light waves are oscillating, is also expected to be higher for light coming from a hot bubble of plasma.



▲ The EHT team took this image of Sgr A*; Levis's team used part of these data to generate the 3D video of the moving hotspots. See the video at **https://is.gd/SgrAhotspot**.

The team used data from the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile, which was imaging Sgr A* on April 11, 2017, when the black hole had also just emitted an X-ray flare. To incorporate 2D data (brightness and polarization) into a 3D rendering of events, the team employed a relatively new form of artificial intelligence known as *neural radiance fields*, developed in part by team member Pratul Srinivasan (Google Research). In addition to feeding this neural network the ALMA data, the algorithm was also given rules of sorts, according to the physics that the astronomers know or assume to be operating near Sgr A*.

The result is a 3D video showing two hot pockets of gas moving around the black hole, elongating as they go. The brightest part is only 2 astronomical units from the black hole's event horizon. A fainter hotspot lags behind at a somewhat greater distance.

This video isn't a simulation, but it isn't a direct recording of events, either. "It is a reconstruction based on our models of black hole physics," Levis says. "There is still a lot of uncertainty associated with it, because it relies on these models being accurate."

■ MONICA YOUNG

DASCH SCANNING: KAYLEIGH MACDONALD; SGR A*: EHT COLLABORATION

SPACE MISSIONS

Chandra Observatory Faces Premature End

AFTER A QUARTER-CENTURY in space, NASA's Chandra X-ray Observatory might face an early end to its mission, at least according to the President's new budget request for NASA. Astronomers are now lobbying to restore funding to the mission.

NASA's budget for 2025 as well as projections for future years call for a steep reduction in Chandra's funding. This change would slash support not only for telescope operations but also for research projects in X-ray astronomy, especially in the U.S. — which in turn affects both professional astronomers and students who rely on that funding to do their work.

Chandra received $68.3 million for normal operations in 2023. (Chandra operated under a continuing resolution in 2024.) Under the new fiscal year (FY) 2025 budget request, funding for the telescope would drop to $41.1 million, starting this October. Projections for following years call for $26.6 million for FY2026, 27, and 28, before dropping to just $5 million by FY2029.

Patrick Slane (Center for Astrophysics, Harvard & Smithsonian), director of the Chandra X-ray Center, notes that the FY2025 budget request is not enough for the telescope to continue making observations. In a letter to the Chandra community, he states, "The funding levels provided in the new budget plan are consistent with levels for . . . closeout activities, but lower than can accommodate operation of the Chandra science mission."

◀ This composite image of the Crab Nebula combines X-rays from Chandra (blue and white) with visible and infrared data from Hubble (purple) and Spitzer (pink), respectively.

NASA cites Chandra's downgraded performance as a reason to draw the mission to an end, noting that an increase in instrument temperature creates restrictions in scheduling observations. The efficiency at which the main detector picks up the lowest-energy X-rays has also decreased over the years due to the build-up of contamination.

However, Slane notes that workarounds are in place, resulting in good science from Chandra's instruments with no decrease in observing efficiency or quality of science.

Astronomers in the community have reacted to the news by starting a grassroots organization, called SaveChandra (**savechandra.org**), both to promote awareness of the role the mission serves in X-ray astronomy, especially in the U.S., as well as to present a path for rescuing the observatory.

■ **DAVID DICKINSON**

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

SOLAR SYSTEM

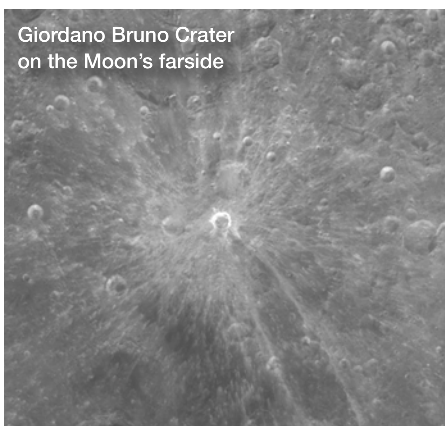
Earth's Mini-moon Linked to Lunar Farside Crater

RESEARCHERS MIGHT HAVE located the birthplace of 469219 Kamoʻoalewa, a small asteroid that has been described as Earth's "mini-moon."

Kamoʻoalewa is the closest and most stable of the quasi-satellites that — despite not being bound by our planet's gravity — co-orbit the Sun with Earth over long time periods. Kamoʻoalewa has an orbit that takes it out as far as 100 times the distance of the Moon. It also rotates quickly, spinning around every 28 minutes.

In previous work, Ben Sharkey (University of Arizona) and others have suggested that the body has a lunar origin, because its *reflectance* — the light reflected back from its surface — is more akin to that of samples collected from the Moon than it is to observations of near-Earth asteroids.

Yifei Jiao (Tsinghua University, China) and colleagues set out to determine which lunar crater is most likely responsible by simulating impacts of various sizes. They find that the originating crater must be larger than 10 to 20 km. The team was able to further whittle down the candidates because Kamoʻoalewa is younger than most of the craters on the Moon. One candidate remains the best fit: a 22-kilometer-wide crater on the farside of the Moon called Giordano Bruno, made in an impact some 1 to 10 million years ago. The results were published April 19th in *Nature Astronomy.*



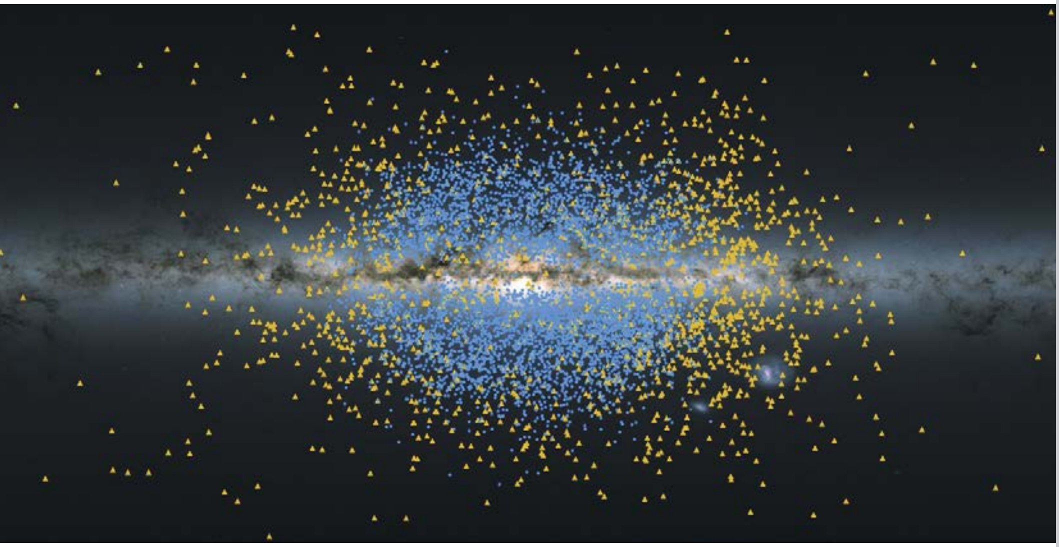
Giordano Bruno Crater on the Moon's farside

Sherry Fieber-Beyer (University of North Dakota), who wasn't involved in the study, notes that the previous work from Sharkey's team "laid the groundwork" for Jiao and his team "to map the dynamics straight back to the Moon." That connection, she says, "is equivalent to finding a needle in a haystack."

In 2025 China will launch Tianwen 2 to escort Kamoʻoalewa for a few months before dropping a lander to retrieve samples. The mission will offer the opportunity to study Kamoʻoalewa in more detail and verify its origin.

■ **KIT GILCHRIST**

CHANDRA IMAGE OF CRAB PULSAR: X-RAY: NASA / CXC / SAO; OPTICAL: NASA / STSCI; INFRARED: NASA / JPL-CALTECH; LRO IMAGE OF LUNAR CRATER: NASA



ESA / GAIA / DPAC / K. MALHAN

MILKY WAY

Shiva and Shakti: Two New Stellar Streams?

TWO NEWLY DETECTED stellar groups in the inner Milky Way could be the remnants of ancient protogalaxies — or, more prosaically, they might represent stars in resonance with our galaxy's bar.

Khyati Malhan and Hans-Walter Rix (both at Max Planck Institute for Astronomy, Germany) identified the groups using data from the Gaia satellite, publishing the results in the April 1st *Astrophysical Journal*. The two groups, which Malhan and Rix nicknamed Shiva and Shakti after two Hindu deities, are distributed between us and the galactic center.

The astronomers teased out the two subpopulations by the comparable properties of their orbits. Combined with other measures of their ages, such as the stars' compositions, the data suggest that the two groupings could have joined the Milky Way between 11 and 12.5 billion years ago.

While it may seem surprising that such populations would still be identifiable after more than 10 billion years, Rix compares the process to observing small bodies in the solar system. A comet may disintegrate into fragments that gradually spread out along its orbit; however, even when that trail spans millions of miles, those fragments would still retain a distinct identity by their orbits' similarity.

▲ This image shows the location and distribution of stars that are part of the Shakti (yellow) and Shiva (blue) streams in the Milky Way.

Not everyone is convinced, though. Adam Dillamore (University of Cambridge, UK) and colleagues have a different interpretation for such stellar groups, contending that they cluster due to a resonance effect.

For example, passages of the galaxy's central bar every several hundred million years can group stars in the same way that asteroids gather in resonance along Jupiter's orbit. Dillamore and colleagues have posted their study on the arXiv astronomy preprint server.

Dillamore says that the orbits of the Shakti group correspond to the *corotation resonance*, "when the stars orbit the galaxy with the same average frequency as the bar's rotation." The case is less clear for the Shiva group, Dillamore acknowledges, but he thinks it's still possible that those orbits correspond to a different resonance.

Rix argues that the resonance interpretation doesn't quite match the data, but he adds that it's alright if the question remains unresolved.

"I think sometimes we need to let people see the soup kitchen of science," Rix says. "It's not just instant eternal truth that comes out."

■ DAVID L. CHANDLER

IN BRIEF

Mars Sample Return On Shaky Ground

NASA's Perseverance rover has collected two dozen samples from Jezero Crater, but it's unclear how those samples will come home. The initial plan — which involved a lander with helicopters, an ascent vehicle, and an orbiter/return vehicle — was planned for launch in 2028, with samples back on Earth by 2031 at the earliest. However, while the Mars Sample Return concept passed its first independent review board evaluation, a second review three years later found that the program would need to either grow its budget (up to $11 billion) or extend its mission (with return by 2040). NASA administrator Bill Nelson called the new budget "too expensive" and the new timeline "unacceptably too long." To avoid canceling the mission altogether, NASA is now asking for alternative architectures, with requests out to NASA centers, the Jet Propulsion Laboratory, and industry. Associate administrator Nicky Fox emphasized that the agency is looking for tried-and-true technologies to lower risk and cost. Concept studies will be due by the fall, after which NASA will evaluate them and decide how to proceed.

■ MONICA YOUNG

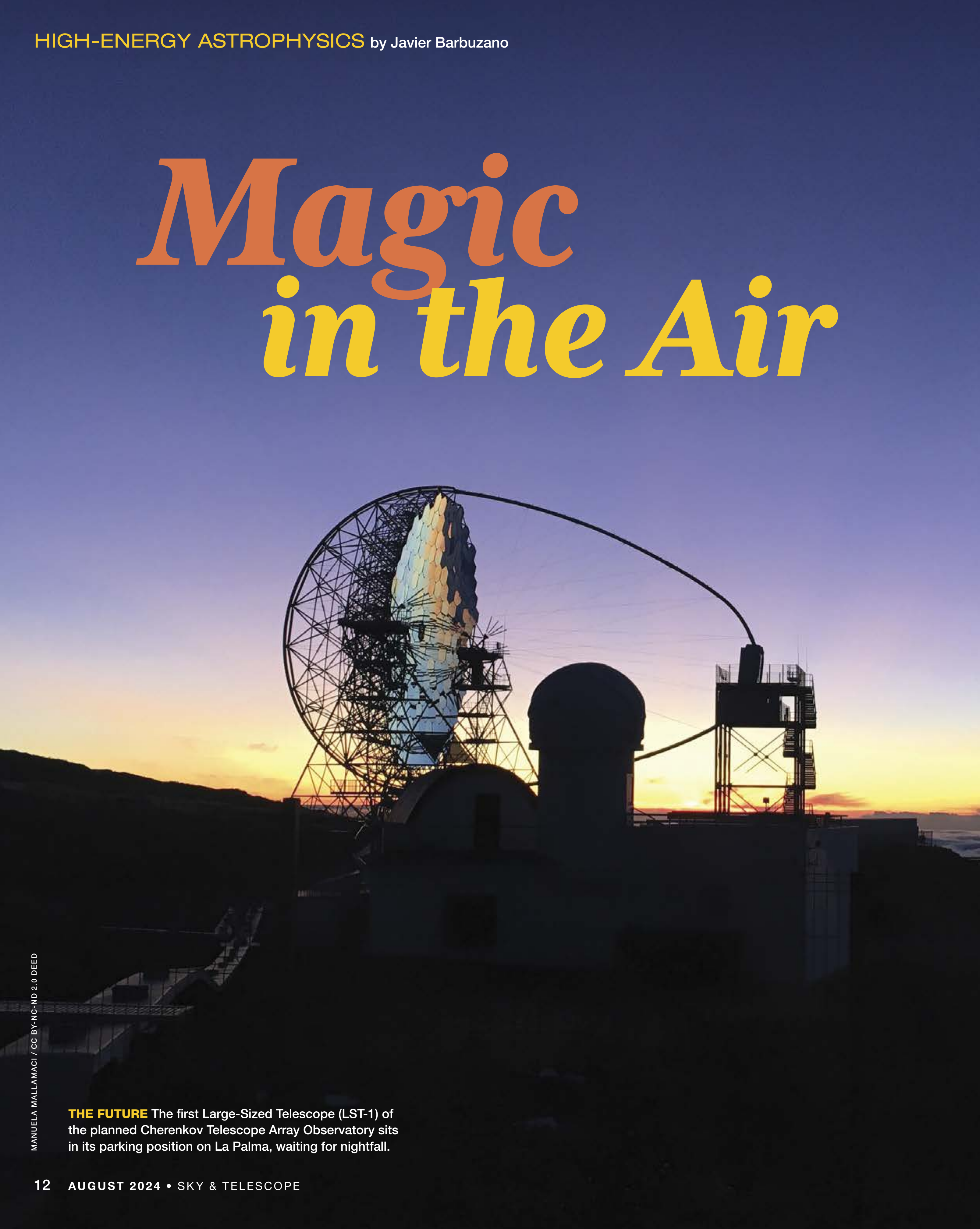
Melting Mimas

Until recently, nobody expected an ocean in Saturn's moon Mimas (see **https://is.gd/MimasOcean**). "Usually, we equate oceans with super-active surfaces," explains Geoffrey Collins (Wheaton College). Mimas's surface is geologically dead. "This is why a lot of people (including myself) were incredulous about the recent ocean result." However, the moon's rotation and orbital motion do indicate a subsurface ocean and, in the June 1st *Earth and Planetary Science Letters*, Alyssa Rhoden (Southwest Research Institute) and coworkers suggest how it could have appeared. The ocean might be young, created when some event not terribly long ago shifted the moon into an eccentric orbit, driving tidal heating and melting the moon's interior. But tides giveth, and they taketh away: Tidal friction gradually makes Mimas's orbit more circular, resulting in less tidal friction and less interior heat. Rhoden's simulations show that Mimas is now on its way to freezing solid again. The odds of such lucky timing improve when we visit enough moons.

■ EMILY LAKDAWALLA

 by Javier Barbuzano

Magic in the Air



THE FUTURE The first Large-Sized Telescope (LST-1) of the planned Cherenkov Telescope Array Observatory sits in its parking position on La Palma, waiting for nightfall.

Astronomers are building an array of intriguing telescopes that will enable them to detect the highest-energy gamma rays — from the ground.

“Tourists!” Paolo Calisse complains as he maneuvers past a rental car that has stopped in the middle of the road. The astronomical observatory at the Roque de los Muchachos, on the Spanish Canary Island of La Palma, is busy with cars and visitors wandering in small groups. Unlike at many other observatories, here road access isn’t restricted, and locals and foreigners alike can drive up to the mountaintop to see the telescopes, enjoy the newly opened visitor center, or even catch an organized tour to peek inside some of the facilities.

Calisse is the La Palma site manager of the Cherenkov Telescope Array Observatory (CTAO), a planned ensemble of 64 telescopes that will hunt for very-high-energy gamma rays, the most powerful type of electromagnetic radiation. These rays are only produced in the most extreme environments of the universe, such as supernova explosions or colliding stars. The array, currently under construction, will be split between two locations, one part here and the other part in the Atacama Desert of northern Chile.

Despite his earlier complaining, Calisse enjoys giving impromptu talks to curious visitors. And the site certainly attracts curiosity. Both CTAO’s first prototype, the 23-meter (75-foot) Large-Sized Telescope (LST), and its smaller Palmeran predecessors, the twin MAGIC telescopes, use an unusual type of instrument called an *imaging atmospheric Cherenkov telescope* (IACT). These telescopes consist of a large, segmented mirror and a detector in the main focus. The telescopes don’t have domes, making their massive, naked mirrors conspicuous amongst the mountaintop’s white and silver observatories. The open design enables them to rapidly reposition to catch transient events such as gamma-ray bursts, which appear suddenly and last for minutes at best.

The gigantic prototype, already built and currently under commissioning, gleams in the intense sunlight of the Canaries. In its parking position, the mirror points towards the horizon, its 2-ton camera resting in a special enclosure atop a five-story tower. The reflection in the mirror segments forms a broken image, like a scrambled sliding puzzle.

“A lot of visitors ask why the mirrors aren’t aligned during the day,” Calisse says. Caught by the mirror’s intended parabolic shape, Calisse answers, concentrated sunbeams could very easily set the surrounding vegetation on fire. “It could possibly even melt a car,” he adds.

When completed, La Palma’s CTAO-North will host four such behemoths; the other three are under construction on nearby plots, their circular foundations already in place. Nine 12-meter telescopes, called Medium-Sized Telescopes (MSTs), will complete the northern array. In Chile, meanwhile, construction will soon begin for two LSTs, 14 MSTs, and 37 "small" 4.3-meter telescopes that won't have counterparts on La Palma.

The differences between the two arrays are practical — there's no room for so many telescopes on the crowded slopes of *el Roque* — but also scientific. Astronomers need larger telescopes to detect the lowest-energy sources, which are more abundant outside of our galaxy, and the Northern Hemisphere offers a clearer view of the extragalactic sky. The Milky Way, on the other hand, hosts the sky's most energetic gamma-ray sources, and these are best studied from the Southern Hemisphere site with an extended array.

When finished, these two arrays will form the world's most sensitive instrument for studying high-energy phenomena in the cosmos.

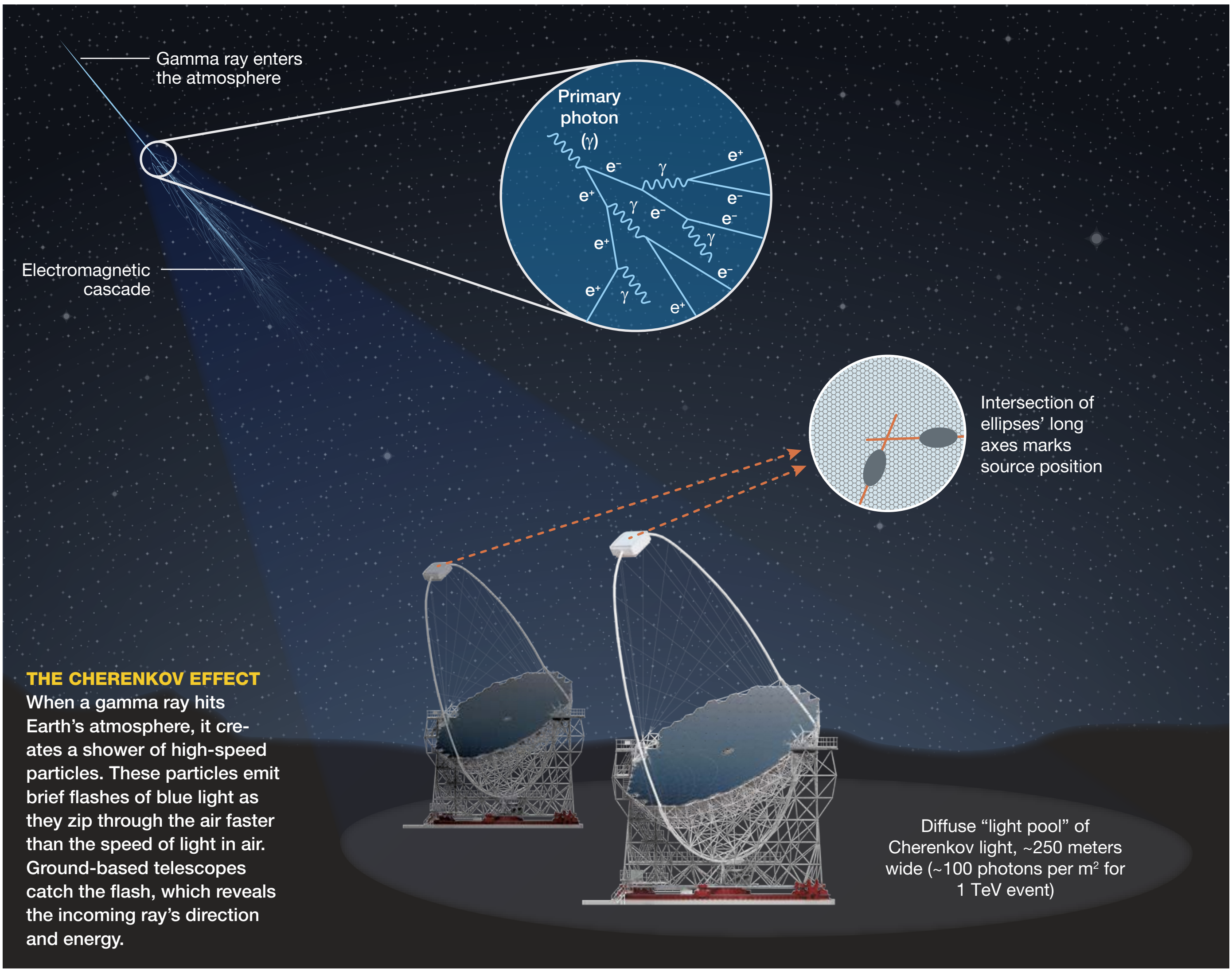
Faster than Light

Both La Palma and Chile offer very dark skies. Darkness is necessary in this case because these telescopes aren't looking into the infinity of space; instead, they point at our atmosphere, waiting to catch faint flashes of blue light produced when gamma rays hit atoms high up in the air.

Gamma rays are extremely energetic photons, occupying the highest range of the electromagnetic spectrum. Visible blue-light photons have energies of around 3 electron volts (eV), while more energetic X-ray photons are in the 100 to 100,000 eV range. Gamma rays, on the other hand, often carry millions or billions of electron volts (MeV and GeV, respectively), and the most energetic gamma rays can reach petaelectron-volt (PeV) energies, or quadrillions of eV. (Yes, that's a real number: 10^{15}, which is a 1 followed by 15 zeroes.) While radioactive decay, thermonuclear explosions, or par-

Cascades

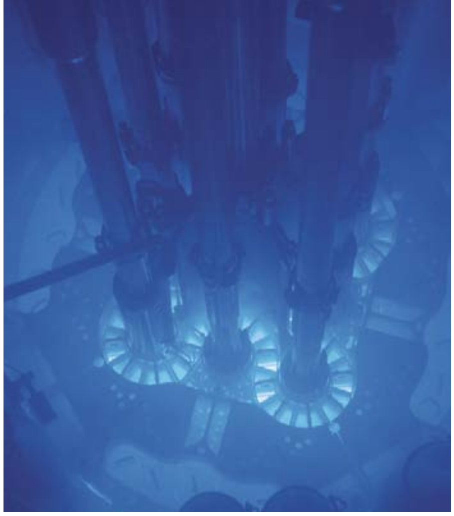
Particle cascades created by gamma rays reach a *shower maximum* (the altitude at which the highest number of particles is produced) roughly 10 km above sea level. Higher-energy gamma rays make it lower into the atmosphere. Showers are about 5 km long.



THE CHERENKOV EFFECT When a gamma ray hits Earth's atmosphere, it creates a shower of high-speed particles. These particles emit brief flashes of blue light as they zip through the air faster than the speed of light in air. Ground-based telescopes catch the flash, which reveals the incoming ray's direction and energy.

BEATRIZ INGLESSIS / *S&T*, SOURCE: R. WHITE (MPIK) / K. BERNLOHR (MPIK) / DESY AND J. A. HINTON AND W. HOFMANN / *ANNUAL REVIEW OF ASTRONOMY AND ASTROPHYSICS* 2009 ticle accelerators can produce lower-energy gamma rays, nothing on Earth can boost photons to the high energies the universe produces.

Earth's atmosphere blocks gamma rays. This otherwise fortunate circumstance — gamma rays can damage living cells and their DNA — prevents ground-based telescopes from observing these photons directly. But when gamma rays hit atoms in the upper atmosphere, the photons transform into electron-positron pairs. These, in turn, interact with other particles and produce lower-energy gamma rays, which transform again, resulting in cascades of subatomic particles called *particle showers*.



◀ **CHERENKOV LIGHT** This photo of the Advanced Test Reactor's core in Idaho shows the eerie blue glow of Cherenkov radiation, created when particles emitted by the nuclear reactor travel through the surrounding water faster than the speed of light in water.

For a brief period, these particles move faster than the speed of light in air, which makes them emit *Cherenkov light*, an eerie blue glow produced by particles that move faster than light's speed limit in a given medium. "In a broad sense, it's similar to a sonic boom produced when breaking the sound barrier," says Rubén López-Coto (Astrophysics Institute of Andalucía, CSIC, Spain).

These Cherenkov flashes are faint and short-lived, lasting just a few nanoseconds, and thus can't be seen with the naked eye. To detect them, Cherenkov telescopes need large mirrors to collect enough light and fast electronics to record such brief events. In the LST's case, that means recording between 5,000 and 7,000 images per second, López-Coto adds.

Most of these images, however, contain only noise. Much of the noise comes from *cosmic rays*, charged particles such as protons or helium nuclei sent shooting through the cosmos by energetic processes. Cosmic rays also cause particle showers and Cherenkov light and are thousands of times more abundant than very high-energy gamma rays.

Unlike gamma rays, cosmic rays are deflected by magnetic fields. Since they don't travel in a straight line, it's difficult to link them to a specific source. So to learn about extremely energetic goings-on, astronomers must weed out the abundant signals from cosmic rays in order to find the few from gamma rays.

"Cherenkov telescopes are more software machines than hardware machines — if you look at them, they are pretty simple: just one detector, a primary mirror, no dome, nothing fancy," Calisse says. Their power lies in their computing abilities. "We receive a huge amount of events that only last billionths of a second, every single second, and these events must be filtered out, because nobody can save this amount of data for later analysis."

To reduce the deluge of information to manageable levels, the images are processed in real-time using machine-learning algorithms trained with simulations. The most important task is classification: to determine if a particle shower was caused by a gamma ray or not. This requires extensive simulations, following everything that happens when a gamma ray or a cosmic ray reaches the atmosphere, from the interaction it has with particles and the millions of particles produced in the cascade, to the light those particles produce and how the mirror and other equipment respond to these photons, López-Coto says. Luckily for astronomers, cosmic-ray showers look very different from gamma-ray showers.

By simulating gamma rays of different energies, researchers train the algorithm until it's able to recognize useful signals instantly and save them to the hard drive. The rest are deleted.

These shower images, however, don't look anything like the actual object being studied. "What you are observing are these kind of ellipse-like features which don't look like anything, it's just the image of the [particle] showers," says Elina Lindfors (University of Turku, Finland). "My background is in optical astronomy, so I initially found the concept of Cherenkov astronomy very strange, because in optical we are used to seeing what we are observing."

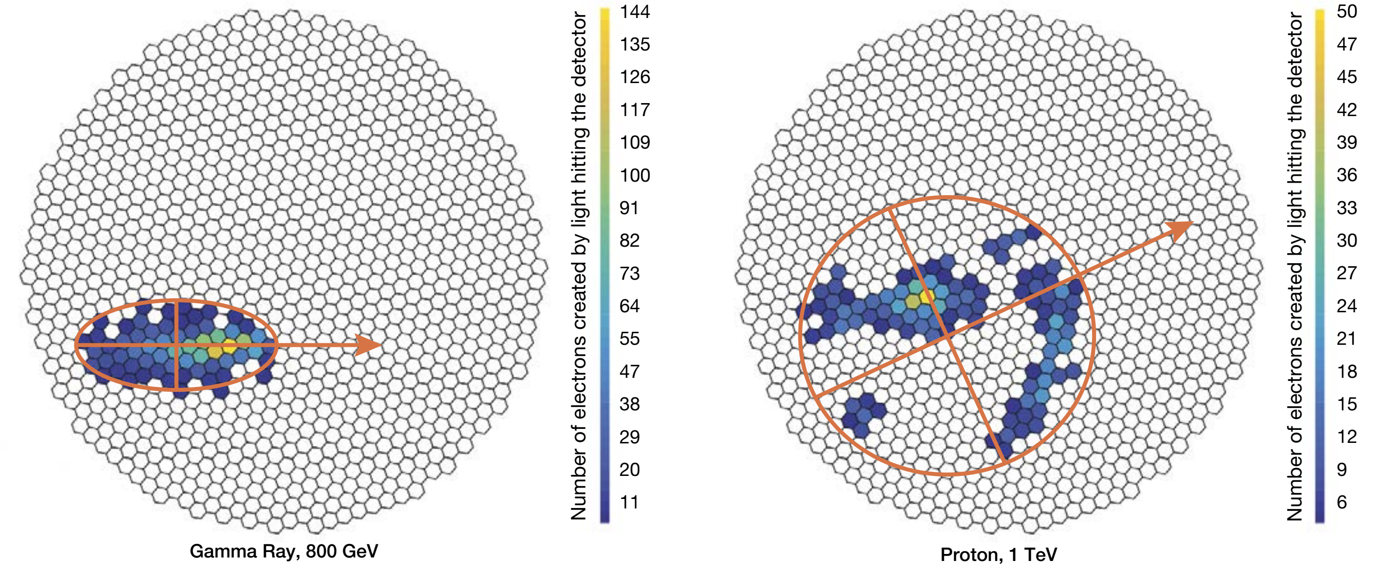
Based on how extensive the shower is, astronomers can determine the energy of the gamma ray that produced it. The shape of the ellipse can reveal the direction the photon came from. Having several telescopes is very useful for both tasks, thanks to stereoscopic effects that allow a better estimate of the direction and intensity of the particle showers, increasing precision and sensitivity significantly.

With this information, researchers can chart how many photons the source emits over a range of energies, generating a spectrum. By tracking how this spectrum evolves over time, they can also build a light curve. Based on the spectra and light curves, they can start modeling the astrophysical processes that produce the high-energy photons, Lindfors says.

Slow-Growth Science

It took decades for Cherenkov telescopes to detect high-energy gamma-ray sources. Soviet scientists installed the first array in Crimea in the 1960s, but their search was unsuccessful. A few research groups — mostly in the Soviet Union, the U.S., and Japan — persevered until the first confident detection was accomplished in 1989 using the Whipple 10-meter telescope in Arizona. Using Whipple, astronomers measured teraelectron-volt emission (that is, trillions of electron volts, or TeV) from the Crab Nebula, a supernova remnant that we now know is the brightest steady source in the sky at TeV energies.

"For a long time this was a science without any sources to study," says astroparticle physicist Razmik Mirzoyan (Max



▲ **SHOWER IMAGES** These simulated images show the shower created by a gamma ray *(left)* and by a cosmic-ray proton *(right)*. The ambient light of the night sky has been removed. Gamma rays make narrow showers, so their images are narrow and elongated. The ellipse's long axis corresponds to the air shower's vertical extension and points back to the source position in the field of view (arrow). Cosmic rays, on the other hand, create wider showers and subshowers and thus wider and irregular images.

Planck Institute for Physics, Germany). Even before the Whipple detection, Mirzoyan was developing a Cherenkov array in his native Armenia. However, the collapse of the Soviet Union forced him to pack up the array and move it to La Palma. A collaboration with German astronomers allowed him to secure funding and access to the site.

"The astronomers in La Palma were smiling at us a bit, not laughing, but smiling," Mirzoyan says. "All we had were these cheap telescopes without domes, standing outside, so they were a little bit . . . you know."

However primitive the array might have looked, it worked very well. In 1992, after just two months of operations with a single telescope, it detected the Crab Nebula's emission — the first independent confirmation of the Whipple results. Mirzoyan attributes the success to the maturity of the Cherenkov technology. "We measured it in two months because everything was ready, the know-how was ready, everything was understood," he says. Named HEGRA (High Energy Gamma Ray Astronomy), the completed array included six 5-meter telescopes and operated for 10 years, detecting 10 additional sources.

HEGRA's success led Mirzoyan and his colleagues to plan for a more capable instrument. They spearheaded the Major Atmospheric Gamma-ray Imaging Cherenkov (MAGIC) project, a 17-meter telescope also constructed on La Palma. "Our competitors only wanted to do proven things, but we wanted to go below 100 GeV, maybe 20 or 30 GeV," Mirzoyan says. That required many changes, including building larger telescopes and improved hardware. "It was very challenging because nobody knew what kind of problems we were going to find."

MAGIC started routine operations in 2004, receiving a second telescope and a complete overhaul of its camera and electronics between 2009 and 2012. Elsewhere, other teams have built VERITAS, heir of the Whipple telescope and also built in Arizona, with an array of four 12-meter telescopes, and HESS, built in Namibia, which also started with four 12-meter telescopes but incorporated a single 28-meter unit in 2012. These three projects are usually referred to as the third generation of IACTs. They're capable of observing photons made by gamma rays with energies from a few tens of billions to tens of trillions of electron volts.

MAGIC included a series of novelties. Not only was it the largest of its generation, at least initially, but it was the only one designed with rapid repositioning in mind. The goal was to be able to point anywhere in the sky in less than 25 seconds. This was important to catch transient, short-lived events, such as flares from the centers of distant galaxies that host massive black holes, cosmic explosions observable as gamma-ray bursts, and eruptions known as novae.

To achieve this rapid repositioning, both MAGIC telescopes had to be as light as possible. This meant using unconventional materials, such as carbon fiber, for its lightweight design, achieving a weight of 64 tons per telescope. In comparison, the neighboring Gran Telescopio Canarias, a 10.4-meter optical-infrared telescope, weighs around 400 tons. This featherweight construction in turn brings other complications, such as a wobblier structure that makes it more difficult to keep the mirrors aligned. A system of lasers and motors enables the mirrors to align automatically, Mirzoyan explains.

Other tricks to increase sensitivity included superfast electronics. MAGIC checks for cascading particles several times per nanosecond. Once it detects a cascade, it records up to 300 images per second. In this way, it can capture the light from the cascading particles while reducing the amount

ALEXANDER HAHN / MAX PLANCK INSTITUTE FOR PHYSICS (2) of background light that infiltrates each snapshot, just like increasing the shutter speed on a photographic camera lets less light in.

Twenty Years of MAGIC Discoveries

The twin MAGIC telescopes have enabled researchers to gain numerous insights into the workings of the violent universe. MAGIC observations have yielded more than 200 refereed papers, some of them paradigm-shifting.

The most awaited result, the detection of long gamma-ray bursts (GRBs), took more than 15 years to achieve. These bursts are brief flashes of gamma-ray emission produced when a massive star collapses to form a black hole.

On January 14, 2019, two space satellites, the Neil Gehrels Swift Observatory and the Fermi Gamma-ray Space Telescope, independently discovered a GRB and sent an alert to astronomers worldwide. On average, one GRB occurs every day, but this was the first time everything was just right for MAGIC to start observing just 50 seconds after the initial detection.

While MAGIC's design was optimized precisely to catch GRBs, it turned out to be more difficult than expected. "Even if there's one gamma-ray burst per day, it has to be observable during good weather, with a very dark night — so no Moon — and significantly above the horizon," Lindfors says.

In addition, the explosion has to happen relatively close to Earth because when traveling over long distances, high-energy gamma rays end up being "absorbed" by other photons suffusing the universe. "Gamma-ray bursts have an average redshift around two" — corresponding to a travel time of some 10 billion years — "and those are beyond what we can catch."

MAGIC probes higher energies than space-based gamma-ray telescopes do, and it revealed that the 2019 source had emitted high-energy photons that reached 1 TeV. Those energetic photons were 100 times more abundant than the same emission from the Crab Nebula. As usual for GRB afterglows,

Powering Up

In order to move the Large-Sized Telescope (LST) to point to anywhere in the sky within 20 seconds, the telescopes are equipped with an energy-storage device that can release the equivalent of 1 megawatt almost instantly. Lithium batteries are too slow and too expensive; in fact, there isn't enough power in the electrical grid of the entire island of La Palma to power the device.

Instead, the telescope uses an inertial mechanism. A massive wheel spins in a vacuumed enclosure and, when necessary, electromagnets engage and slow the wheel, releasing kinetic energy that is converted to electricity. The exact same technology, albeit much more compact, is used in Formula 1 cars, called KERS (Kinetic Energy Recovery System). The LST's KERS devices are housed in shipping-like containers, next to the telescopes.

UNUSUAL SIGHT The LST prototype (right) sits with the two MAGIC telescopes on the slopes of the Roque de los Muchachos. The LST's parabolic mirror comprises 198 smaller, hexagonal segments, creating a total reflective surface of 400 square meters.

the emission faded quickly, falling under MAGIC's detection limits within half an hour. Follow-up observations revealed that the GRB came from a galaxy located several billion light-years from Earth.

The high-energy photons MAGIC detected were unexpected. Astronomers had thought the photons in these bursts were *synchrotron radiation*, which is caused by electrons spiraling along magnetic field lines. But synchrotron radiation cannot reach such high energies. The finding prompted researchers to think that a different process could be at work: *inverse Compton scattering*, in which photons gain energy after colliding with speedy electrons. This is the first evidence of this process occurring in GRBs.

MAGIC has also dipped into the realm of multi-messenger astronomy by determining the source of a cosmic neutrino detected by the IceCube experiment in Antarctica. Neutrinos are extremely hard-to-detect subatomic particles with no electrical charge and barely any mass (*S&T:* May 2023, p. 14). Astronomers are actively trying to track cosmic neutrinos back to their sources in order to understand energetic physical environments in the universe, but they've had minimal success.

On September 22, 2017, IceCube detected a very high-energy neutrino and pinpointed its arrival direction with some accuracy. The Fermi satellite revealed that the arrival direction of the neutrino aligned with the location of a flaring supermassive black hole named TXS 0506+056, whose light had traveled nearly 4 billion years to reach Earth. MAGIC then measured the gamma rays the black hole emitted, which reached 400 GeV, making the TXS 0506+056 black hole the most probable neutrino source candidate to date.

Against the Elements

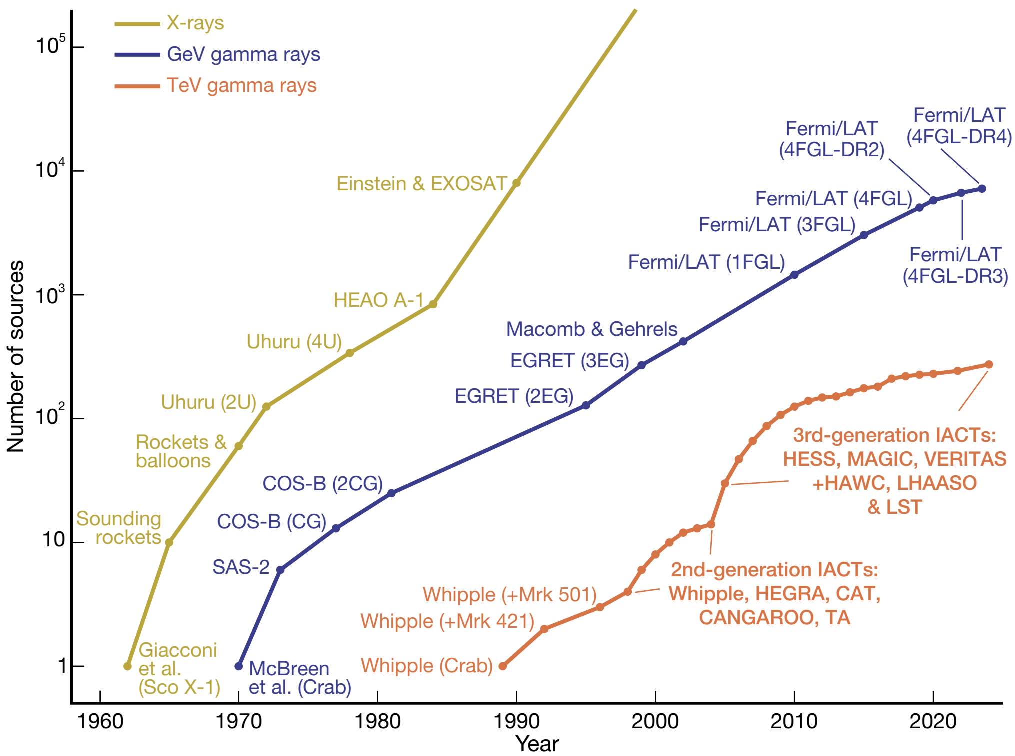
The LSTs are designed to withstand winds up to 200 km/h (more than 120 mph) in their parked positions, lest they become giant windsails and be blown away. In 2020 the prototype survived winds above 170 km/h with minimal damage.

"It's very important to try to pinpoint the sources," Lindfors says. The neutrino's high energy suggests whatever made it was an extreme particle accelerator. "Of course you want to know if it's some violent phenomena in the universe you already know, or if it's something completely new."

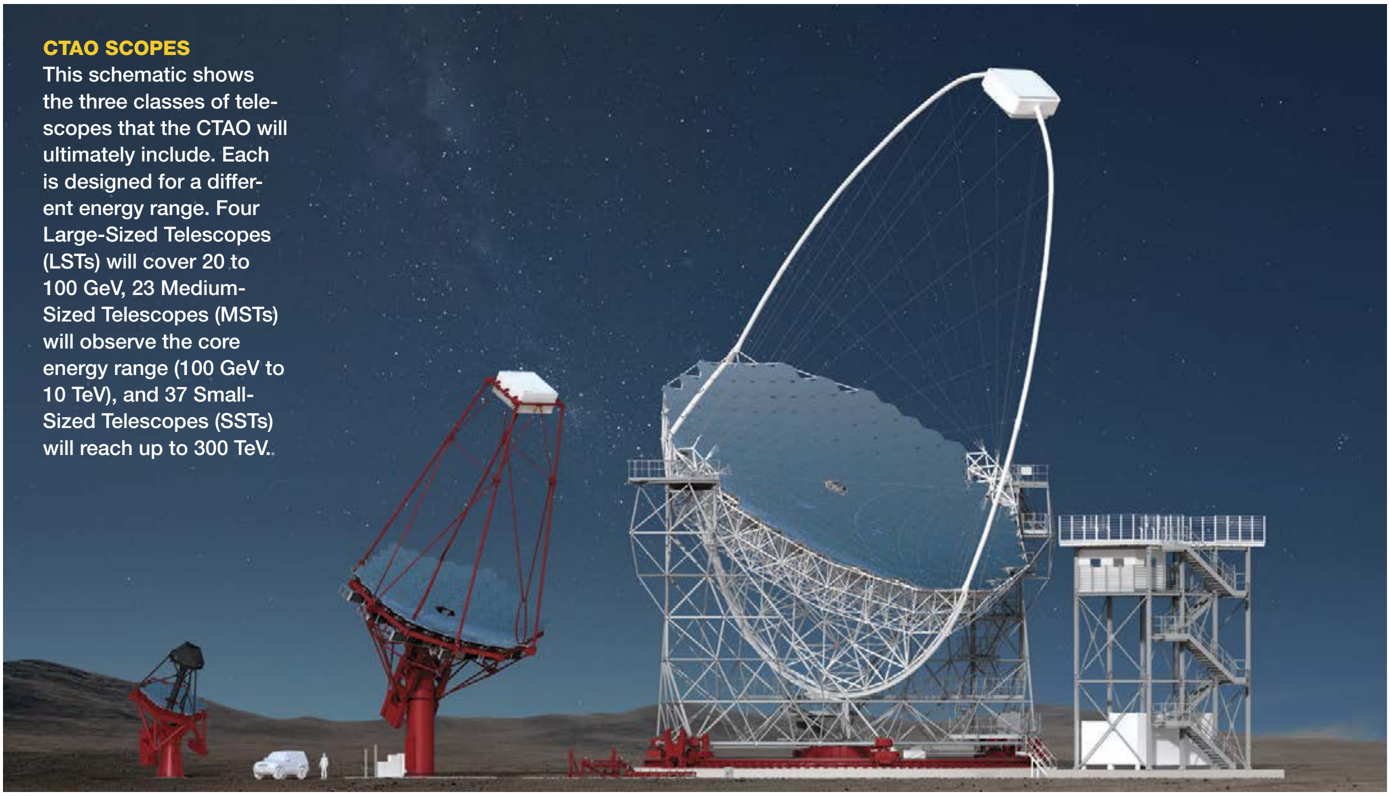
MAGIC also revealed that pulsars can emit high-energy gamma rays. There are a few thousand known pulsars, but only about 400 of them emit gamma rays. In 2008, MAGIC was the first telescope to measure gamma rays above the 25-GeV range coming from the Crab pulsar, the neutron star whose supernova in 1054 produced the Crab Nebula. In 2016, MAGIC scientists announced they'd detected even higher energies coming from the Crab pulsar, clocking in at a whopping 1.5 TeV.

These findings created a lot of trouble for the models that explain how pulsars produce gamma rays, directly ruling out some of those scenarios. Theoreticians are still trying to come up with new models that could account for such high photon energies.

The remnants of smaller stars can also produce gamma rays, it turns out. *Novae* are thermonuclear explosions that occur when a white dwarf — the corpse of a star like our Sun when it has burned through all the fuel in its core — steals too much gas from a companion star (*S&T:* Apr. 2023, p. 36). The gas builds up on the white dwarf's surface until the extreme pressure and temperature incite a runaway nuclear reaction. These explosions are luminous, temporarily shining as brightly as 10,000 Suns, but not cataclysmic. Sometimes, astronomers



GROWING FIELD In the last 60 years, the number of sources detected at X-ray and gamma-ray energies has increased substantially. Astronomers hope that CTAO will increase the tally of the highest-energy gamma-ray sources (orange) to more than 1,000.



CTAO SCOPES
This schematic shows the three classes of telescopes that the CTAO will ultimately include. Each is designed for a different energy range. Four Large-Sized Telescopes (LSTs) will cover 20 to 100 GeV, 23 Medium-Sized Telescopes (MSTs) will observe the core energy range (100 GeV to 10 TeV), and 37 Small-Sized Telescopes (SSTs) will reach up to 300 TeV.

see the same white dwarf erupt multiple times.

On August 8, 2021, the light of one of these explosions from the object RS Ophiuchi reached Earth, after traveling for nearly 9,000 years. Again, the Fermi satellite alerted MAGIC, which was able to detect gamma-ray emission in the 60 to 250 GeV energy range.

By combining the Fermi and MAGIC observations, researchers concluded that the gamma rays detected by MAGIC were from protons accelerated to near the speed of light by powerful shockwaves produced by the nova explosion. This discovery helps explain the origin of a portion of cosmic rays out there, because it shows that novae can accelerate protons to these high energies.

"For galactic cosmic rays, we still don't know how or where [they] are accelerated or how they propagate," says López-Coto. "There are lots of open questions, and being able to add one piece to the puzzle, to say, 'There, what is being accelerated are protons,' is very important."

Looking Forward

Given MAGIC's ongoing discoveries, scientists are eager to start working with the new CTAO. However, after navigating both a global pandemic and a volcanic eruption in 2021 that halted operations for months, those in charge are wary of giving dates for the beginning of science observations.

"I expect in my best dreams that the first telescope will be opening for early science by 2026 or late 2025," Calisse says. La Palma's three remaining LSTs and the smaller telescopes should follow soon thereafter. In the meantime, in Chile, the access road to the observatory has just been completed, and the construction of the inner roads and telescope foundations will begin soon. Construction of the first telescopes there won't start until 2026.

That isn't stopping astronomers from doing research now, though. The LST-1, still under commissioning, is already making discoveries. In December 2023, scientists reported the detection of the most distant quasar emitting at very high energies that's been found to date. It's the second most distant gamma-ray source ever observed, with a redshift of 0.997, meaning its light has traveled nearly 8 billion years to reach us.

When completed, CTAO will be the largest and most sensitive detector of gamma rays in the world. It will cover a wide range of energies, from 20 GeV up to 300 TeV, pushing the edge of the observable electromagnetic spectrum. Researchers expect that it will add more than 1,000 new sources to the roughly 250 known today.

"For everybody in the field it's evident that we are seeing only the tip of the iceberg," Lindfors says. "There are a lot of sources that we can only see when they are brightly flaring, because the current telescopes aren't sensitive enough." Then there's the unexpected, she adds. "The history of science shows that in addition to the guaranteed, you will see some things that you didn't expect, and of course that is the most exciting part."

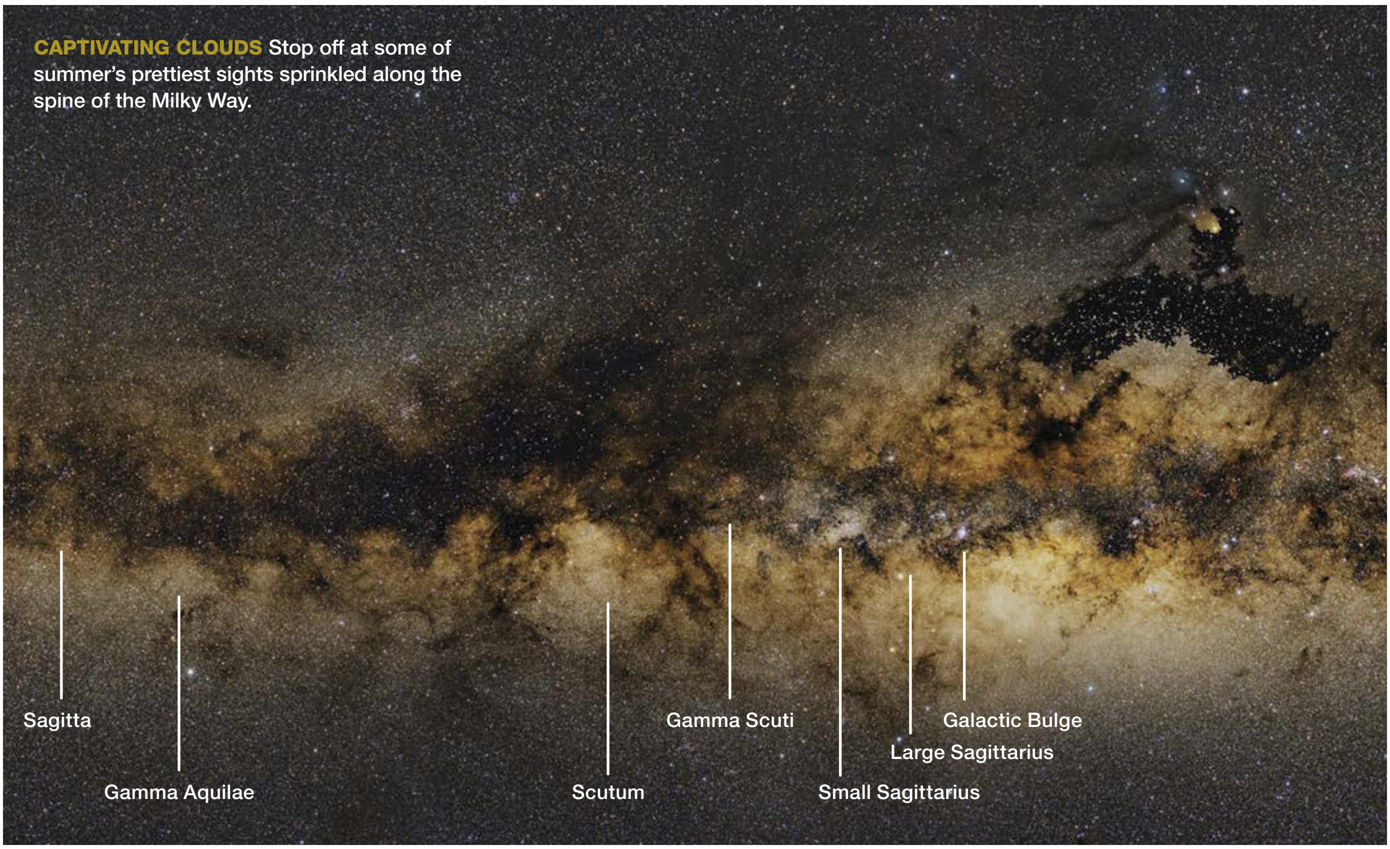
Contributing Editor **JAVIER BARBUZANO** (**@javibarbuzano**) is a science journalist based in Barcelona, Spain. He day-dreams about living on La Palma.

Summer Star Clouds

Spend some time navigating among shimmering sights.

During summertime, when it's too cloudy for astronomy, I often quench my thirst for starlight with a remarkable series of century-old photographs by Edward Emerson Barnard, the patron saint of Milky Way observers and imagers. In his *A Photographic Atlas of Selected Regions of the Milky Way*, published in 1927 (and updated by Gerald Orin Dobek in 2011), Barnard's images show the staggering beauty and complexity of a major spiral galaxy seen close up (*S&T:* Aug. 2023, p. 28). They also inspire new ideas for observing projects throughout the year.

Barnard's pioneering astrophotography helped elucidate the structure and contents of the Milky Way in the early 20th century, especially the nature of the dark nebulae he captured in his images. Many of these nebulae were eventually compiled into a catalog of 349 "Barnard" objects. But Barnard also revered the brilliant starry patches in the Milky Way that he first observed as an amateur comet hunter. In his book he wrote, "The stars pile up in great cumulous masses like summer clouds," especially where the "extreme brilliancy of these great star clouds" was most prominent



CAPTIVATING CLOUDS Stop off at some of summer's prettiest sights sprinkled along the spine of the Milky Way.

SPINE OF THE MILKY WAY: FRANK SACKENHEIM; SAGITTARIUS: BRIAN VENTRUDO

SHIMMERING SIGHTS Sagittarius offers splendid views of Milky Way fields comprising thousands of stars. The fun doesn't stop there — follow the Milky Way northward through neighboring constellations for more star clouds.

Object	Type	Mag(v)	Size	RA	Dec.
M7	Open cluster	3.3	75′	17^h 53.8^m	–34° 48′
B287	Dark nebula	–	25′ × 15′	17^h 54.4^m	–35° 12′
B286	Dark nebula	–	15′	17^h 53.1^m	–35° 37′
NGC 6437	Star field	–	40′	17^h 48.4^m	–35° 26′
NGC 6455	Star field	–	58′	17^h 51.1^m	–35° 20′

For all tables: Angular sizes are from recent catalogs; right ascension and declination are for equinox 2000.0.

▲ **STAR CLUSTER UPON A STAR CLOUD** The Scorpius open cluster M7 is a foreground object in the line of sight of a much more distant star cloud. Accompanying M7 are two clumpings of stars listed in the *New General Catalogue of Nebulae and Star Clusters* but that aren't technically clusters — instead, they're designated as star fields.

RAINER RAUPACH / JOSEF PÖPSEL / FRANK SACKENHEIM / CAPELLA OBSERVATORY

toward Sagittarius and Scutum. Barnard likely wasn't the first to use the term *star cloud*, but his images have long inspired stargazers to observe them.

What is a star cloud? Unlike open or globular star clusters, there's no strict scientific definition. We now understand that what Barnard called star clouds are simply distant and star-dense patches of our galaxy's bulge or spiral arms seen through gaps in the dark thunderheads of interstellar gas and dust. In summer, Northern Hemisphere observers get their best looks at the most prominent star clouds, and many serve as bases for exploring deep-sky sights nearby. For this tour, I deployed a pair of 2.1×42 "constellation binoculars" and image-stabilized 15×50 binoculars for wide views, an 85-mm f/6 refractor, and a 10-inch Dobsonian f/4.7 to bring out detail on smaller objects. Let's begin with some bright summer star clouds low in the south then move northwards along the Milky Way's starry band.

A Glimpse into the Center of the Milky Way

Some 5° northeast of the Stinger of Scorpius, the Scorpion, you'll find the lovely open cluster **M7**. If you're looking at the Messier, you're also looking at a small, dense star cloud. The 3.3-magnitude cluster, which spans about 75′, is a foreground object around 1,000 light-years away, while the star cloud lies at least 10,000 light-years distant toward the center of the galaxy. The cloud is roughly rectangular, about 1.7° × 0.7°

▲ **THE ARCHER'S DUO** West of the Teapot asterism is the larger of the two star clouds we'll visit on this tour in Sagittarius. This image and the one on page 24 were captured under the dark skies of Eastern Maine on photographic film using a Pentax 67 camera with a 400-mm f/4 prime lens piggybacked on an 8-inch Meade 2080.

Object	Type	Mag(v)	Size	RA	Dec.
B295	Dark nebula	–	50′	$18^h\ 04.1^m$	–32° 00′
B289	Dark nebula	–	35′ × 7′	$17^h\ 56.6^m$	–29° 01′
NGC 6520	Open cluster	7.6	5′	$18^h\ 03.4^m$	–27° 53′
B86	Dark nebula	–	5′	$18^h\ 03.0^m$	–27° 52′
NGC 6522	Globular cluster	9.9	9.4′	$18^h\ 03.6^m$	–30° 02′
Baade's Window	Star field	4	60′	$18^h\ 03.6^m$	–30° 02′
NGC 6528	Globular cluster	9.6	5′	$18^h\ 04.8^m$	–30° 03′
B298	Dark nebula	–	4′	$18^h\ 05.2^m$	–30° 06′

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stretching in a northeast-to-southwest direction with M7 near its geometric center. The dark nebula **B287**, spanning 25′ × 15′, lies immediately southeast of the cluster, while the smaller oval of **B286**, some 15′ across, sits around 50′ south of M7 and features the 6th-magnitude foreground star HD 162517. When I aim right at M7 with my 85-mm refractor with a 13-mm Ethos eyepiece (46× and 2.2° field of view), I see a spectacular vista. The cloud behind M7 appears off-white — a striking contrast with the blue-white stars of the cluster. Images reveal a yellow tinge to these ancient stars near the Milky Way's core.

Two concentrations of stars lie within the larger star cloud. Look for 40′-wide **NGC 6437** about 1° southwest of M7. Between NGC 6437 and M7, you'll find **NGC 6455**, a Milky Way field featuring several 7th- to 9th-magnitude stars. At first, I couldn't distinguish these clumpings of stars with my small refractor from the broader cloud. But I finally extracted them with my 10-inch Dob fitted with a 35-mm Panoptic yielding a 2° field. (A tip of the hat to Chris Beckett of the Royal Astronomical Society of Canada for pointing me to these little concentrations.)

Now slew to the **Large Sagittarius Star Cloud** northwest of the spout of the Teapot asterism. Here we're looking directly toward the center of our galaxy some 26,000 light-years away. The cloud's brightest section spans about 6° × 4° and extends northeast to southwest on its long axis. Along its northwestern edge it borders the dark Great Rift, which

Object	Type	Mag(v)	Size	RA	Dec.
B92	Dark nebula	–	15′ × 9′	18^h 15.6^m	–18° 14′
B93	Dark nebula	–	15′ × 2′	18^h 16.9^m	–18° 04′
NGC 6603	Open cluster	11.1	4′	18^h 18.4^m	–18° 24′

▲ **PUFF OF STEAM** The Small Sagittarius Star Cloud appears to emerge from the spout of the Teapot asterism and is one of the prettiest sights in the summer night skies — and you don't need optics to enjoy it.

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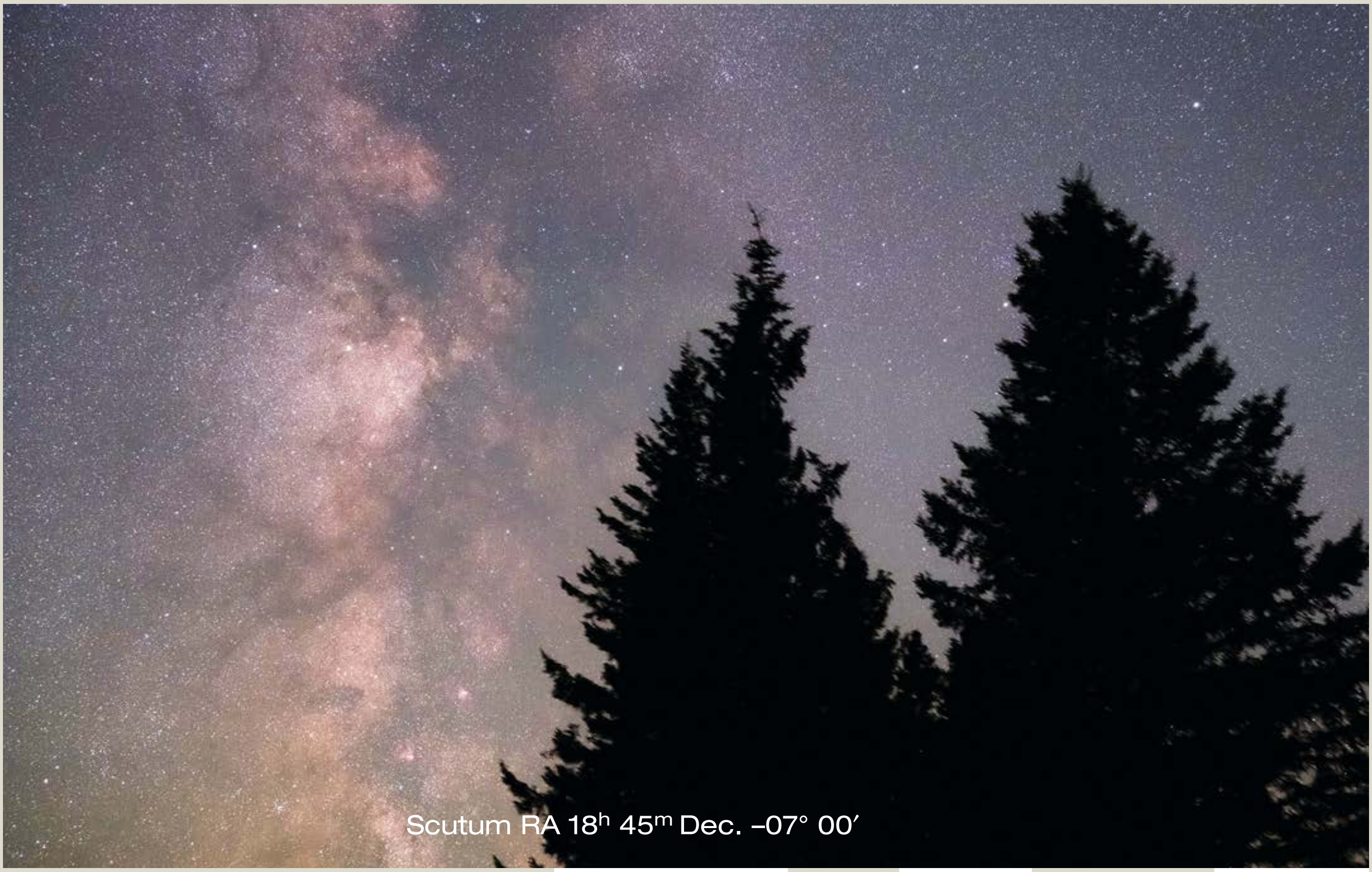
bisects the Milky Way from Sagittarius all the way to Cygnus. In 15×50 binoculars, I see the Rift impinge irregularly into the unresolved stars of the cloud. On its southeastern edge, the star cloud fades gradually. My 85-mm refractor at 25× shows the round dark nebula **B295**, about 50′ in diameter, on the southeastern edge of the cloud some 48′ southwest of Gamma (γ) Sagittarii, as well as the small, rectangular **B289** (35′ × 7′) inside the northwestern edge around 2½° northwest of Gamma. The star cloud is particularly bright just east of B289. With a 24-mm Panoptic (at 25× and a 2.7° field), my refractor reveals a sandpapery texture that hints at a staggering number of ancient and distant stars.

In the cloud's northern reaches, the 8th-magnitude open cluster **NGC 6520** looks tight and grainy in my 85-mm and just 2′ wide. My 10-inch reflector with an 8-mm Ethos at 150× opens the cluster beautifully and showcases its blue-white stars. At 5′ across, the small foreground dark nebula, **B86**, lies west of the cluster's center and has the 7th-magnitude orange star HD 164562 on its northwestern edge, making the field even more spectacular.

Look for the 10th-magnitude globular cluster **NGC 6522** about 40′ northwest of Gamma Sagittarii on the cloud's southeastern edge. The cluster coincides with 1°-wide **Baade's Window**, a fairly dust-free region that reveals stars just 1,800 light-years offset from the galactic center. These stars are brilliant and gritty, more concentrated than the rest of the cloud. In my 10-inch Dob I easily see NGC 6522 along with **NGC 6528**, another 10th-magnitude globular 15′ to the east. This memorable field also includes the small (4′), dark nebula **B298** about 5′ east-southeast of the center of NGC 6528.



Object	Type	Mag(v)	Size	RA	Dec.
B111	Dark nebula	–	120′	18^h 50.6^m	–04° 57′
B110	Dark nebula	–	11′	18^h 50.1^m	–04° 48′
B113	Dark nebula	–	11′	18^h 51.4^m	–04° 19′
B103	Dark nebula	–	4′	18^h 39.4^m	–06° 40′
M11	Open cluster	5.8	11′	18^h 51.1^m	–06° 16′
IC 1295	Planetary nebula	12.5	1.5′	18^h 54.6^m	–08° 50′
NGC 6712	Globular cluster	8.1	9.8′	18^h 53.1^m	–08° 42′

▲ **IN THE SHIELD** Even a small constellation such as Scutum, the Shield, holds not one but two star clouds. The Scutum Star Cloud occupies the northern reaches of the constellation, while you'll find the Gamma Scuti Star Cloud, as the author designates it, in its southern reaches.

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Star Clouds in the Sagittarius Arm

Farther northeast lies the spectacular **Small Sagittarius Star Cloud** (M24). You'll find it 2° north of Mu (μ) Sagittarii above the Teapot asterism. Just 2° × 1° in size, the cloud also runs northeast to southwest and fits in the low-power field of my 85-mm scope at 25×. This star cloud may be the single most beautiful patch of sky except possibly for the region in the southerly constellations of Carina and Centaurus around the Eta Carinae Nebula.

Like its larger neighbor, M24 is a gap in the dark dust clouds that offers us a look at nearly unattenuated starlight from 9,000 light-years away in the galaxy's Sagittarius Arm. But the stars here are far bluer and younger than those in the Large Cloud or those near M7. The entire band of the Milky Way would appear as clear and luminescent as M24 if it weren't for the vast clouds of fine interstellar dust ejected by the nuclear smokestacks of generations of dying stars.

The stars in M24 range from magnitude 6 down to undetectable in my 85-mm at 25× and appear blue-white or even green. In steady air, M24 assumes a shimmering three-dimensional quality. On its northern edge, look for the small, oval dark nebulae **B92** and **B93** (both 15′ long). The former has a single 11th-magnitude star near its eastern side that I can just see in my refractor. Both nebulae are foreground objects. The compact open cluster **NGC 6603** also lies within M24 to the northeast. At 11th magnitude and just 4′ across, it appears in my refractor at 46× as a fuzzy patch 4′ north of the 7th-magnitude orange star HD 167976. In my 10-inch it opens into an irregular and ill-defined group of stars. Some older catalogs misidentify the M24 star cloud as NGC 6603, which was likely too dim for Messier to observe.

Moving about 5° northeast into Scutum we find a small, vaguely triangular star cloud around 3° east of the Eagle Nebula (M16). The cloud has 5th-magnitude Gamma Scuti at its southwestern corner, where it's particularly bright and dense. It spans about 2° at its base, which extends eastward from Gamma then stretches 3½° northward to 5th-magnitude HD 171391. **B312** lies to the cloud's south. The stars of this **Gamma Scuti Cloud** (as I call it) fall off markedly to the east and more gradually to the west, where a small gulf lies between the star cloud and M16. In my refractor at 25×, the cloud's bone-white stars fill the field and appear slightly granular and less uniform than those in M24, but it's still quite a lovely sight.

Let's move up to the **Scutum Star Cloud**, an anvil-shaped outcropping 5° long running northwest to southeast between Beta (β) and Delta (δ) Scuti. The star cloud joins the broader Milky Way in the southeast. In the northeast it ends abruptly at the prominent 2°-wide bay of **B111**, which harbors two smaller and even darker nebulae, **B110** and **B113**. To the west, the cloud ends at **B103**. Larger than M24 and roughly as bright, the Scutum Star Cloud reveals a splendid starscape that I can partially resolve with averted vision in my 85-mm refractor at 25×.

On the eastern edge of the Scutum Star Cloud we see the spectacular **M11**, the Wild Duck Cluster. Named for its triangular shape resembling a flock of migrating birds, this 6th-magnitude open star cluster spans 11′, but it's so packed with stars that it needs substantial magnification to pull it apart. I prefer the view of M11 in my Dob fitted with a 13-mm Ethos, which delivers 92× — the dense cluster of white stars on the more distant starry background is breathtaking.

About 2.7° south-southeast of M11, look for the planetary nebula **IC 1295** and the globular cluster **NGC 6712** about 25′ west-northwest of the nebula. At magnitude 12.5, IC 1295 looks dim but obvious in my 10-inch. It spans about 1.5′, making it a little larger than the Ring Nebula (M57). At 92× the almost-10′-wide, 8.1-magnitude globular appears noticeably brighter than the pale glow of the planetary. The charts of the *interstellarum Deep Sky Atlas* label NGC 6712 as the "Weird Globular." The cluster is somewhat peculiar to astronomers as it appears to have a dearth of low-mass stars compared to other globulars. Such stars may have been yanked away by external gravitational forces as the cluster passes through the galaxy.

Moving on, look about 3° northwest of Gamma Aquilae (Tarazed) to see another pleasing star cloud that spans 4° × 2°. As with the other star clouds described here, it stretches in a northeast-to-southwest direction. Larger than M24 but not nearly as scintillating, the **Gamma Aquilae Star Cloud**, as I've dubbed it, appears uniform in both my 15×50 binoculars and in my refractor at 25× except for the single irregular dark nebula, **B337**, which is about 3′ long and lies just northeast of center. The cloud fades to the northeast into the Milky Way. To the west it drops off suddenly in a region of darkness nearly as large as the star cloud itself. The southern edge of this dark patch interrupts the starry haze for about 1°. Southwest of this dark bay lies a protruding patch of stars about 1° wide that resembles a miniature version of the Scutum Star Cloud and appears just as bright in my refractor.

While you're exploring here, look about 1½° west of Gamma Aquilae to take in the inky-dark fingers of **B142** and **B143** that comprise the irregular region, a bit less than 1° long, known as Barnard's E. The view of orange Gamma and the unmistakable shape of the nebulae deliver a superb sight in my 85-mm at 25×.

Continuing on our northeasterly route along the Milky Way let's stop briefly in Sagitta, which harbors a dense star field next to the Great Rift to the north and east. Barnard noted this small **Sagitta Star Cloud** (again, my moniker), less than 1° across, centered about 12′ north-northeast of a line between Alpha (α) and Beta Sagittae. Sure enough, as I aim my refractor with the 13-mm Ethos in this direction, I see a shimmering patch of unresolved blue-white stars that sticks out from the broader Milky Way to the east and south. The dark nebula **LDN 731**, about as large as the cloud, lies immediately to its west.

The Northern Milky Way

At last we arrive at the **Cygnus Star Cloud**, the brightest section of the northern Milky Way and the largest cloud on this tour. It spans 16° from Beta Cygni (Albireo) in the southwest to Gamma Cygni (Sadr) in the northeast. To the northwest it blends into the broader Milky Way; to the southeast it disappears into the dark nebulae of the Great Rift. We see this cloud's stars through a gap in interstellar dust in the Orion-Cygnus Arm of the Milky Way.

The Cygnus Star Cloud looks spectacular even without optics, but it's especially beautiful in my super-wide-angle 2.1×42 binoculars, an ideal instrument for observing it. Near Albireo the cloud appears orderly, uniform, and mostly unre-

Gamma Scuti RA 18^h 33^m Dec. –14° 20′

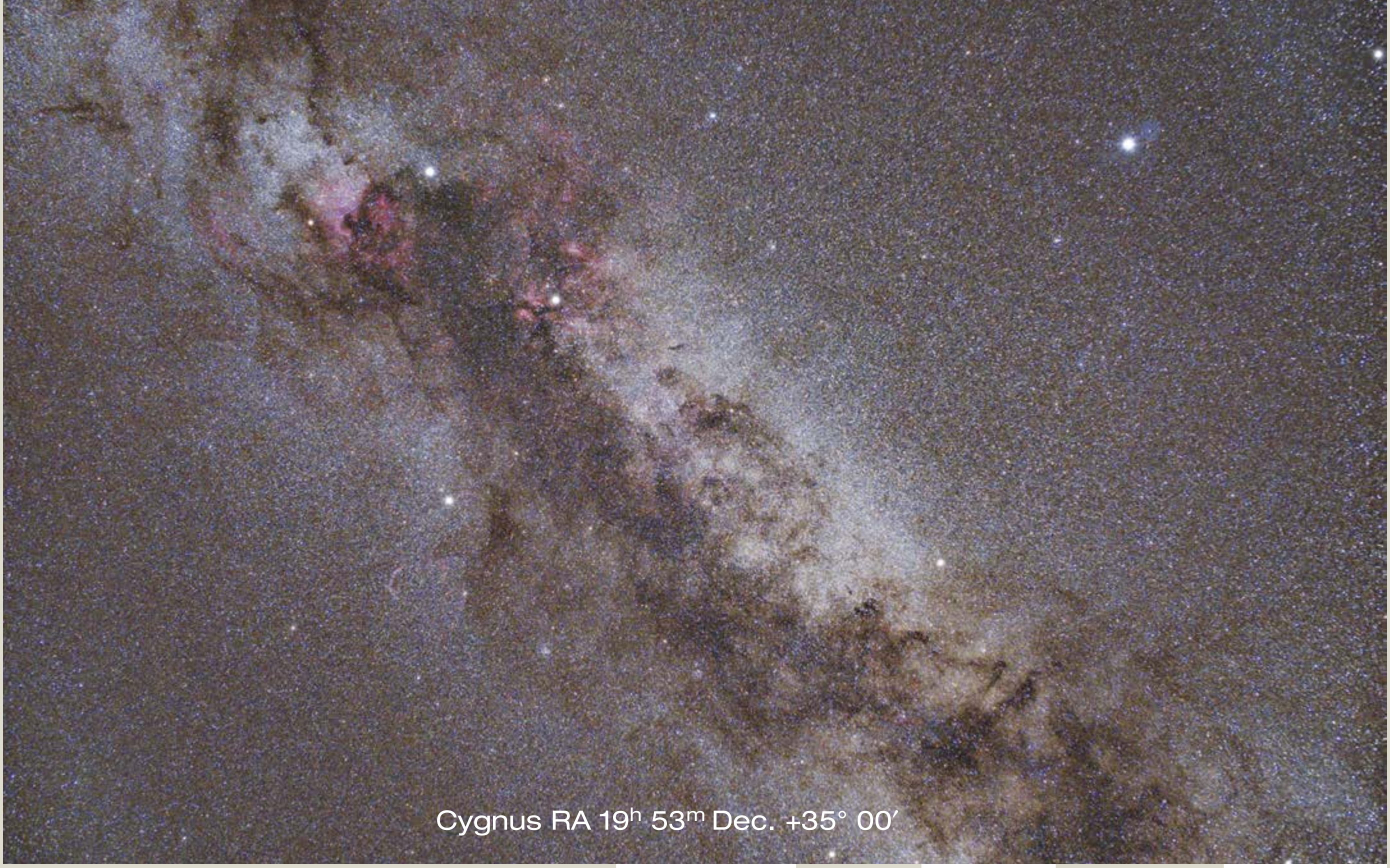
Object	Type	Size	RA	Dec.
B312	Dark nebula	100′ × 30′	18^h 32.2^m	–15° 35′

Gamma Aquilae RA 19^h 31^m Dec. +11° 38′

Object	Type	Size	RA	Dec.
B337	Dark nebula	3′	19^h 37.0^m	+12° 24′
B142	Dark nebula	40′	19^h 39.7^m	+10° 31′
B143	Dark nebula	60′	19^h 41.4^m	+11° 00′

Sagitta RA 19^h 41^m Dec. +18° 07′

Object	Type	Size	RA	Dec.
LDN 731	Dark nebula	30′	19^h 38.2^m	+17° 37′



▲ **GLORIOUS CYGNUS** You'll find the crowning glory of summer's shimmering sights in the celestial Swan. Overhead on August nights is the Cygnus Star Cloud. But do spend some time on its neighboring targets — you'll likely return again and again.

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Object	Type	Mag(v)	Size	RA	Dec.
B144	Dark nebula	–	270′ × 90′	19^h 58.7^m	+35° 20′
IC 1318	Emission nebula	–	50′ × 30′	20^h 22.2^m	+40° 15′
NGC 6910	Open cluster	7.4	10′	20^h 23.2^m	+40° 47′
M29	Open cluster	6.6	10′	20^h 24.1^m	+38° 30′
NGC 7000	Emission nebula	5.0	120′ × 100′	20^h 59.3^m	+44° 31′

solved aside from a few 6th- to 8th-magnitude foreground stars. I see a bright patch about 1° southeast of a line between Albireo and Phi (φ) Cygni. About 2° southeast of 3.9-magnitude Eta (η) Cygni you'll find three tiny clouds, each around 1° across, which pop in my 15×50 binos. Near the center of the Cygnus cloud lies **B144**, with Eta on its southwestern edge. About 4.5° long and 1.5° wide, this dark nebula is easily visible without optics in a good sky.

Towards Sadr, the cloud blends into patches of darkness and bright nebulosity. Look for a dark channel ¼° south of Sadr, with the brightest parts of the **IC 1318**, the Butterfly Nebula, on either side. I see the emission nebula's ghostly glow in my refractor with the 13-mm Ethos. The field includes the small Y-shaped open cluster **NGC 6910** with two 7th-magnitude yellow-white stars and a handful of fainter 9th- and 10th-magnitude glints covering 10′. When I nudge the scope to put Sadr at the northern edge of the field, the distinctive, 6.6-magnitude open cluster **M29** pops into view to the south. It looks like two parentheses of three 9th-magnitude stars, each with a few fainter stars sprinkled in.

We'll end near the **North America Nebula** (NGC 7000), which Barnard calls "a splendid mixture of stars and nebulosity," about 3° east of Deneb (Alpha Cygni). While the nebula is visually intriguing, a stunning view lies 2° northeast of its center, where we see a brilliant star cloud just beyond the nebula's "Alaska." With a diameter of about 2°, the cloud equals M24 and the Scutum Star Cloud in brightness and beauty, especially for observers at northerly latitudes who can view it nearly overhead. In my 85-mm at 46×, I see resolved 9th- and 10th-magnitude stars in a truly spectacular field. Nudging the scope 2° west across a dark gulf reveals yet another star cloud of equal size but slightly lesser brightness.

More star clouds lie along the Milky Way, but I'll let you sweep the sky to discover your own favorites. In time, you may begin to navigate the best parts of the summer sky not by constellation but by the prominent clots of stars and dark nebulae along this starry backbone of the night.

■ Contributing Editor **BRIAN VENTRUDO** is a writer, scientist, and longtime amateur astronomer based in Calgary, Canada. He explores the Milky Way on short summer nights with binoculars, telescopes, cameras, or just with the unaided eye. He writes about astronomy and stargazing at his website **CosmicPursuits.com**.

The Challenging History of New Worlds

How a revolutionary idea was born and gained acceptance despite a lack of solid scientific support.

When you're out sharing the night sky with friends and family, how often are you asked about Earth-like worlds and the possibility of life on them? Probably a lot. The questions might center around news stories about the thousands of exoplanets that have been discovered, or UFO sightings, or maybe about whether the interstellar visitor 'Oumuamua was a product of extraterrestrial technology. And references to pop culture arising from Star Trek or the cinematic universes of Star Wars and Marvel might get mixed in, too.

Most people think of the idea of life on other planets as being based on science. But history and current research challenge that thinking.

Trillions Upon Trillions

The modern idea of other planets originates with Nicolaus Copernicus (1473–1543) and Giordano Bruno (1548–1600). Copernicus envisioned Earth circling the Sun, along with Mercury, Venus, Mars, Jupiter, and Saturn — the planets then known. Bruno, a Copernican, considered stars to be faraway suns, circled by other inhabited earths.

Prior to Copernicus, planets were merely celestial lights — stars that wandered from one zodiacal constellation to another (the word *planet* comes from the Greek for "wanderer"). Under Copernicus, however, the idea of the planets orbiting the Sun meant they had something in common with Earth. And if planets had one thing in common with Earth, why couldn't they have others? Why couldn't life be one of those things? As Bernard Fontenelle (1657–1757 — yes, those dates are correct) put it in his 1686 book *Conversations on the Plurality of Worlds*,

> *. . . we find that all the planets are of the same nature, all obscure bodies, which receive no light but from the sun, and . . . their motions are the same . . . they are alike; and yet, if we are to believe that these vast bodies are not inhabited, I think they were made to little purpose: why should nature be so partial, as to except only the earth? . . . I must believe the planets are peopled as well as the earth.*

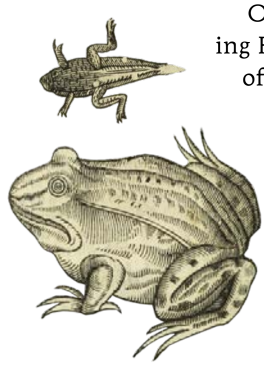
It was a logical idea, for more reasons than just the obvious similarities between the other planets and Earth. People had long thought that life emerged naturally from matter. Mice were believed to spontaneously form from dirt. Ancient Jewish Rabbis even discussed whether the dirt that generated a mouse would be unclean, since the Bible lists mice as being among the various "creeping things" that are unclean.

Antonie van Leeuwenhoek, the pioneering Dutch microscopist of the 17th century, complained of "respectable and learned men" who told him that eels were spontaneously generated from dew, "in confirmation of which they add, that if no dew has fallen, there will be no eels found." Edward Topsell's 1658 book *The History of Four-Footed Beasts and Serpents*, included a little poetry, inspired by reports of frogs seen forming from mud:

> *Durt hath his seed ingendring Frogs full green,*
> *Yet so as feetlesse and without legs on earth they lie,*
> *So as a wonder unto passers-by is seen,*
> *One part hath life, the other earth full dead is nye.*

If matter naturally generated life, all planets should have life on them. Fontenelle said that even were "the moon but one continued rock" and nothing more, he would presume it to be populated with rock-eating creatures. And with the stars being, as he said, "so many suns" each having "planets, to which they give light," humankind was looking at a universe positively teeming with life.

Over the decades, various writers could be found echoing Fontenelle, discussing how our universe must be full of worlds like ours, inhabited by lifeforms like ourselves. By the 1830s, the British science popularizer Thomas



◀ **SPAWN OF MUD** Edward Topsell's discussion of frogs in his 1658 *History of Four-Footed Beasts and Serpents* reflected the widespread belief, enduring from ancient times through the end of the 19th century, that some life was spontaneously generated from lifeless matter. If life was a natural product of matter, then life on other planets (or even the Sun!) was inevitable.

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JUST ONE AMONG MANY
Bernard Fontenelle's 1686 *Conversations on the Plurality of Worlds* opens with this image of the Sun and its planets in a universe full of other worlds orbiting other stars.

Dick estimated the population of the planets of our solar system to be in the tens of trillions. This was not counting "innumerable orders of sentient and intelligent beings" on the Sun. After all, eminent astronomers like William Herschel (discoverer of Uranus) and François Arago (Director of the Paris Observatory) had proposed that the Sun was inhabited. Dick's population for the entire universe? Trillions of times greater still!

So, when we view the universe as being well-populated with intelligent extraterrestrial life — the sort of universe where an object passing through the solar system might be the product of an extraterrestrial civilization — we are thinking like Bruno, Fontenelle, and Dick. Such notions are exciting, of course, but Johannes Kepler in the 17th century, Jacques Cassini in the 18th, and William Whewell in the 19th all argued they're not *scientific*.

Kepler's One and Only Sun

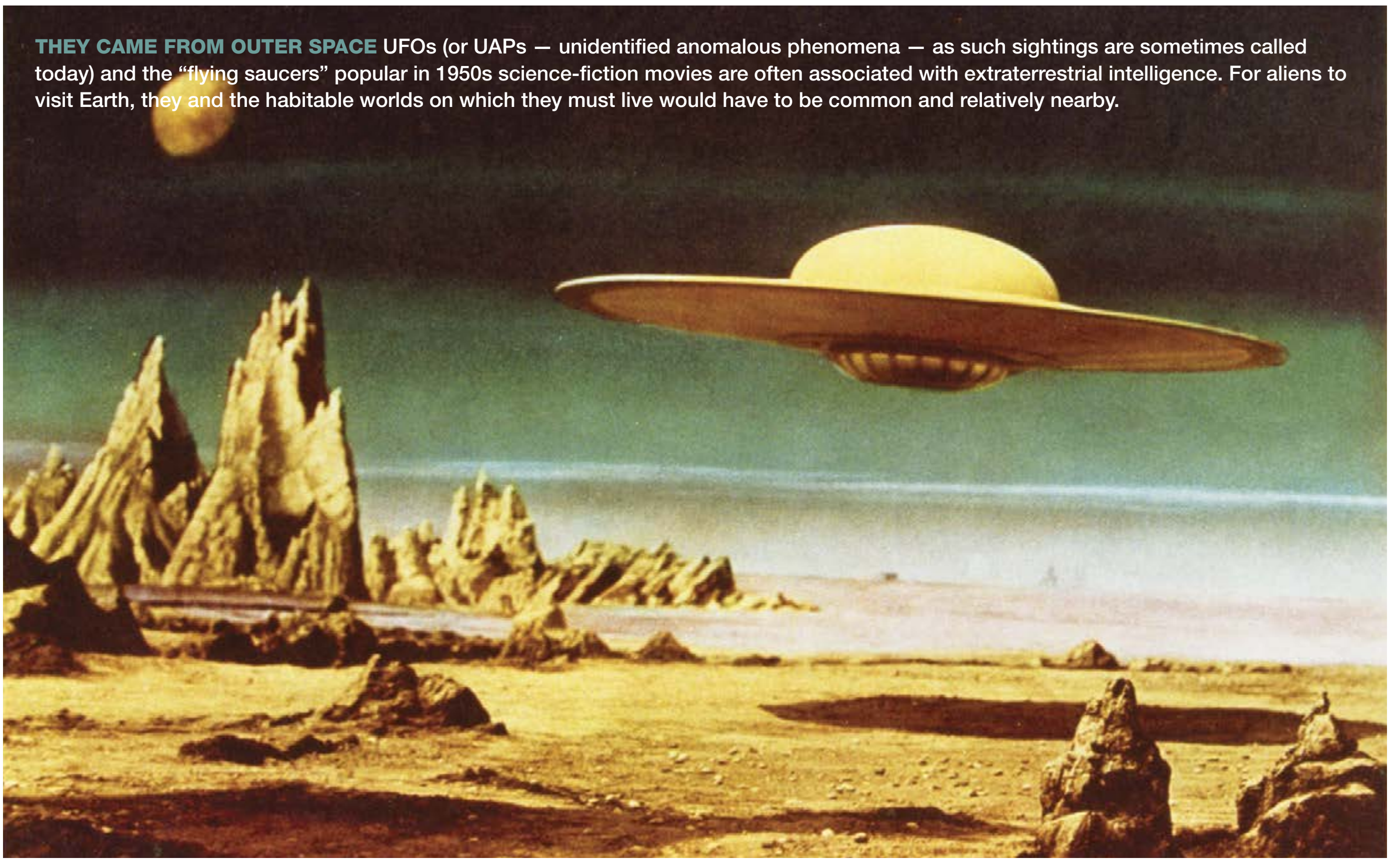
Kepler (1571–1630) was a Copernican, like Bruno. He developed the laws of planetary motion that we still use today to describe the orbits of planets and other bodies in the solar system. Kepler liked the idea of inhabited worlds, imagining intelligent life on Jupiter, for example, and supposing that its four big moons served the Jovians well, illuminating the skies of their stupendous world. But he took exception to Bruno stating that stars were suns.

Kepler said that simple observations, measurements, and calculations — basic science — showed that stars were not suns. In his 1610 *Conversation with Galileo's Starry Messenger*, Kepler wrote:

> *If they* [the stars] *are suns having the same nature as our sun, why do not these suns collectively outdistance our sun in brilliance? Why do they all together transmit so dim a light...? When sunlight bursts into a sealed room through a hole made with a tiny pin point, it outshines the fixed stars at once. The difference is practically infinite.*

Newcomers to telescopes are often surprised by how small stars look even when high magnification is used. To the naked eye, stars appear much larger. Pre-telescopic astronomers, from Ptolemy in the 2nd century to Tycho Brahe in the late 16th, repeatedly measured the apparent diameters of stars to be roughly $1/30$ that of the Moon. Sirius, Jupiter, and Venus appeared larger still — comparable to small lunar maria.

Kepler pointed out that all the stars combined together would appear as large as the Sun's disk (larger, he said, if you added in the thousands of stars Galileo said were visible only telescopically). Still, Kepler said, the Sun outshines them all by a "practically infinite" amount. This was not a factor of distance, he noted. "Will my opponent tell me that the stars are very far away from us?" he asked. "This does not help his cause at all. For the greater their distance, the more



THEY CAME FROM OUTER SPACE UFOs (or UAPs — unidentified anomalous phenomena — as such sightings are sometimes called today) and the "flying saucers" popular in 1950s science-fiction movies are often associated with extraterrestrial intelligence. For aliens to visit Earth, they and the habitable worlds on which they must live would have to be common and relatively nearby.

ENTERTAINMENT PICTURES / ALAMY STOCK PHOTO

◀ **ADVOCATE FOR PLANETARY DIVERSITY** In the 19th century, William Whewell used science to argue against what astronomers for centuries had simply assumed to be true — that planets everywhere would be home to life, including intelligent life, just like on Earth.

does every single one of them outstrip the sun in diameter." Stars had to be huge to both be as distant as Copernicus required (to explain the absence of parallax) and at the same time appear 1⁄30 the diameter of the Moon. In 1604, Kepler calculated that Sirius was bigger than the orbit of Saturn. Every single star visible to the eye had to be bigger than the orbit of Earth.

Kepler's basic science showed that stars were dim, and stars were huge. Bruno was wrong — stars were not suns. And so, Jovians aside, stars could not be other suns circled by other inhabited earths. Any skilled astronomer could make some basic measurements, reproduce Kepler's results, and conclude that the Sun was a unique body in the universe, and therefore its planets were also unique.

What Kepler Got Wrong

Given what was known in Kepler's time, his case against Bruno seems solid. When we look at the planets and stars, our eyes see dots of different sizes — similar to the way stars and planets are rendered on star maps and in planetarium apps. Simply put, brighter equals bigger to the unaided eye. And that didn't change with the advent of the telescope, at least not initially.

The first telescopes often had apertures of only 10 to 20 mm — much smaller than even the smallest backyard telescopes today. In the early 17th century, astronomers didn't understand the relationship between resolving power and aperture. In fact, they often deliberately reduced the apertures of their telescopes with a mask to isolate the best part of the imperfectly made lenses, or to reduce the glare (what Cassini called "la vivacité de la lumière" or "the vivacity of the light") from small, bright objects.

But small apertures have the unfortunate effect of making stars look like distinct disks, much like the naked eye does. Constrict the aperture of your scope to 10 or 20 mm and you can see the effect for yourself. John Flamsteed (1646–1719), England's first Astronomer Royal, argued that with a (small-aperture) telescope he could make out the disk of Sirius better than he could make out the disk of Mercury. Both appeared about the same size, he noted.

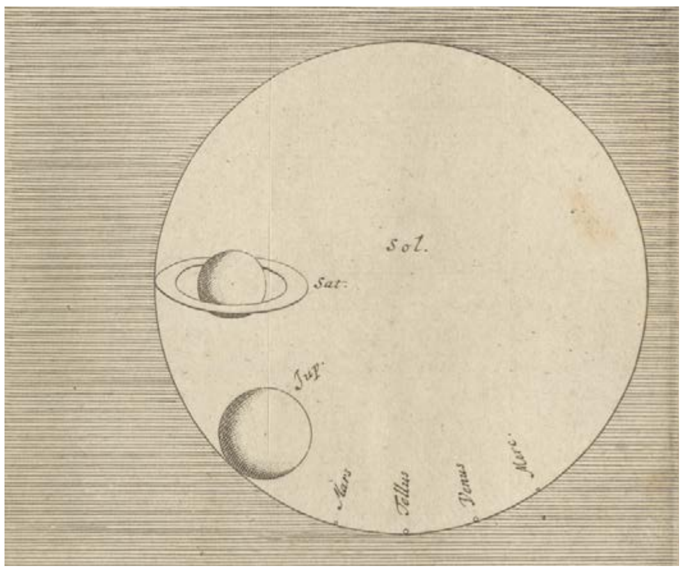
Flamsteed didn't know that this was just a function of the limited resolving power of his telescope and revealed nothing about the true size of Sirius. But taken at face value, his observation would mean that Sirius would be as many times larger than Mercury as it is vastly more distant. Throw in a few rough numbers and you quickly arrive at the conclusion that Sirius must make the Sun look like a mere speck!

Many Different Types of Stars

In the early 18th century, Cassini measured the size of Sirius using a telescope with its aperture masked down (to reduce the "vivacity of the light") and concluded that the star had a diameter equivalent to Earth's orbit. While Fontenelle had said stars were other suns, Cassini presumed that they were other *Siriuses*. Stars differed from one another in appearance, Cassini reasoned, because of differing distances. Based on the sizes of stars as seen in a telescope at 200× magnification, he calculated that the most distant telescopically visible stars were 1,200 times farther than Sirius. Astronomers agreed with Cassini's measurements, which they found quite reproducible.

Cassini's numbers were still being cited at the end of the 18th century, but by then observers were beginning to understand that telescopes can't resolve stellar disks. The decisive blow came in the early 19th century when George Biddell Airy explained the relationship between telescope aperture and resolving power in terms of the wave nature of light (*S&T:* July 2024, p. 75). But as astronomers began to understand how truly different stars can be from one another, another challenge to the idea that the universe was full of earthlike worlds was rising.

Agnes Mary Clerke, who was a multilingual, one-woman hub for astronomical communication and knowledge in the late 19th century, described how this understanding came about. In her 1885 book *A Popular History of Astronomy During the Nineteenth Century*, she wrote that at the beginning of the century, stars were merely the background against which astronomers measured the motions of the planets. William Herschel, she noted, operated on the assumption that "the



▲ **THE SCALE OF THINGS** It was 17th-century Dutch astronomer Christiaan Huygens who correctly determined the relative sizes of the planets through micrometer measurements, one of his many notable accomplishments. Huygens is perhaps best known to today's amateur astronomers as the discoverer of Saturn's biggest moon, Titan, and for the eyepiece design that bears his name.

PORTRAIT OF WHEWELL: ERNEST EDWARDS / MITCHELL LIBRARY, STATE LIBRARY OF NEW SOUTH WALES / WIKIMEDIA COMMONS / PUBLIC DOMAIN; HUYGENS DRAWING OF PLANETS AND SUN: ETH LIBRARY / PUBLIC DOMAIN

ORBITING A RED DWARF This artist's rendering portrays the TRAPPIST-1 planetary system. Although astronomers assumed planets existed beyond our solar system for centuries before they were first detected, those assumptions were based on fantastical ideas rather than solid science.

ESO / N. BARTMANN / SPACEENGINE.ORG

brightness of a star afforded an approximate measure of its distance." This supposes that one star is pretty much like another, echoing both Cassini and Fontenelle. But when astronomers finally developed telescopes powerful enough to detect parallax and thus directly measure stellar distances, that notion quickly became obsolete.

By the end of the 19th century, Clerke wrote, the distances to roughly 100 stars had been calculated, and:

> *The list* [of stars with measured distances] *is an instructive one, in its omissions no less than in its contents. It includes stars of many degrees of brightness, from Sirius down to a nameless telescopic star in the Great Bear . . .*

Many of the brightest stars were too far away for their distances to be ascertained, while most of those found to be nearest to Earth were quite faint. Estimating the distance to the stars from their brightnesses turned out to be futile, Clerke wrote. Moreover:

> *. . . the splendid Canopus, Betelgeux, and Rigel can be inferred, from their indefinite remoteness, to exceed our sun thousands of times in size and lustre; while many inconspicuous objects, which prove to be in our relative vicinity, must be notably his inferiors. The limits of real stellar* [luminosity] *are then set very widely apart.*

In short, one star is not at all like another. Therefore, stars are not all suns.

Today we understand that the Sun is a star — a gravitationally bound globe of dense gas, heated to incandescence by nuclear reactions occurring deep within it. We understand that other stars are these nuclear-powered, incandescent, gas globes. But as Clerke observed, the range of what counts as a "star" is very wide. We have learned much in the century-plus since she wrote her book, but her observation still holds true. Although there actually are stars that are enormous — comparable to the sizes Kepler determined — they are rare. Stars like the Sun are much more common. But most common of all are the red dwarf stars, notably inferior to the Sun (*S&T:* May 2024, p. 34). Of the 100 stars currently known to be the Sun's nearest neighbors, roughly 80 have less than 1% of the Sun's power output. All 80 combined would not equal the Sun. This great diversity among stars that science revealed undermines Fontenelle's vision of a universe of other suns orbited by other, inhabited earths.

Not Many Earths

Not only are stars diverse, so are planets. English polymath William Whewell (1794–1866) worked hard to bring attention to this fact. Just as astronomers made assumptions about stars all being other suns that did not hold up to the available science, they also made some assumptions about planets that did not hold up. For example, in the 17th century some astronomers insisted that the sizes of the planets increased in lockstep with their distances from the center of the solar system so that each planet would appear exactly the same size as viewed from the Sun. Such a scheme would require Earth to be smaller than Mars but bigger than Venus. Yet, observers at that time knew the relative distances of the planets, and they could see their apparent sizes telescopically just as anyone can today, and those apparent sizes obviously contradicted this "farther equals bigger" idea. Nevertheless, scientists such as English astronomer Jeremiah Horrocks (1618–1641) and German physicist Otto von Guericke (1602–1686) seemed set on it.

Meanwhile, in 1659 Christiaan Huygens published measurements he'd made using a micrometer fitted to a telescope to correctly determine the relative sizes of the planets. But despite the huge size difference between Earth and Jupiter, even Huygens assumed Jupiter would be so much like Earth that there had to be Jovian sailing ships with pulleys, just like on Earth! After all, Earth has oceans and ships equipped with ropes and pulleys — why wouldn't Jupiter? Plus, Jupiter's retinue of moons would be so very useful for navigation!

Whewell, however, used science to argue in his 1853 book *Of the Plurality of Worlds: An Essay* that the planets were diverse, not just other Earths. They received widely differing amounts of light and heat from the Sun and had widely differing densities and surface gravities (something Isaac Newton had worked out a century earlier). Geological evidence indicated that Earth had existed for vast periods of time without human beings, suggesting that intelligent life wasn't a given even here. Whewell thought that even if the other planets in the solar system weren't populated by sentient and intelligent beings, they might still host life. He imagined a watery Jupiter with "aqueous, gelatinous creatures; too sluggish, almost, to be deemed alive, floating on their ice-cold water, shrouded forever by their humid skies." Not so different from the "vast living balloons" Carl Sagan suggested could live on Jupiter in his 1980s television series, *Cosmos*.

Whewell's astronomer friend John Herschel (William's son) was among the many who disagreed. Herschel said that there might yet be intelligent fish in the deeper, warmer Jovian waters. Such fish might even build underwater structures to rival London's Crystal Palace! Of course, even now it would be a monumental discovery if a future space probe found even one small colony of the most microscopic gelatinous creatures in the waters under the ice of Jupiter's moon Europa.

Planetary diversity goes far beyond what Whewell envisioned. He surely would have been surprised to find that Venus is utterly unlike Jupiter, and yet both worlds are so unlike Earth as to be uninhabitable. No doubt he would also have been shocked by the diversity seen in the oddball planets found in exoplanet systems. The orange dwarf star HD 83443 in the southern constellation Vela, for example, features one Jupiter-size planet in an orbit that makes Mercury's look large, while another planet has a comet-like eccentric orbit. The exoplanet TrES-2b is darker than coal. The planets of the TRAPPIST-1 system are all in tight, lockstep orbits around a red dwarf. Moreover, half the exoplanets discovered are of a size not found in our solar system — worlds bigger than Earth, yet smaller than Neptune (*S&T:* Mar. 2017, p. 22). Of course, it might be that *our* solar system is the one that's odd. Posting on NASA's exoplanet exploration site (**https://exoplanets.nasa.gov/**), science writer Pat Brennan has proposed that ours is "the weirdest solar system we've found so far."

If Whewell would be shocked by recent discoveries, what of Fontenelle or Bruno or Dick? And what would they think about the scarcity of life? The idea of spontaneous generation finally died off in the late 19th century, thanks to scientists building on the work of Leeuwenhoek, who showed that even eels beget young. Today science is very far from spontaneous generation. Current hypotheses propose that life on Earth originated some 3.8 billion years ago through a process neither reproducible in a lab nor found reoccurring in nature, and that more complex life originated in a merger of two primitive, single-celled organisms — a merger so improbable that it occurred but once in our planet's history, and only after primitive life had existed for many hundreds of millions of years. Thus, palace-building fish under Europa's ice stretches scientific plausibility, yet a lifeless Europa does not.

▲ **VISITOR FROM BEYOND** 'Oumuamua's 2017 passage through the solar system prompted suggestions that the object was the product of extraterrestrial intelligence. Such an idea presupposes that extraterrestrial intelligent life is common enough for us to encounter their machines.

ESO / M. KORNMESSER

The Challenge of History

History shows that science has repeatedly challenged the idea of other Earths. Science — be it the mistaken theorizing of Kepler and Cassini, or the work of Whewell that has stood the test of time — has always pointed toward diversity, not a universe full of Earths. Our best efforts today show that most planets differ greatly from our Earth, most stars differ greatly from our Sun, and most planetary systems differ greatly from our solar system. Indeed, science even tells us that most of the matter and energy of the universe is "dark," differing greatly from the stuff of ordinary experience.

Despite this, we human beings have consistently embraced the assumption that the universe is full of worlds like Earth populated by life that just naturally emerges from matter. That is an exciting universe. Attributing 'Oumuamua to extraterrestrial intelligence; reputable media outlets featuring fantastical accounts of UFOs; NASA panelists being questioned about what they are "hiding" when they can't produce evidence supporting alien visitations — all reflect the ongoing embrace of assumptions that follow the long tradition of Bruno, Fontenelle, and Dick. And as Kepler, Cassini, and Whewell show us, that tradition is less based in science than we think.

■ **CHRISTOPHER M. GRANEY** is an astronomer and historian of science with the Vatican Observatory. This article is adapted from his paper "The challenging history of other Earths", published in the *International Journal of Astrobiology* 22:6 (December, 2023).

STELLAR SCIENCE by Elizabeth Fernandez

In Search of the Most Massive Star

Astronomers are scouring the universe and their computer models to discover how big stars can be.

In 2006, I found myself gazing through a telescope at the Sun as a small dot slowly slid in front of our star. It was Mercury, an entire world. During the transit, the massive Sun dominated most of the telescope's field of view. Yet Mercury, which lay much closer to Earth, looked utterly small. It was dwarfed by the sheer size of the Sun.

Compared with the terrestrial planets, the Sun is indeed huge: It's as massive as 300,000 Earths. Yet our Sun is tiny next to other stars within our galaxy. For example, Antares is 12 solar masses (where one solar mass is the mass of our Sun), and Rigel is around 21 solar masses.

Such comparisons beg the question: How big can stars get? Can they grow arbitrarily large, or is there some fundamental process that halts a star's growth at a certain mass when it first forms?

There are two different ways to answer this question. The first is with observations. Truly massive stars are rare. However, if we look at enough stars, we can obtain a sufficient statistical sample to see if there is a limit to how massive stars can be.

TARANTULA NEBULA The Large Magellanic Cloud's 30 Doradus is the largest star-forming region in the Milky Way's neighborhood. Seen here in near-infrared wavelengths by the James Webb Space Telescope, it contains stars 200 to 300 times more massive than the Sun.

NASA / ESA / CSA / STScI / WEBB ERO PRODUCTION TEAM

The Perfect Sample: Arches

In 2005, astronomer Donald Figer (now at Rochester Institute of Technology) found a perfect place to obtain this statistical sample: the Arches cluster. Arches is a beautiful open cluster in the constellation Sagittarius. As the densest cluster in the Milky Way, it contains 11,000 solar masses' worth of stars. If the area around our Sun were as populated as Arches is, there would be more than 100,000 stars between us and our nearest star, Proxima Centauri.

Another reason why Arches is a perfect place to search for massive stars is that it is young. Massive stars live fast and die young, burning through their nuclear fuel within a few million years. As far as clusters go, Arches is a baby at 2½ million years old. To put this in perspective, our hominid ancestors were walking on Earth before Arches formed. Figer calculated that Arches was young enough that if stars up to 500 times the mass of our Sun had formed there, they would still be shining today.

Observing Arches is not easy, however. It's 25,000 light-years from Earth, and its stars are packed so tightly that they are difficult to resolve individually.

Yet, even with these difficulties, Figer found stars with up to 130 times the mass of our Sun. But he didn't find any stars even close to 500 solar masses. Figer concluded that stars of 150 solar masses or more simply couldn't form.

The results were convincing. After that, astronomers used 150 solar masses as the limit for how large a star could be.

But the Tarantula told a different story.

Massive Nebula, Massive Stars

The Tarantula Nebula, located in the Large Magellanic Cloud some 160,000 light-years from us, is one of the most massive nebulae known. Light takes more than 500 years to traverse its extremes. It is so huge that if it were located where the Orion Nebula is (some 1,500 light-years from Earth), it would have an angular size of about 20°, about the diagonal size of the Great Square of Pegasus.

Such a giant nebula creates an opportunity for more massive stars to form, explains Paul Crowther (University of Sheffield, UK). Only a small percentage of gas in a nebula will end up in stars, so the more massive a nebula is, the more raw materials it has to work with. If there are stars larger than 150 times the mass of our Sun out there, then the Tarantula Nebula is an ideal place to look for them.

When the Gemini South telescope in Chile set its sights on the middle of the Tarantula Nebula in 2021, it was able to resolve stars in the massive cluster at its center, R136. A star within this cluster, R136a1, is the most massive star yet discovered. Various studies peg it at anywhere from 200 to more than 300 times the mass of our Sun.

R136a1 is not alone. There are hundreds of massive stars lurking near the center of this nebula, ranging from a few tens to hundreds of solar masses.

These stars may have even started out more massive than we see them today, says Erin Higgins (Armagh Observatory and Planetarium, Northern Ireland). That's because very massive stars often have strong winds, which propel gas out and away, whittling the star down over time. These winds can be so strong that the star can lose a fifth of its mass within a million years.

Observations from the Tarantula Nebula indicate that perhaps the limit to stellar mass is around 300 Suns — that is, if the stars there didn't begin life larger.

But again, is this the whole story? Is there any way to build an even bigger star? To answer this question, astronomers turn to a second approach besides observations: the theory of how stars form.

A Galactic Cookbook: Stellar Edition

In order to build a massive star, you need a lot of gas. Pressure from the motions of warm gas counteracts the cloud's own gravity and keeps it from collapsing. In this way, a nebula can remain stable . . . for a while.

Compression can come along and upset this balance. A nearby supernova could compress the gas, or a shock wave from a collision with another nebula or galaxy could ripple through a cloud to initiate collapse. Density waves within a galaxy can also squeeze the gas — we see the results of these waves in the starbursting spiral arms of many galaxies (*S&T:* Mar. 2023, p. 14). But compression from the outside isn't always necessary: Perhaps the gas is simply clumped just enough that its own gravity wins.

◀ **ARCHES CLUSTER** This cluster lies some 25,000 light-years from Earth, in the galactic center, and is the densest known star cluster in the Milky Way. Dusty clouds obscure the cluster from view in visible light; this is an infrared image.

NASA / ESA

Whatever the cause, when the gas is squeezed, gravitational collapse can begin. The gas will fragment into smaller and smaller chunks. Eventually, these chunks develop into a cluster of *protostars*, which continue to grow as gas pours in.

Researchers starting in the 1970s pointed out that, once a growing star reaches 20 solar masses, the outward pressure from the star's own photons should clear away the remaining infalling material. But if this were the whole story, then stars would not be able to grow beyond 20 solar masses.

Subsequent work has shown that the remedy lies in the star's *accretion disk*. This disk encircles the forming star and channels material down onto it; feeding from the disk is how a protostar grows. The disk also funnels the star's outpouring radiation in certain directions, limiting its ability to erode the infalling gas.

The disk helps determine how big the star will be. While neat accretion disks typically lead to modest-size stars, larger stars form more chaotically, with streams of infalling material acting like conveyor belts, dumping gas onto the forming star in sudden bursts.

Although theoretical models aren't perfect, they do allow us to tweak variables to see how environment affects stellar mass. Models also allow us to envision the conditions in a location that is very difficult to observe — the early universe — to see if the first stars could have been more massive than their modern-day counterparts.

Long Ago and Far Away

Donghui Jeong (Penn State University) and James Gurian (Perimeter Institute, Canada) use computer modeling to understand the characteristics of the first stars, which formed more than 13 billion years ago. Their models are missing one thing that stellar models of the nearby universe include: a rich array of elements.

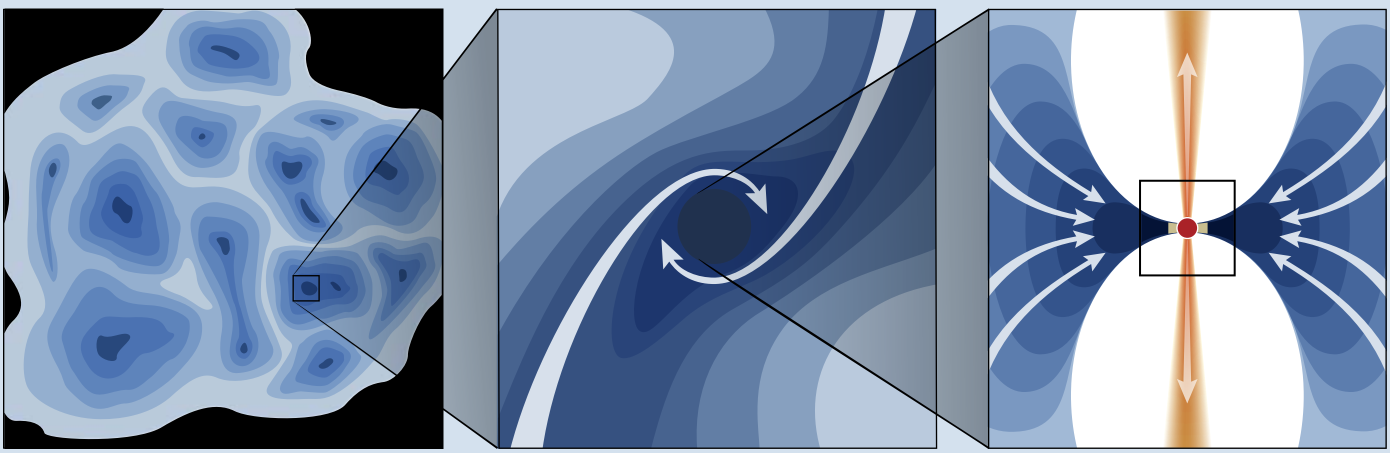
All elements heavier than hydrogen, helium, and lithium were formed thanks to stars — either in stellar fusion, in stars' deaths, the collisions of stellar remnants, or by the later breakup of the atoms that stars make. With no stars before them to make heavy elements, such as carbon and iron, the first generation of stars should have been pristine. These stars are dubbed *Population III stars*.

Heavy elements can have a major impact on a star's birth and evolution. Jeong explains that two of the most important ingredients in determining the final mass of a Population III star are rotation — which can determine how much gas falls onto the protostar — and how efficiently that infalling gas can cool. Heavy elements affect the latter.

It may seem counterintuitive, but gas must first cool before it forms a star: Gas that is too hot will resist gravity's inward tug. As gas radiates away this energy, it can collapse and become gravitationally bound. This cooling occurs due to collisions within the gas cloud. Collisions can excite electrons within an atom or a molecule, or the collision's energy can be stored in the atom or molecule's rotational or vibrational modes. When the atom or molecule releases this energy again, it may emit a photon, which carries away some of the energy within the gas. Thus, the gas cools.

Heavy elements can host electrons at a wider variety of energy levels than hydrogen or helium can and have more available rotational and vibrational modes. If there are heavy elements present in the gas, then there are more ways for atoms and molecules to lose energy, and the gas can cool

Star Formation, the Early Years



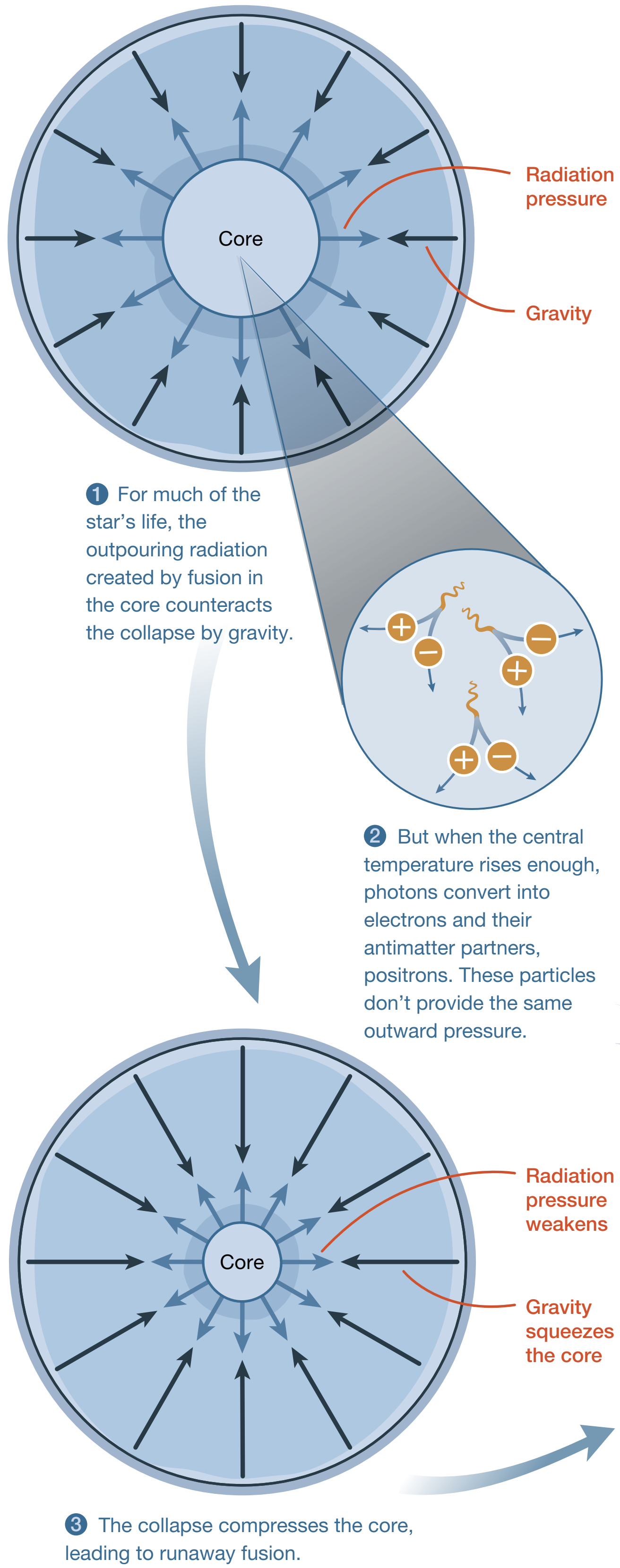
▲ **MOLECULAR CLOUD** Stars are born in clouds of dust and molecular gas.

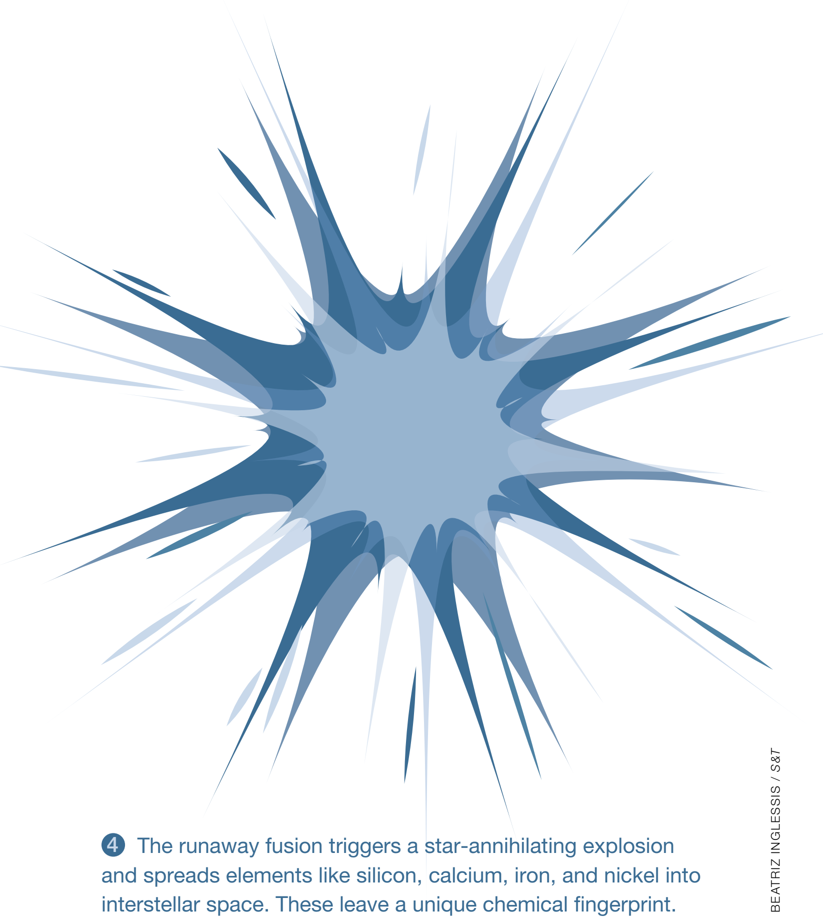
▲ **DENSE CORE** Dense regions in the cloud collapse due to their own gravity. As they collapse, they rotate.

▲ **PROTOSTAR** The star forms inside the collapsing core, fed from a disk of gas (box). The star ejects material as outflows from its poles, and the disk funnels the star's radiation in these directions, too, protecting the disk from erosion.

GREGG DINDERMAN AND BEATRIZ INGLESSIS / S&T, SOURCE: K. PEEK

▼ **PAIR-INSTABILITY SUPERNOVAE** Stars with an initial mass between 140 and 260 Suns are expected to blow themselves apart without leaving a black hole.





BEATRIZ INGLESSIS / *S&T*

more efficiently. Conversely, without heavier elements, the gas has a more difficult time cooling. In this case, gas would not be able to fragment into smaller clumps as efficiently. Instead of forming a rich stellar cluster, a gas cloud might only make a few giant stars.

In the team's models, Population III stars end up with a couple hundred solar masses. Other groups have produced much bigger stars, though, some of them reaching a gargantuan 1,000 solar masses.

Astronomers can combine such theoretical models with observations of stars forming very early in the universe. While Population III stars remain beyond our reach for now, other stars may help us learn how star formation kicked off and how massive these early stars were.

One of the most distant stars observed so far is Earendel, shining at us from only 1 billion years after the Big Bang (*S&T:* Aug. 2022, p. 11). This star lies behind the massive galaxy cluster WHL0137–08. The cluster's gravity acts like a giant magnifying glass, amplifying the light of objects beyond it, including Earendel, enough that we can see them. If Earendel is a single star, then it may be anywhere from 20 to 200 solar masses.

It is also possible to investigate how massive early stars were using more indirect methods. For example, astronomers can search for specific elements and isotopes and their relative abundances in early galaxies. These chemical patterns can tell us about the mass of stars that produced them.

The chemical makeup of one of the most distant galaxies ever imaged, GN-z11, may indicate gargantuan stars have formed there. This galaxy, located only about 440 million years after the Big Bang (at a redshift of about 11), has high levels of nitrogen and low levels of oxygen — in fact, the ratio of nitrogen to oxygen is four times what is seen in our Sun. A group of astronomers led by Corinne Charbonnel (University of Geneva, Switzerland) recently suggested that this over-abundance of nitrogen implies that GN-z11 hosts truly massive stars — on the order of 5,000 to 10,000 solar masses!

However, Chiaki Kobayashi (University of Hertfordshire, UK) and Andrea Ferrara (Scuola Normale Superiore, Pisa, Italy) suggest that such an abundance pattern could instead be created by starting, stopping, and then re-starting star formation. In this scenario, hot, blue Wolf-Rayet stars on the order of about 100 solar masses add abundant nitrogen after the second burst of star formation. Another group led by Roberto Maiolino (University of Cambridge, UK) suggests that this abundance pattern could be created by an accreting black hole of about 1 million solar masses.

One specific chemical abundance pattern is made by what are called *pair-instability supernovae*. Theoretically, for a Population III star between about 140 and 260 solar masses, conditions in the star may be just right so that the gamma rays created by nuclear fusion start converting into electron-positron pairs. Unlike photons, these particles do not exert the pressure necessary to hold the star up against the force of gravity. The core collapses.

The collapse triggers more fusion, creating more gamma rays, which in turn create more electron-positron pairs. The core suddenly ignites in a runaway reaction, causing an explosion that completely demolishes the star: No neutron star or black hole is left behind, and all of the elements produced during the star's life and death are thrown into space, enriching the surroundings.

A pair-instability supernova should leave behind a very particular chemical abundance pattern, one that many astronomers are searching for. If detected, it would mean that Population III stars can reach at least 130 solar masses. Astronomers have found a star with hints of this pattern, but it has yet to be confirmed.

True Stellar Monsters

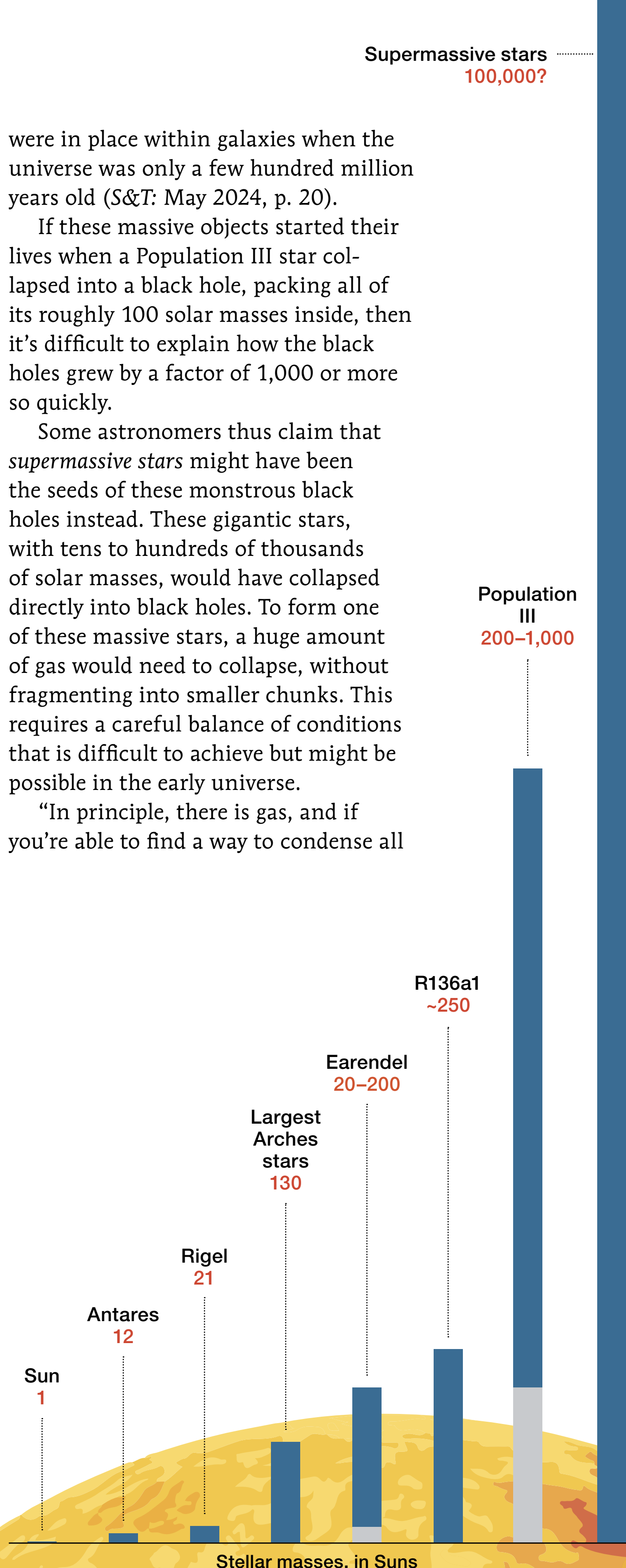
There's one final reason to suspect that early stars could have been large — very large. If some stars were incredibly massive, then that could help explain one of the biggest mysteries in astrophysics: how the first big black holes formed.

In almost every large galaxy lurks a supermassive black hole, weighing on the order of millions to billions of times the mass of our Sun. Observations show that massive black holes were in place within galaxies when the universe was only a few hundred million years old (*S&T:* May 2024, p. 20).

If these massive objects started their lives when a Population III star collapsed into a black hole, packing all of its roughly 100 solar masses inside, then it's difficult to explain how the black holes grew by a factor of 1,000 or more so quickly.

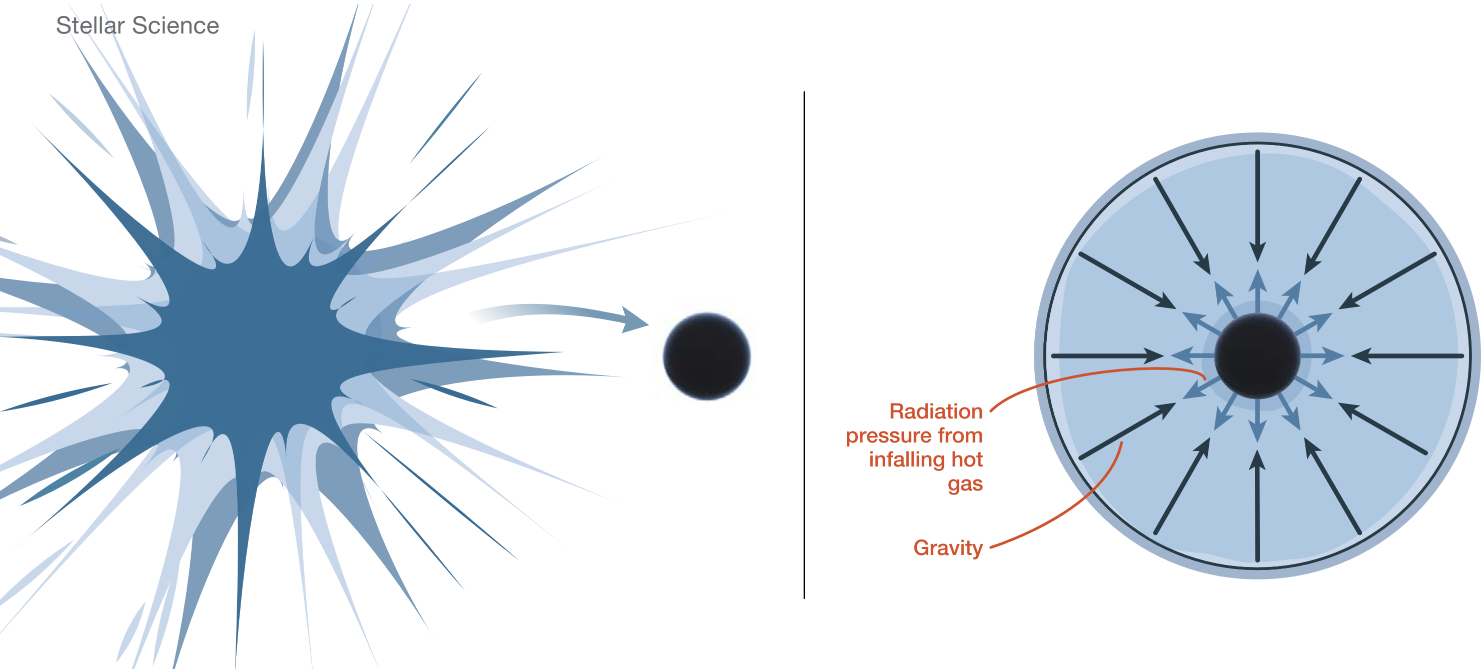
Some astronomers thus claim that *supermassive stars* might have been the seeds of these monstrous black holes instead. These gigantic stars, with tens to hundreds of thousands of solar masses, would have collapsed directly into black holes. To form one of these massive stars, a huge amount of gas would need to collapse, without fragmenting into smaller chunks. This requires a careful balance of conditions that is difficult to achieve but might be possible in the early universe.

"In principle, there is gas, and if you're able to find a way to condense all



▲ **JUST HOW MASSIVE?** Familiar stars such as Antares and Rigel are significantly more massive than the Sun, but even these are puny when compared with the behemoths found in intense star-forming regions in the Milky Way and other galaxies. Astronomers speculate that in the earliest days of the universe, stars may have been thousands of solar masses or more.

BEATRIZ INGLESSIS / S&T



▲ **BLACK HOLE SEEDS** In the early universe, some massive stars created black holes when they went supernova. But it's also possible that other black holes formed inside humongous, *quasi-star* objects, replacing what would normally be a core powered by nuclear fusion.

of this [gas] . . . into a bound object, then you're done," says Ferrara, who studies star formation in the distant universe. "They would live a very short time, and then they would collapse into a black hole."

It's unclear how truly starlike these objects would be. Hydrogen fusion might briefly ignite inside a supermassive star. But it's also possible that the supermassive star might skip the fusion phase altogether. In that case, the core would be so dense that it would collapse into a black hole without throwing off the immense weight of the surrounding layers. What's left is a "star" with a black hole at its center, which eats the object from the inside out. Material falling into the black hole would heat up as it falls inward, and this heat would make the quasi-star glow. These objects aren't stars in the traditional sense but are a new type of object altogether.

Perhaps, then, we can define the maximum size of a star as the greatest mass at which a supermassive star will sustain fusion instead of collapsing directly. Unfortunately, we don't know exactly what that mass is. Both the calculations and the observations are complex, and the maximum mass varies depending on the effects of general relativity on a supermassive star's stability and how quickly gas accretes onto the star. This process could lead to stars on the order of tens of thousands of solar masses.

But that, of course, assumes supermassive stars ever existed, and that we have gotten all of the physics right.

Could Some of the First Stars Still Exist Today?

While massive stars have short lifetimes, small stars can have very long lifetimes — longer than the current age of the universe. If some very small Population III stars managed to form in addition to the big ones, then those small, pristine stars may still exist in the modern universe. To find out, astronomers have turned to Gaia, Europe's space telescope tasked with mapping billions of stars in the galaxy. Gaia has been unable to find a single star lacking elements heavier than helium. While it's possible that small Population III stars may be hiding where we haven't found them yet, it's also possible that they weren't small at all.

The Search Continues

So how massive can a star be? We've come a long way in the past two decades, but we still don't have an exact answer. Star formation is a complex process, and there are many factors that can influence how large a star is when it's born. In our local universe, it seems that stars can reach hundreds of solar masses, while in the early universe, they may have been thousands or even tens of thousands of solar masses.

More definitive answers will not come easily. Some astronomers, like Higgins, are working to find a way to estimate stars' birth masses based on how the stars look now. Others are introducing more complexity into simulations of the messy physics of star formation. And explorations of the early universe — both in observation and theory — continue.

For now, the safest answer is the simplest one: We don't know.

■ **ELIZABETH FERNANDEZ** is a science writer with a PhD in astronomy. She writes on the hard sciences as well as science and society and has read *S&T* since she was young.

EXPLOSION: BEATRIZ INGLESSIS / *S&T*; BLACK HOLE: SUDAKARN VIVATVANICHKUL / SHUTTERSTOCK.COM

SKY AT A GLANCE
August 2024

2 DAWN: Face east-northeast to see the waning crescent Moon about 6° right of Gemini's bright lights, Castor and Pollux. The trio forms an isosceles triangle that climbs higher as the rising Sun brightens the sky. Turn to page 46 for more on this and other events listed here.

3 MORNING: In the east, Jupiter is between the horns of Taurus, the Bull, with Mars a bit more than 5½° upper right. Aldebaran twinkles right of the pair.

5 DUSK: The Moon, less than two days past new, hangs ½° above Venus. This view will be a challenge to catch — you'll need an unobstructed horizon toward the west-northwest. Binoculars will enhance the delicate scene.

9 DUSK: The waxing crescent Moon leads Virgo's brilliant star, Spica, by 4½° as they sink together toward the west-southwestern horizon.

11–12 ALL NIGHT: The Perseid meteor shower is expected to peak. The almost-first-quarter Moon sets before midnight and shouldn't affect viewing. This is an exceptionally long shower, so start looking for Perseids anytime after mid-July. Page 48 has the full story.

13 EVENING: Face south-southwest to see the waxing gibbous Moon 1½° lower right of Antares, the red supergiant in Scorpius.

14 MORNING: The sight of Mars and Jupiter climbing in the east will greet early risers. Less than ½° separates the duo.

20 EVENING: The Moon, one day past full, rises above the east-southeastern horizon with Saturn a mere ¼° above it.

26 MORNING: The last-quarter Moon and the Pleiades, around 3° apart, are high in the east.

27 MORNING: The clustering of the waning lunar crescent, Jupiter, and Mars graces the eastern sky. The Moon gleams less than 5° upper left of the gas giant.

30 DAWN: We close this month's events as we started it, with the waning crescent Moon in Gemini. This time, it's some 4° below Pollux, while Castor hangs above, completing a ragged line.
—DIANA HANNIKAINEN

▲ A pair of Perseids flashes across the sky above the Dolomites in northern Italy. The peak at left is the Croda dei Toni. GIORGIA HOFER

AUGUST 2024 OBSERVING
Lunar Almanac
Northern Hemisphere Sky Chart

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

MOON PHASES

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

NEW MOON
August 4
11:13 UT

FIRST QUARTER
August 12
15:19 UT

FULL MOON
August 19
18:26 UT

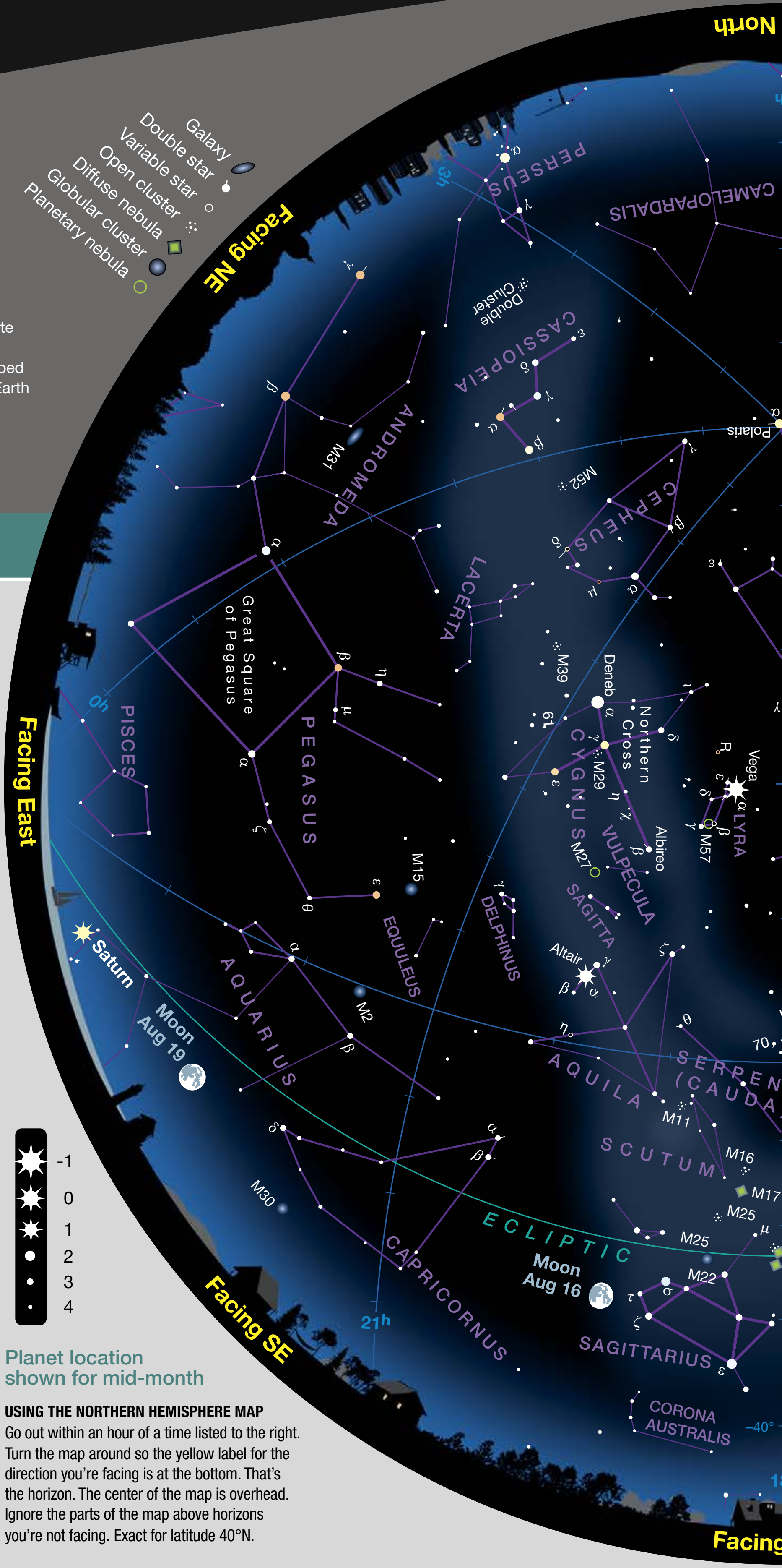
LAST QUARTER
August 26
09:26 UT

DISTANCES

Apogee	August 9, 2^h UT
405,297 km	Diameter 29′ 29″
Perigee	August 21, 5^h UT
360,197 km	Diameter 33′ 10″

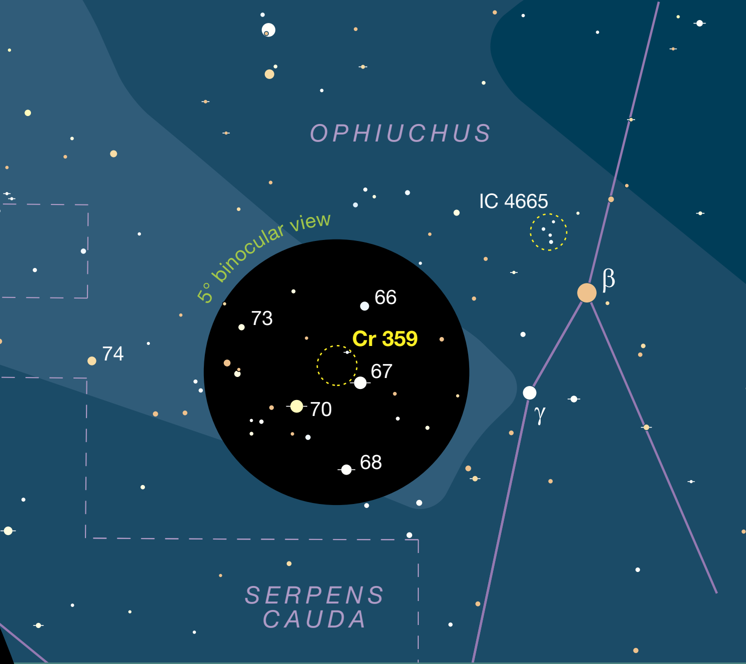
FAVORABLE LIBRATIONS

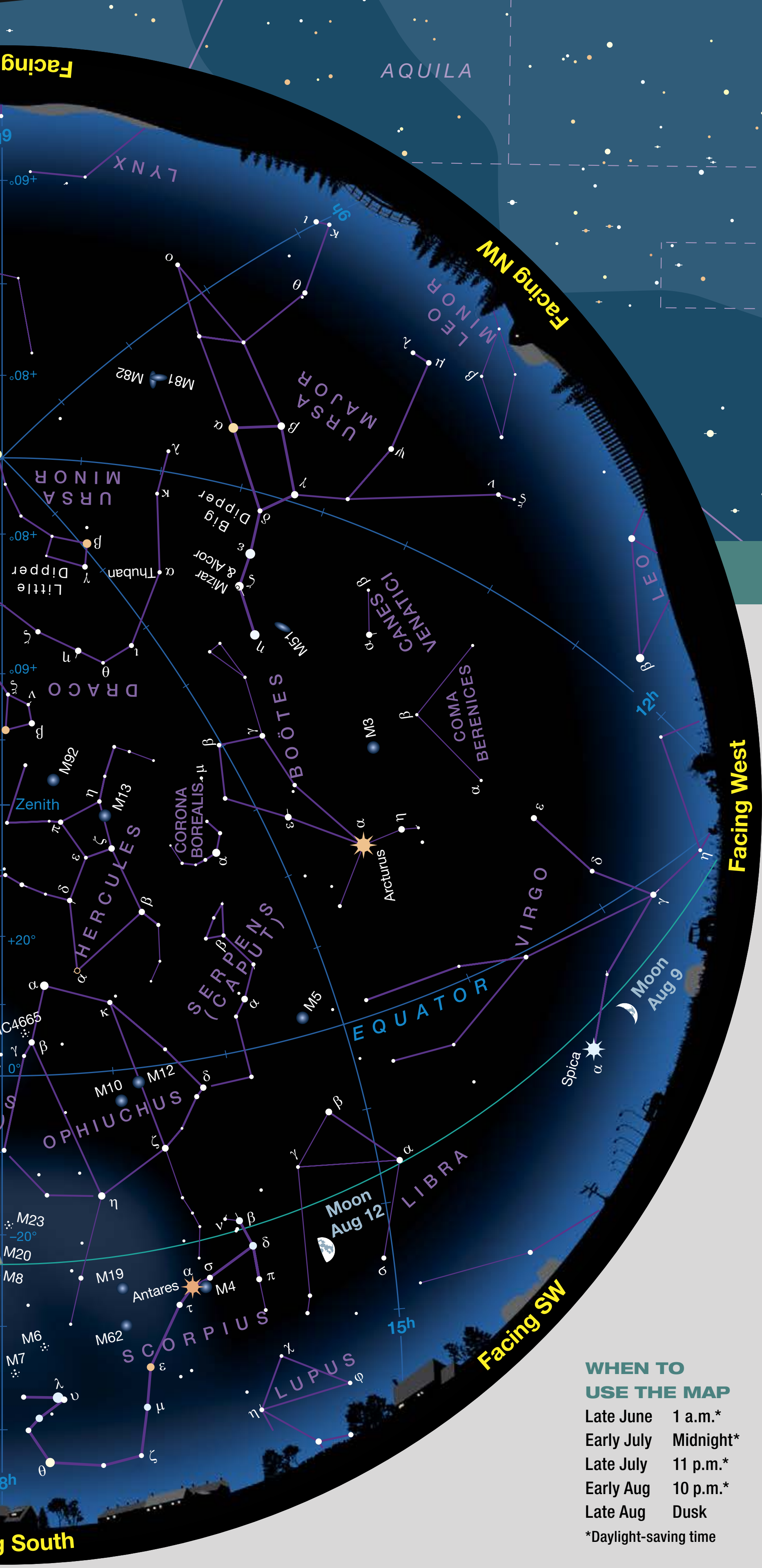
• Jeans S Crater	August 7
• Helmholtz Crater	August 8
• Repsold Crater	August 19
• Cleostratus Crater	August 20



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.





Drifting Apart

Astronomy often involves seeing things before we understand them. We saw the stars before we knew they were other suns, spiral nebulae before we knew they were galaxies, and quasars before we knew they were active galactic nuclei.

So too with this month's target, the probable open cluster **Collinder 359**, also cataloged as Melotte 186. Just as professional astronomers have, we'll approach it through successive approximation. Start with Gamma (γ) Ophiuchi, on the eastern shoulder of Ophiuchus, the Serpent Bearer. Look for a brighter glow resembling a fat tadpole extending about 8° east to 74 Ophiuchi at the tail. Within that span, you'll see a concentration in the diffuse glow of the Milky Way, spangled with 4th- to 6th-magnitude stars.

The most famous grouping here is the acute triangle formed by 66, 67, 68, 70, and 73 Ophiuchi. This miniature mimic of the Hyades in the constellation Taurus, the Bull, was part of the now-defunct constellation Taurus Poniatovii (*S&T:* Aug. 2022, p. 20), and it remains a charming asterism for binocular observers. I use 7×50s to provide some context around Cr 359, but 10×50s show more stars. A roughly 4°-wide circle centered on 67 Ophiuchi — itself a nice binocular double — marks the western boundary of the cluster. Cr 359 is similar in distance and proper motion to the nearby open cluster IC 4665, 4.5° northwest of 67 Ophiuchi. The two clusters may have interacted early on, but over millions of years IC 4665 has held together, while the stars of Cr 359 have started to drift apart — the eventual fate of all open clusters. Comparing the two allows us the heady experience of witnessing galactic evolution firsthand.

■ **MATT WEDEL** wonders about all the open clusters that dissipated before he could observe them, while keeping quite busy with the ones that are still around.

WHEN TO USE THE MAP

Late June	1 a.m.*
Early July	Midnight*
Late July	11 p.m.*
Early Aug	10 p.m.*
Late Aug	Dusk

*Daylight-saving time

Southern Hemisphere Sky Chart

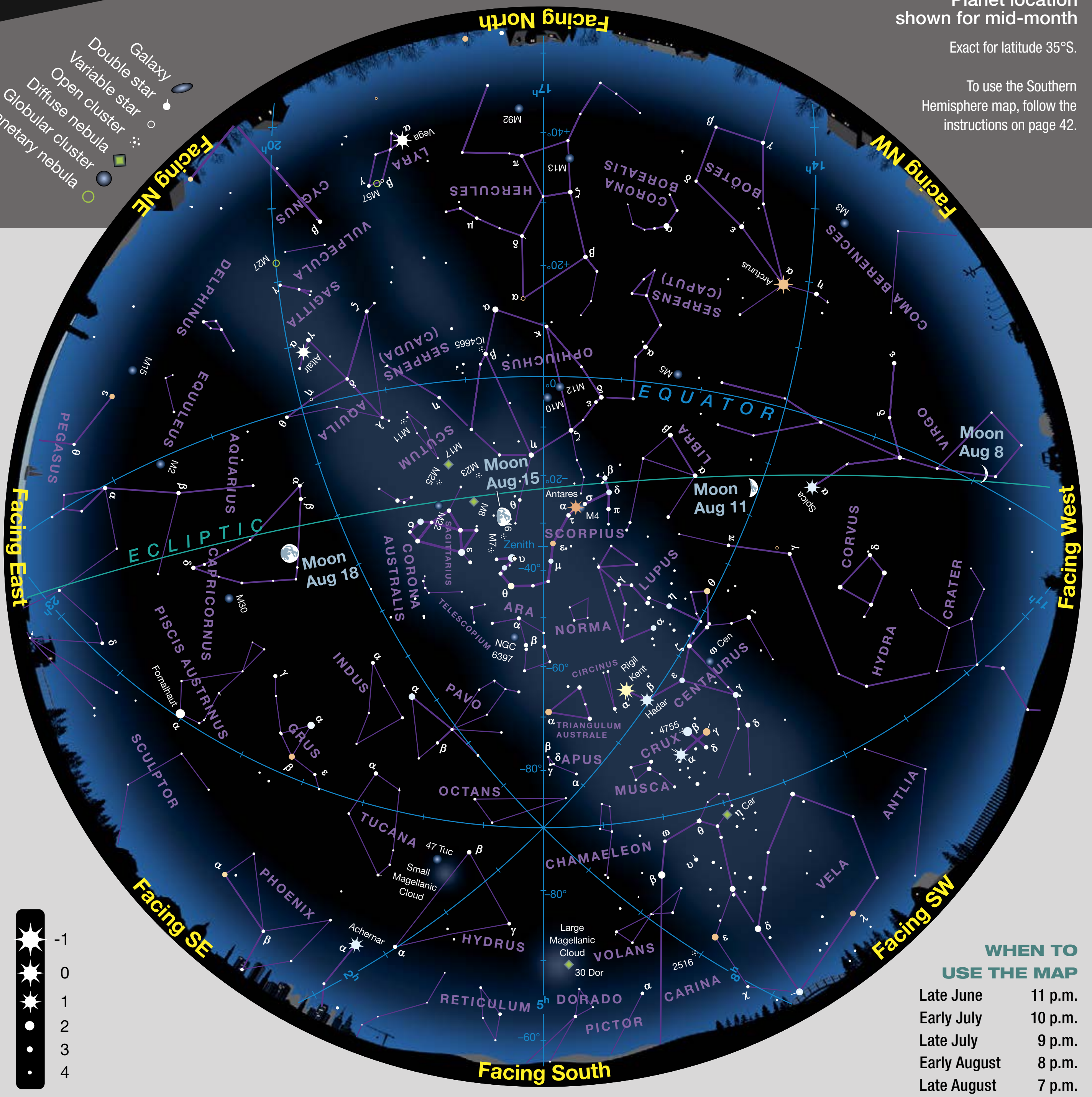
by Jonathan Nally

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

Planet location shown for mid-month

Exact for latitude 35°S.

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



Magnitude scale: -1, 0, 1, 2, 3, 4

WHEN TO USE THE MAP

Late June	11 p.m.
Early July	10 p.m.
Late July	9 p.m.
Early August	8 p.m.
Late August	7 p.m.

ARA, THE ALTAR, is an oft-overlooked constellation about halfway between the celestial equator and the southern pole. It has two fairly bright stars — bluish Alpha (α) at magnitude 3.0 and orange Beta (β) at 2.9. Ara is one of the few constellations in which the Beta star shines brighter than the Alpha. And yet Beta is farther away — 720 light-years distant, compared with 270 light-years for Alpha.

Even though Ara's borders include a swath of the Milky Way, it's not exactly bristling with deep-sky treasures. One fine exception, however, is NGC 6397 — a 5.3-magnitude globular star cluster that can be seen with the unaided eye under clear, dark skies. The cluster's main claim to fame is that it is one of the nearest globulars to Earth, at a distance of only 7,800 light-years. ■

Hercules and Ophiuchus Head-to-Head

How a pair of summer constellations have much in common.

Two ancient constellations on this month's Northern Hemisphere sky chart (pages 42 to 43) stand head-to-head, one on top of the other: Hercules, the mightiest of heroes, and Ophiuchus, the Serpent Bearer. Like Ophiuchus, Hercules deals with a serpent; in his case it's Draco, which was imagined as a serpent before it became a dragon. Both constellations also symbolize tales of good and evil, and of life and death.

The two celestial figures have been linked for millennia. In his 1899 book *Researches into the Origin of the Primitive Constellations of the Greeks, Phoenicians and Babylonians*, Robert Brown suggests that the pairing is a reduplication of Gemini, the Twins. In early Babylonian art, Gemini was frequently depicted as two figures, one above the other — just as we see Hercules and Ophiuchus today. William Tyler Olcott expands on this in his 1911 book *Star Lore of All Ages*:

One of the most peculiar features of the arrangement of the stars into constellations by the ancients is the fact that many of the figures are repeated, and in almost every case the two constellations similar in figure are situated close together in the sky.

We know Hercules and Ophiuchus are head-to-head because Rasalgethi, the Alpha (α) star of Hercules, translates to "the Kneeler's Head," while the name for Alpha Ophiuchi, Rasalhague, means "the Head of the Serpent Bearer." The two Alphas are only 5° apart, with Rasalgethi being the more northerly.

The Babylonian Hercules and Ophiuchus weren't twins — rather, they were king and queen of the Underworld, respectively. Ophiuchus was known as *Allat*, who had the head of a lioness, the body of a huge hairy ape, and the feet of an eagle. Babylonian stone engravings often portrayed an important figure as a mythical beast comprising many different animal parts. However, these parts were chosen to represent the strongest qualities of the figure, not an actual appearance.

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

▲ Ophiuchus, the Serpent Bearer, is shown here as depicted in Alexander Jamieson's 1822 *Celestial Atlas*. Note the upside-down head of Hercules at the top of the map.

Allat's consort was *Lugal*, who rises in the night sky along with the Scorpion, an ancient symbol of darkness. The scene, Brown writes, is a "pre-constellational aspect of the Snake and the Scorpion, as connected with death and darkness." This connection was linked to the autumn equinox, when the Sun dips below the celestial equator, the gateway to the celestial Underworld. During Babylonian times, the point of the autumn equinox was located in the Scorpion's claws — symbolizing the death of the Sun and the long dark nights of Northern Hemisphere winter.

Fast-forwarding to Greek mythology, Heracles (the Roman Hercules) was originally known as *Egonasi* or *Engonasin*, meaning "the Kneeling One." He was also known as "the Phantom." In the *Phaenomena*, Greek poet Aratus (271–213 BC) tells us that the Phantom seems to sit on bended knee with his hands upraised in a pleading gesture. As Olcott remarks, "It is . . . an incongruous position for a hero . . . There appears no satisfactory explanation for this attitude."

But maybe there is. All we have to do is use our imaginations to combine the Babylonian twin motif with the classical myth about the infant Heracles. In this construct, Zeus, king of all gods, disguises himself as Amphitryon, the husband of the most wise and beautiful mortal, Alceme. Alceme unknowingly beds Zeus one night, and Amphitryon on the following night. Twins are born from these unions: Heracles on one day, and Iphicles on the next. (Such "twins" are allowed in mythology.)

When Zeus's wife Hera learns of her husband's infidelity, she sends two venomous snakes to the infants' cribs. Terrified, Iphicles cowers. But before the serpents have a chance to strike, Heracles takes hold of the snakes and strangles them. This courageous display reveals to Amphitryon that Iphicles was his son and that Heracles belongs to Zeus.

On clear August nights, see if you can imagine the constellation Ophiuchus as the young Heracles, clutching the serpents in his hands, while the figure of Hercules serves as his terrified younger brother, Iphicles. He holds his arms outstretched toward his stronger brother, as the jaws of the coiled serpent Draco nears one of his feet in this tale of life and death.

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

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

Mars and Jupiter Meet at Dawn

A month of close encounters has several eye-catching highlights.

FRIDAY, AUGUST 2

It might seem a bit out of season starting August's column with an event occurring in **Gemini**, but that's one of the great benefits of rising early in summer — you get a preview of the winter sky, but the weather is far more pleasant. Your incentive for an early alarm this morning is a lovely configuration that includes a very narrow crescent **Moon** and the two brightest stars in Gemini, **Castor** and **Pollux**.

The trio forms a tidy isosceles triangle hanging above the east-northeastern horizon just as twilight begins to lighten the sky. The Moon is about 4% illuminated and only two days shy of being new, after which it will reappear at dusk. Among the other winter luminaries on display this morning are the stars of Orion and, of course, Taurus, which is currently playing host to Mars and Jupiter.

MONDAY, AUGUST 5

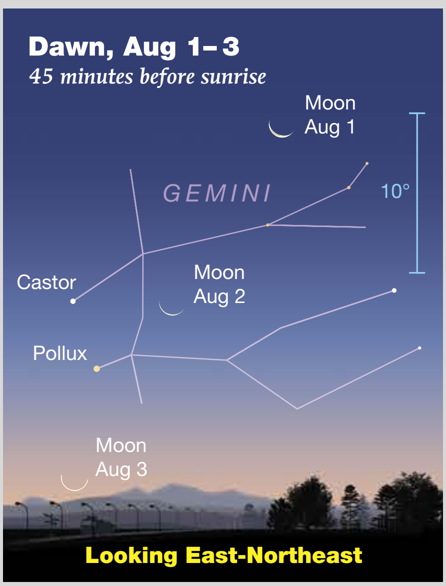
Less than two days after reaching new, the **Moon** appears at dusk to keep **Venus** company. And what a lovely sight this is! The waxing lunar crescent is just 2.4% illuminated and positioned a scant 40′ above the brilliant Evening Star, which shines at magnitude –3.8.

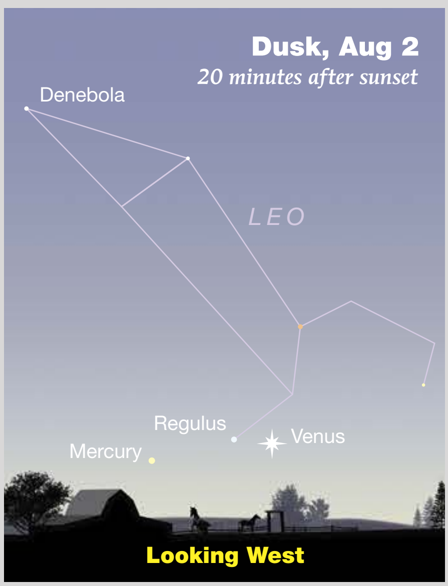
Of all the monthly meetings between the Moon and Venus this year, this one is by far the closest. The only caveat is that the pair won't be very high. The Moon sets just one hour after the Sun and hangs a mere 4° above the west-northwestern horizon 30 minutes after sunset. They're at their very closest (32′ apart — the width of the lunar disk) at 8:43 p.m. EDT, which is twilight for observers on the East Coast but daytime for the rest of the U.S. Of course, if you want a real observing challenge, you could try sighting them *before* the Sun goes down. Both objects are certainly bright enough to be seen in full daylight — the trick is locating them. Use your binoculars, but first make sure you've set focus by aiming at a distant object. Then, slowly scan the area above the western horizon to sweep them up.

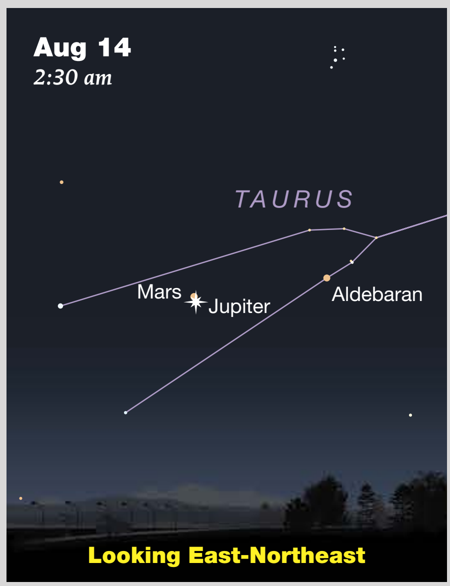
TUESDAY, AUGUST 13

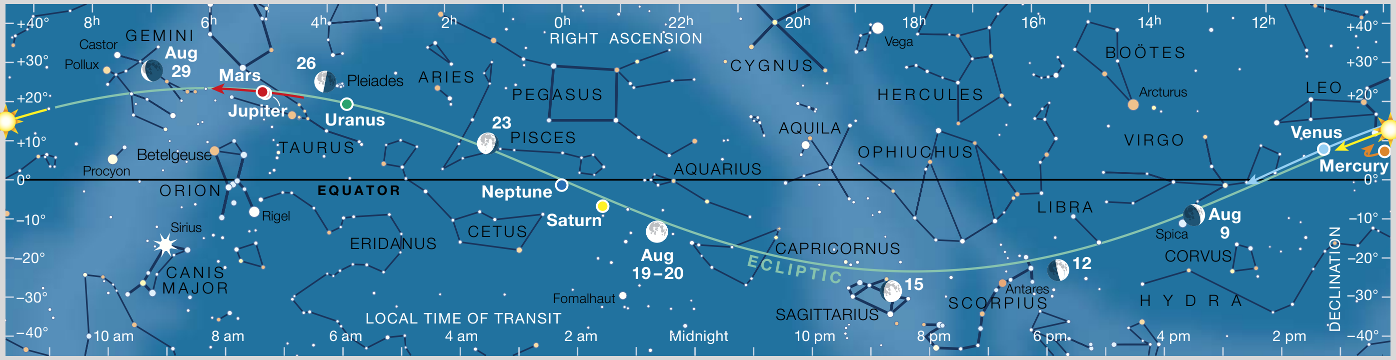
The **Moon** has its best stellar encounter of the month this evening when it approaches within 40′ of **Antares**, the golden-hued heart of Scorpius, the Scorpion. The key here is to look as late in the evening as possible — they'll be at their very closest at 11:37 p.m. PDT. That timing favors locations on the

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









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

West Coast, but even from the opposite coast the view is enjoyable. This is a big year for Moon–Antares conjunctions, and the Moon actually eclipses the star several times in 2024. In fact, if you watched today's event from the South Pacific, you would see an occultation. However, for us observers in North America, May's occultation was the final one for 2024. We'll have to wait until 2028 to see the Moon cover Antares once again.

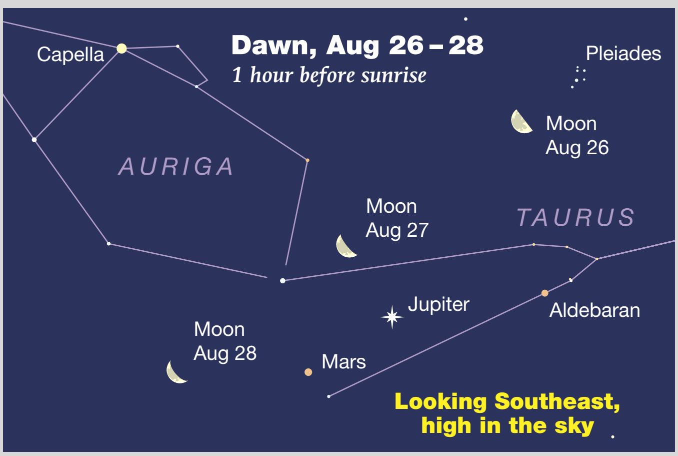
WEDNESDAY, AUGUST 14

This morning features what may well be July's most exciting event: a close conjunction between **Mars** and **Jupiter**. How close is *close?* When the gap between the two worlds is at its smallest at 10:54 a.m. EDT (well after sunrise), just 18′ separates them. However, they'll only be slightly farther apart during morning twilight. You'll still be able to easily see them as two distinct dots with your eyes alone, but the separation is narrow enough that both planets will fit into the eyepiece of a telescope used at moderate magnifications. That said, the naked-eye view is arguably the most arresting as the planetary pair are nestled between the horns of Taurus, the Bull, and not far from the Hyades and Pleiades clusters. Jupiter gleams at magnitude –2.2, while orangey Mars glows more modestly at +0.8 — a 16× brightness difference.

If you continue to watch the two planets over the coming days, you'll see them gradually drift apart as Mars motors eastward. On the following morning (the 15th), the gap between them is 30′, which is still enjoyably close. They'll remain within 2° of each other up to and including the 18th.

TUESDAY, AUGUST 20

As the sky darkens this evening, cast your gaze to the east-southeast to watch the waning gibbous **Moon** and **Saturn** rise together. In a month of close encounters, this one is closest of all. The Ringed Planet is just a bit more than 15′ from the lunar limb at 10:07 p.m. EDT. That's only half a Moon diameter away!



The Moon is just 30 hours past full and 97% illuminated, so "nearly full" would be an apt description. Fortunately, at magnitude +0.7, Saturn is more than capable of withstanding a strong blast of moonlight and should be readily visible even without the aid of a telescope or binoculars.

TUESDAY, AUGUST 27

An eventful month winds down with another lovely dawn scene that includes the **Moon**, **Mars**, and **Jupiter** arranged in a satisfyingly symmetrical right-triangle in northern Taurus. Mars is about 6½° lower left of Jupiter, while the Moon is roughly 5½° upper left of Jove, depending on when you look. (Notice how far Mars has drifted from Jupiter since the 14th!) The solar system trio are framed beautifully by the bright stars of Taurus, Orion, Gemini, and Auriga — a lot of luminosity in a fairly confined bit of sky.

On the following morning (the 28th), the Moon has shifted eastward, and the Moon–Mars–Jupiter configuration has morphed into a curved line, with Mars in the middle. And if you have especially transparent conditions, see if you can fish **Mercury** out of the twilight, low in the east-northeast. The fast-moving little planet rises roughly one hour before the Sun but will be an easier catch on the mornings that follow.

■ Consulting Editor **GARY SERONIK** always enjoys a bit of winter on mild August mornings.

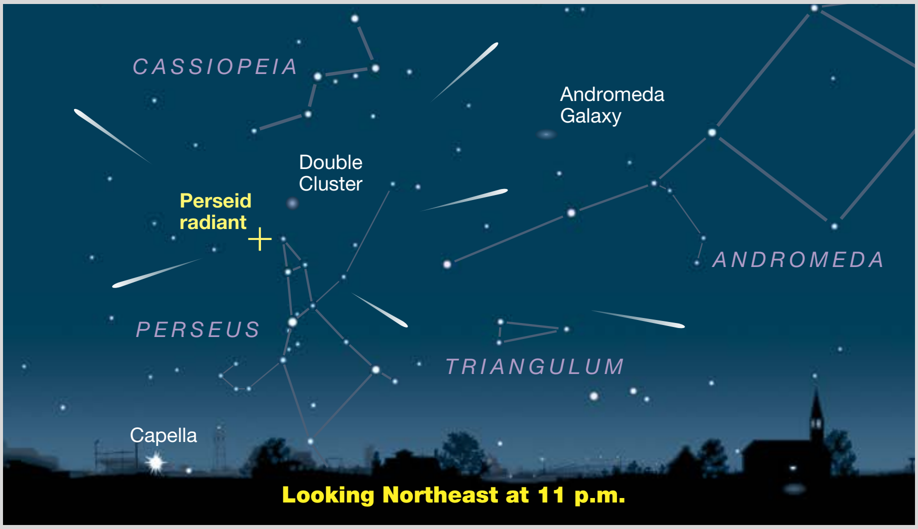
Night of 100 Perseids

The year's most eagerly anticipated meteor shower peaks under nearly moonless conditions.

The most popular annual meteor shower, the Perseids, plays out under excellent circumstances this year. The first-quarter Moon sets before local midnight on the night of the shower's climax, which is fortunate because the display is most active in the hours after midnight.

The Perseid peak occurs on August 12th between 13 UT and 16 UT (9 a.m. to 12 a.m. EDT) making the predawn hours of the 12th the best for meteor watching. However, given the timing of the peak, the night of August 12–13 may also prove worthwhile. Under ideal circumstances, up to 100 Perseids per hour may be seen during maximum, but I always apply a 50% light-pollution discount when I tell family and friends what to expect. A rate of 50 meteors per hour is more realistic for most observers.

Moonlight will reduce meteor counts somewhat before midnight, as will the low altitude of the *radiant* — that invisible gusher in Perseus from which the display's meteors appear to originate. As the chart below shows, on the date of maximum the radiant is located about 7° east of the famed Double Cluster. The radiant really is a perspective effect that occurs when parallel paths appear to converge at a point in the distance, the same way railroad tracks do. Its location gives us a handy way to distinguish Perseids from random meteors (called *sporadics*): If you



◀ This evocative composite image by Miguel Claro of Lisbon, Portugal, shows more than 100 meteors captured over four consecutive nights during the 2023 Perseid meteor shower. He photographed the display from Portugal's Alqueva dark-sky reserve, where exceptional views of the Milky Way and the zodiacal light (also faintly visible in this photo) are possible.

can trace a luminous streak back to the radiant, it's a genuine Perseid. Look about halfway up the sky and off to either side of the radiant for the best views. In the morning hours that means facing approximately southwest or northwest.

The shower is active from mid-July to late August as Earth crosses a broad stream of debris scattered along the orbit of Comet 109P/Swift-Tuttle, the display's parent object. Most particles are sand-size grains, but occasionally peanut-size pieces flare into spectacular fireballs when they plummet into Earth's atmosphere at a speed of 59 kilometers per second (132,000 mph). According to French astronomer and meteor researcher Jérémie Vaubaillon, Earth will encounter five very old meteoroid streams within the comet's debris cloud, primarily on August 12th from midnight to 8 a.m. EDT. You might get to enjoy heightened activity during those hours.

I plan to get out after nightfall on the 11th for a quick taste, and then wake up around 2 a.m. for the main feast. August evenings can be chilly, so I always bring along a wool blanket and a folding lawn chair — being comfortable makes the experience so much more enjoyable.

If you decide to photograph the display, a tripod-mounted camera equipped with a remote shutter-release (the modern version of the old cable release) or an intervalometer will do the job. That way you can let the camera shoot photos automatically while you kick back and take it easy. Use an exposure time of around 30 seconds at ISO 1600 and a wide-angle lens set to its widest aperture (lowest f-stop). With luck, you should net some truly impressive Perseids.

Titan Transits Saturn

AS THE TILT OF SATURN'S ring plane shallows in advance of next spring's edge-on presentation, the planet's close-orbiting moons have been undergoing transits and occultations for some time now. Most of these are exceedingly difficult to observe because the moons are faint and their shadows are mere pinpoints at Saturn's current distance of 1.3 billion kilometers (810 million miles).

Fortunately, Titan is an exception. It began its transit season in May when Saturn was still poorly placed for viewing. Titan orbits close to the equatorial plane, but the slight inclination of its orbit (0.35°) means that Earth and Saturn have to be precisely aligned for us to see the 8.4-magnitude moon pass in front of or behind the planet's disk. This month there are two Titan events: a transit across Saturn's South Polar Region (SPR) and an occultation behind the North Polar Region.

The transit occurs on August 1st, when Titan passes in front of Saturn between about 4:55 UT (12:55 a.m. EDT) and 8:09 UT (4:09 a.m. EDT). Fortunately, the SPR is dusky gray and

▲ Saturn's largest moon, Titan, transits the planet's South Polar Region on the night of July 31–August 1. This simulated view shows the moon at mid-transit at around 2:30 a.m. EDT on August 1st. The moon Tethys appears at far left along with several additional, smaller satellites and their shadows.

could provide a sufficiently contrasty backdrop against which you can make out the moon's disk. Maybe. Titan appears only 0.8″ across — a little smaller than Jupiter's moon Europa when the planet is at opposition.

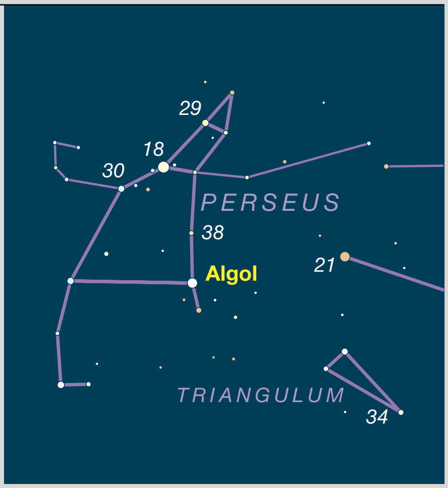
The Titan occultation begins at Saturn's northwestern limb, starting about 3:44 UT on August 9th (11:44 p.m. EDT on August 8th) and wraps up at 6:27 UT (2:27 a.m. EDT on August 9th). Titan orbits relatively slowly, requiring more than 50 minutes for the planet to gobble it up.

To observe these Titan events, use the highest magnification seeing conditions allow. Even if its disk eludes discernment, it's fun to watch Saturn's biggest moon in motion each time it slips in front of or behind the planet's globe.

Minima of Algol

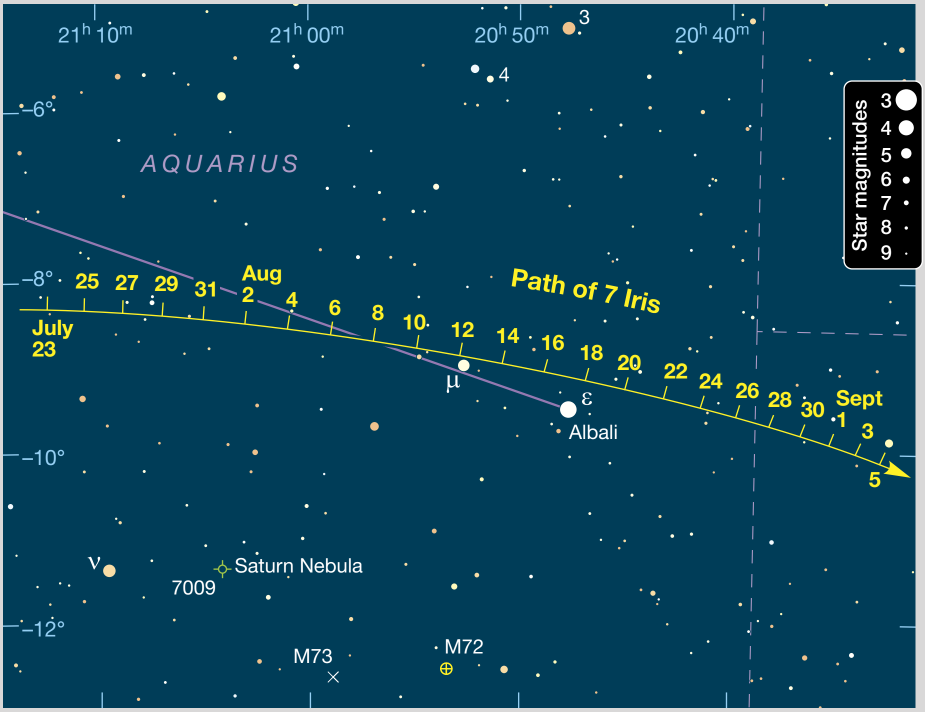
Aug.	UT
3	8:44
6	5:33
9	2:21
11	23:10
14	19:58
17	16:47
20	13:36
23	10:24
26	7:13
29	4:02

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**.



STELLARIUM

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



Rainbow Goddess Asteroid in Aquarius

IN GREEK MYTHOLOGY, Iris is the goddess of the rainbow. It's also the name of a lovely flower, and the seventh asteroid discovered. Iris (the asteroid, that is) comes to opposition on August 6th, when it shines at magnitude 8.3 — placing it within easy reach of a small telescope and even binoculars from dark locations.

As the chart above shows, during August the stony asteroid ambles westward across western Aquarius. (The asteroid's position is plotted for 0h UT on the dates indicated.) On the 2nd Iris passes less than 3° north of the Saturn Nebula (NGC 7009) before slipping just 6′ north of 4.7-magnitude Mu (μ) Aquarii on the night of the 11th. From that date through to the 18th, the asteroid traverses the 1.3° distance between Mu and 3.8-magnitude Epsilon (ε) Aquarii, giving us an entire week during which we can easily gauge the object's nightly motion.

Discovered by English astronomer John R. Hind on August 13, 1847, Iris is a 200-km-wide, main-belt stony asteroid rich in silicates. In the February 2024 article published in *The Planetary Science Journal*, "Detection of Molecular H_2O on Nominally Anhydrous Asteroids," a team of scientists described how they obtained infrared spectra of several asteroids from aboard the now-retired Stratospheric Observatory for Infrared Astronomy (SOFIA) aircraft. Both Iris and 20 Massalia unequivocally revealed the signature of water — the first such detection on otherwise "dry" main-belt asteroids. Just knowing water is present in some form on Iris makes watching it drift through Aquarius, the Water Bearer appropriately enough, even more compelling.

Action at Jupiter

JUPITER IS NOW a prominent sight in the morning sky. During mid-August it rises at around 1 a.m. local daylight time and climbs to an altitude of 56° by sunrise. On the 15th, the planet shines at magnitude –2.2 and presents a disk 36.8″ across. For the sake of comparison, when it reaches opposition on December 7th, it will have brightened to –2.8 and grown to 48.2″ diameter. Between then and now, the big planet shifts just a bit more than ½° eastward against the background stars in Taurus. In that same span of time, Mars — Jupiter's close August companion — motors an impressive 50° eastward!

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify them by their relative positions on any given date and time. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page.

Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Daylight Time is UT minus 4 hours.)

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

August 1: 0:38, 10:33, 20:29; **2:** 6:25, 16:21; **3:** 2:16, 12:12, 22:08; **4:** 8:04, 17:59; **5:** 3:55, 13:51, 23:47; **6:** 9:42, 19:38; **7:** 5:34, 15:30; **8:** 1:25, 11:21, 21:17; **9:** 7:13, 17:08; **10**: 3:04, 13:00, 22:55; **11**: 8:51, 18:47; **12**: 4:43, 14:38; **13**: 0:34, 10:30, 20:26; **14**: 6:21, 16:17; **15**: 2:13, 12:09, 22:04; **16**: 8:00, 17:56; **17**: 3:52, 13:47, 23:43; **18**: 9:39, 19:34; **19**: 5:30, 15:26; **20**: 1:22, 11:17, 21:13; **21**: 7:09, 17:05; **22**: 3:00, 12:56, 22:52; **23**: 8:47, 18:43; **24**: 4:39, 14:35; **25**: 0:30, 10:26, 20:22; **26**: 6:17, 16:13; **27**: 2:09, 12:05, 22:00; **28**: 7:56, 17:52; **29**: 3:47, 13:43, 23:39; **30**: 9:35, 19:30; **31**: 5:26, 15:22

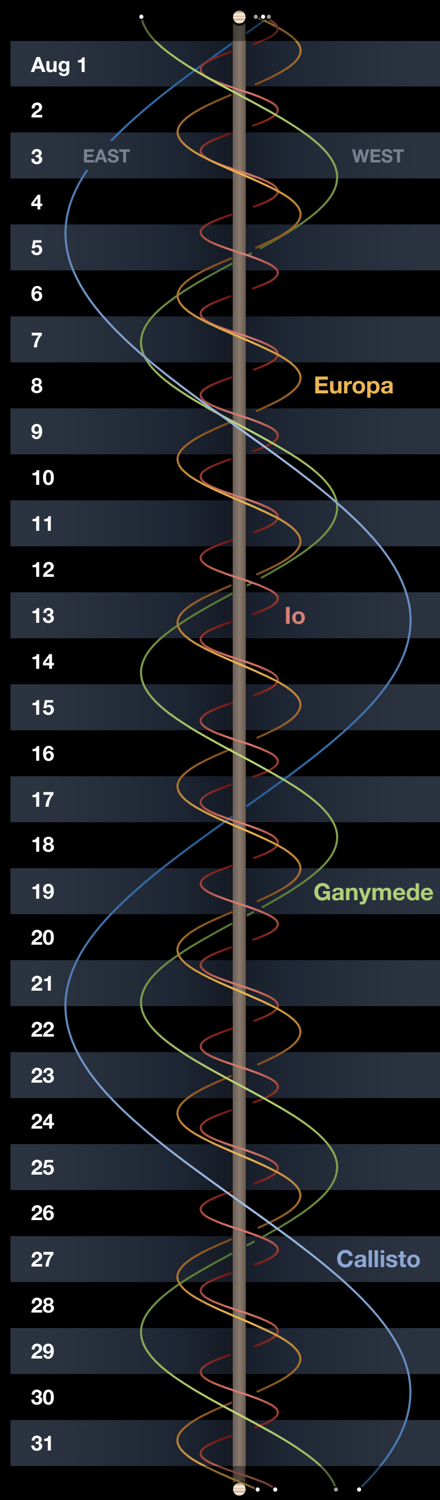
These times assume that the spot will be centered at System II longitude 62° on August 1st. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 62° and 1⅔ minutes later for each degree more than 62°.

Phenomena of Jupiter's Moons, August 2024

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

Lunar Volcanism Seen and Unseen

Maria are a larger portion of the lunar surface than previously known.

Observers have long recognized that large patches of darkness on the Moon must be made of distinctly different material than the surrounding lighter regions. But it wasn't until Apollo 11 astronauts brought home samples from one such dark plain that scientists confirmed the maria are basaltic lava and therefore have volcanic origins (*S&T:* July 2019, p. 14).

The Moon's volcanic history is complex. In 1959, images from the Luna 3 spacecraft revealed that the lunar farside largely lacks the expanses of dark material we're so familiar with on the nearside. This finding later raised questions on precisely how much volcanic material there is on the Moon, how it's distributed, and what it tells us about the Moon's thermal history — all the volcanic material we see must have started as mantle rocks deep inside that were melted.

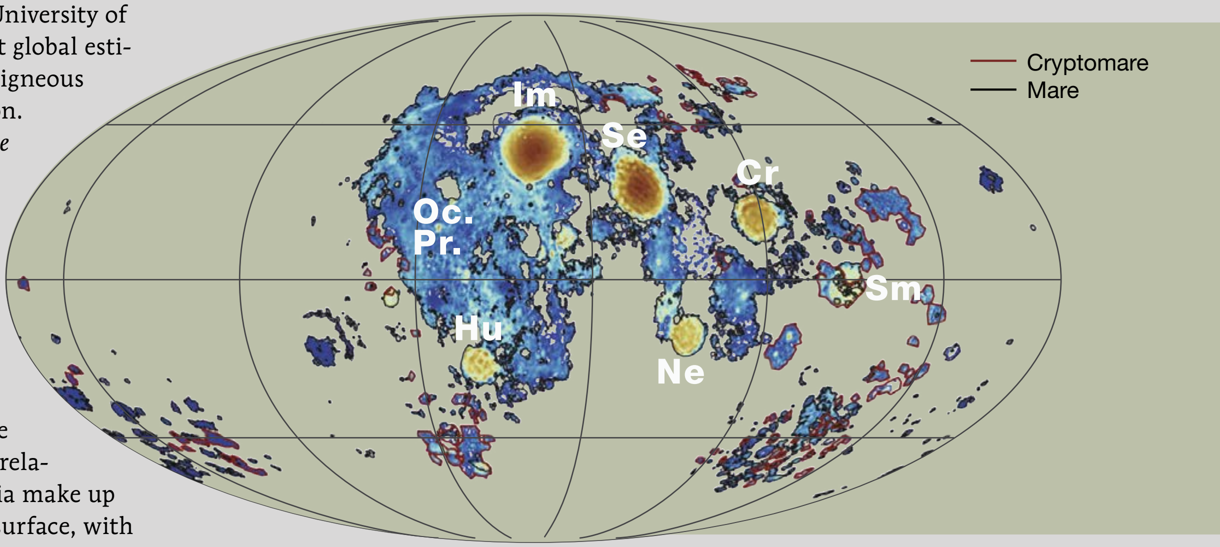
In a recent publication in the journal *Icarus*, Adrien Broquet and Jeffrey Andrews-Hanna (both University of Arizona) present the first global estimates of just how much igneous rock there is on the Moon. They detail both *extrusive rocks* (volcanic material erupted onto the surface) and *intrusive rocks* (magma that solidified beneath the surface, which we can find through careful study).

Measuring the surface area of dark volcanics is relatively easy. The vast maria make up about 17% of the lunar surface, with the lava-covered floors of craters such as **Plato**, **Billy**, and **Mercator** contributing a little more. There are also *cryptomaria*, ancient lava flows now covered by subsequent ejecta from the formation of basins and craters. Cryptomaria were originally identified by the existence of dark-halo craters, such as the 4-km-diameter (2.5-mile-wide) **Copernicus H**. The impactor that formed Copernicus H excavated mare lavas that had lain hidden beneath a covering of bright ejecta produced by the earlier formation of nearby Copernicus. Careful mapping of these dark-halo craters has revealed significant cryptomaria in the Schiller–Schickard, Balmer–Kapteyn, and other basins (*S&T*: Feb. 2023, p. 52).

But there's more igneous material on the Moon than what we can see. Intrusive rocks often are the subsurface portion of a rising column of magma, whose upper end breached the surface and erupted as lava. On the Moon, these intrusive rocks lie concealed within the crust but are detectable by their effects on the lunar surface.

An excellent example of these effects are places where unerupted mare basalts have seeped under the floor of an impact crater and lifted its floor. **Gassendi**, **Posidonius**, and **Atlas** are prominent examples of such floor-fractured craters. Intrusive layers have fractured their floors, creating concentric rilles. In some cases, material also was extruded to create lava-covered floors, rilles, and small volcanic dark-halo craters. Other inferred intrusions manifest as *ring dikes* — circular or arc-shaped deposits that invaded pre-existing fractures such as basin rings — and under volcanic masses such as the Marius Hills to the west of **Marius**.

A more recently discovered type of intrusive activity is interpeted to explain the widespread, linear *gravity anomalies* detected in data from



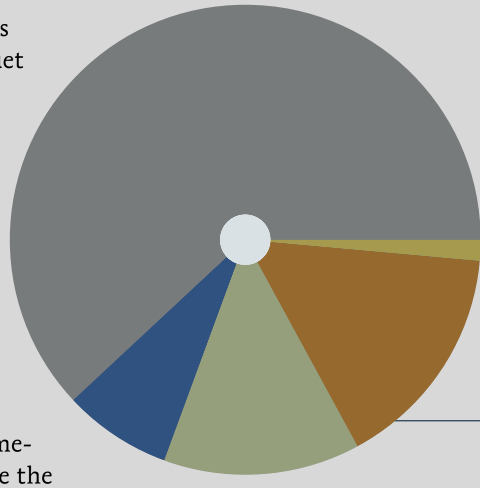
A. BROQUET / J. C. ANDREWS-HANNA

NASA's Gravity Recovery and Interior Laboratory (GRAIL) spacecraft. Gravity anomalies are created by variations in rock density. In a previous publication, Andrews-Hanna and colleagues proposed that the 100- to 1,000-km-long linear anomalies in GRAIL data were ancient magma intrusions or dikes that I like to call worms. Based on the number, lengths, and likely depths of worms, these features are the second-largest intrusive contributor to the total lunar igneous inventory. Their existence also indicates that the Moon's diameter slightly expanded early in its history.

Identifying all the types of intrusive and extrusive lunar volcanism is much easier than determining their depths and extents in order to calculate their volumes. Broquet and Andrews-Hanna combine GRAIL gravity data with Lunar Reconnaissance Orbiter (LRO) altimetry to do the latter. The mathematical models are complex, but the basic idea is that they estimate the igneous body's volume by determining the extent of its gravity anomaly and the subsidence of the crust and upper mantle due to a mare deposit, intruded slab, or dike of solidified magma surrounded by crustal rocks. The models rely on best estimates of several uncertain quantities, such as the density difference between the solid magma and the adjacent non-intrusive crust, as well as the lunar crust's thickness and elasticity.

Using various methods, Broquet and Andrews-Hanna calculated a total volume of more than 29 million cubic kilometers of igneous deposits on the Moon. The estimated 18.2 cubic kilometers of maria are the single biggest contributor of lunar igneous materials. The next largest are basin-ring dikes at 4.6 km^3, linear intrusions and worms with 3.9 km^3, cryptomaria with 2.2 km^3, and floor-fractured craters contributing 0.4 km^3. They also derived the thicknesses of maria to be about 8 km in the major basins like Imbrium and Serenitatis. Away from circular basin centers, mare thickness averages about 1.6 km, which accounts for the appearance of many semi-buried and ghost craters in southern **Oceanus Procellarum**.

As the diagram on the facing page shows, the occurrence of various rock types strongly differs on the Moon's two hemispheres, with the nearside dominated by extrusive rocks and the farside by intrusive rocks. The farside's total volume of igneous rocks is also only one-third that of the nearside.



◀ This pie chart shows the global volumetric fractions of extrusive (gray) and various intrusive igneous materials.

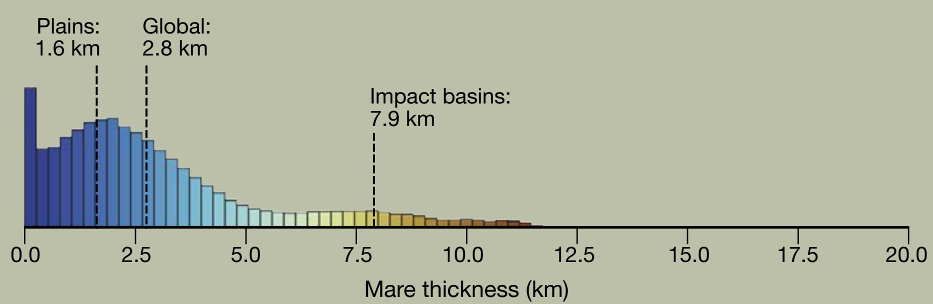
Nearside volcanism is concentrated in the Moon's northwest quadrant, right where the crust is thinnest and the abundance of heat-producing radioactive elements is highest.

The maria are the most conspicuous lunar features, and many observers who are familiar with floor-fractured craters and volcanic shields are now becoming aware of cryptomaria. These are among the most intriguing lunar features to explore on our satellite. Yet this new inventory shows that the volcanism that makes the Moon more than a graveyard of endless impact craters constitutes just 1.5% of the Moon's 40-km-thick crust. We get so much from so little.

■ Contributing Editor **CHUCK WOOD** continually marvels at the complex story the lunar surface tells.

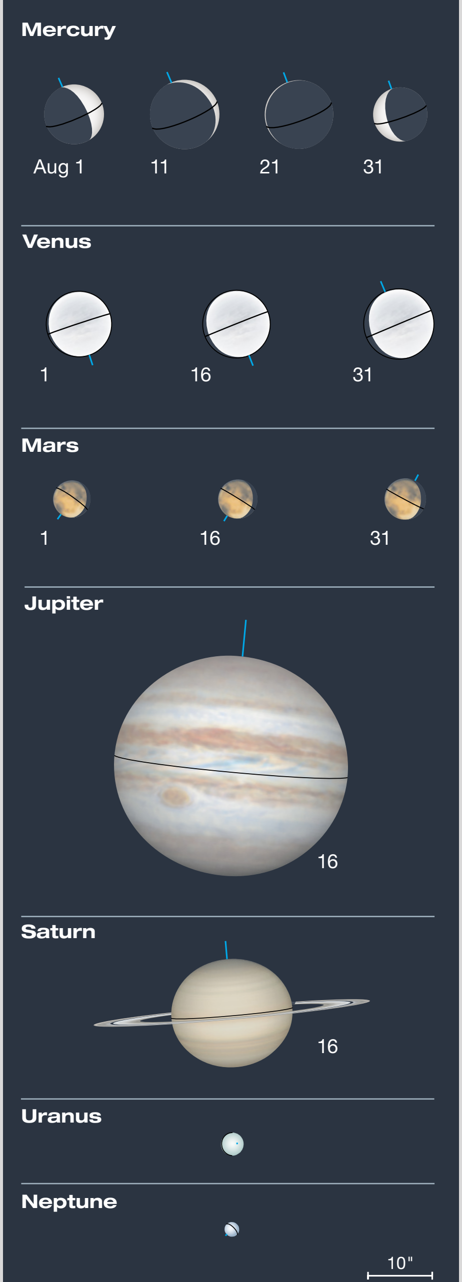
A. BROQUET / J. C. ANDREWS-HANNA (2)

◀▼ This Mollweide projection shows the estimated nominal global mare thickness model with an elastic-crustal thickness of 40 kilometers (25 miles). The color scale shows the estimated area-weighted thickness, with mean thicknesses for the plains, impact basins, and on a global scale. Labels correspond to Oceanus Procellarum (Oc. Pr.), Mare Humorum (Hu), Mare Imbrium (Im), Mare Serenitatis (Se), Mare Nectaris (Ne), Mare Crisium (Cr), and Mare Smythii (Sm).



Mare Thickness

Impact Basin	Mare Volume (million km^3)	Maximum thickness & standard deviation (km)
Imbrium	2.5	8.7 ± 0.7
Serenitatis	2.1	8.8 ± 0.6
Crisium	1	8 ± 0.4
Nectaris	0.7	7.4 ± 0.3
Humorum	0.6	7.3 ± 0.3
Smythii	0.5	6.2 ± 0.3



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

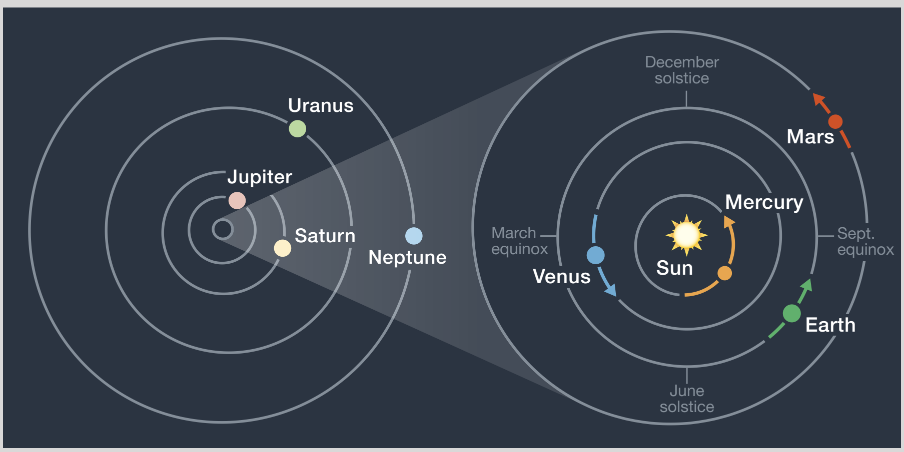
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during August. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dawn starting on the 29th • **Venus** visible at dusk all month • **Mars** and **Jupiter** visible in the predawn hours all month • **Saturn** rises in the evening and transits the meridian in the predawn.

August Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	8^h 45.4^m	+18° 02′	—	–26.8	31′ 31″	—	1.015
	31	10^h 37.7^m	+8° 40′	—	–26.8	31′ 41″	—	1.009
Mercury	1	10^h 15.6^m	+7° 38′	24° Ev	+0.9	9.3″	28%	0.722
	11	10^h 10.4^m	+6° 20′	15° Ev	+2.7	10.8″	9%	0.624
	21	9^h 42.2^m	+9° 21′	5° Mo	+5.0	10.7″	2%	0.629
	31	9^h 33.2^m	+13° 03′	16° Mo	+0.8	8.5″	24%	0.795
Venus	1	9^h 49.7^m	+14° 43′	16° Ev	–3.8	10.2″	96%	1.641
	11	10^h 36.7^m	+10° 20′	18° Ev	–3.8	10.4″	95%	1.606
	21	11^h 22.3^m	+5° 29′	21° Ev	–3.8	10.6″	93%	1.566
	31	12^h 06.9^m	+0° 24′	24° Ev	–3.8	11.0″	91%	1.522
Mars	1	4^h 22.3^m	+20° 57′	62° Mo	+0.9	5.9″	89%	1.598
	16	5^h 04.6^m	+22° 27′	66° Mo	+0.8	6.2″	88%	1.521
	31	5^h 45.7^m	+23° 17′	71° Mo	+0.7	6.5″	88%	1.437
Jupiter	1	4^h 51.2^m	+21° 48′	55° Mo	–2.1	35.5″	99%	5.551
	31	5^h 10.5^m	+22° 15′	79° Mo	–2.3	38.4″	99%	5.135
Saturn	1	23^h 20.1^m	–6° 35′	141° Mo	+0.8	18.7″	100%	8.870
	31	23^h 13.0^m	–7° 25′	171° Mo	+0.6	19.2″	100%	8.669
Uranus	16	3^h 38.3^m	+19° 11′	86° Mo	+5.7	3.6″	100%	19.612
Neptune	16	23^h 58.7^m	–1° 34′	144° Mo	+7.8	2.3″	100%	29.071

The table above 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**.



Creating Star-Trail Photos

Capturing classic images showing Earth's rotation is easier than you might think.

Without question, nightscape photography is the most approachable form of astrophotography. A camera, tripod, and lens. Done. With this simple setup you can capture impressive images of the Milky Way or an auroral display with exposures as short as 10 seconds. And to avoid trailing stars in our astrophotos, with most lenses we rarely expose much longer without the aid of a motorized star-tracking platform or equatorial mount (*S&T:* Feb. 2023, p. 54).

But what if we *want* trailed stars?

Images that show star trails along with an interesting landscape or dramatic piece of architecture are often visually striking while artistically demonstrating Earth's rotation under the starry canopy of the night sky. And if you really need proof that Earth is indeed not flat, star-trail photos can do that for you, too.

The technique is straightforward and doesn't even require an expensive, fast lens. All you need is a manually controlled camera, a wide-angle lens, a tripod, and (ideally) an intervalometer or remote shutter release.

The Basic Idea

In the film days, the brute-force method for creating star-trail images was to combine a very slow (low-ISO) film with a small lens aperture and simply expose for as long as possible — at least an hour or so. This approach, however, leads to badly overexposed pictures when attempted with modern digital cameras, which record light much more efficiently than film does. Instead, the technique is to record a series of many short exposures and combine them later with software. But, unlike with typical deep-sky or nightscape photography, we don't want to register our images on the stars. Instead, each frame is referenced to the landscape, allowing the stars to shift (trail) relative to a stationary foreground. The result is a composite photo that shows the motion of the stars above your chosen scenery.

Because the basic technique requires dozens if not hundreds of individual images shot sequentially, you can probably see why some means of automating the process is helpful. The most basic method is to use a simple, manual shutter release that has a locking mechanism. I set my camera to record 30-second

NORTH VIEW This image of Fort Jefferson taken during a camping trip to Florida's Dry Tortugas National Park shows the motion of stars around the north celestial pole. The author illuminated the fort by using the light-painting technique described in the text.

ALL IMAGES COURTESY OF THE AUTHOR

exposures (the maximum most cameras will allow in Manual mode) and to Continuous Release. When I lock the shutter-release button down on the shutter-release cable, the first exposure begins immediately, and the camera continues to fire 30-second exposures for as long as the button is locked down (or until the camera runs out of battery power).

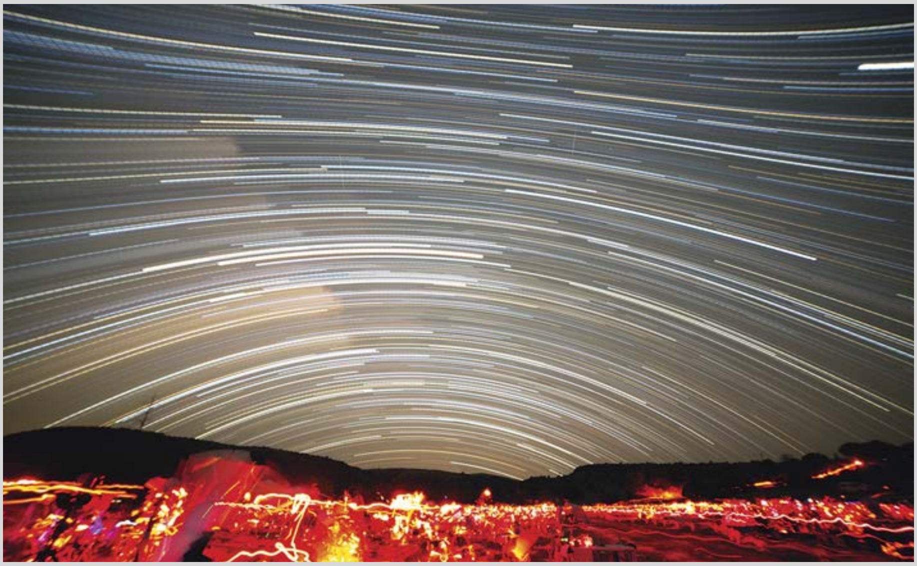
An intervalometer represents a more sophisticated and versatile option. Fortunately, such devices are inexpensive and easy to come by — just be sure to purchase one designed to function with your camera's specific make and model. An intervalometer works with your camera in Bulb mode and lets you program a sequence of exposures of practically any duration, and even set the delay time between frames if you like. I've successfully shot many star-trail images with a series of 2-minute exposures captured over the course of a couple of hours.

Despite the advantages an intervalometer offers, I recently reverted to the more basic method after an attempt to get images at a remote location failed when cold temperatures killed the batteries in my intervalometer. I came home with some nice nightscape shots, but star trails were out of the question. Sadly, I won't be able to revisit that location any time soon. The lesson here is to bring extra batteries — or don't use an intervalometer at all.

Another reason I prefer the more basic shutter release is because the intervalometer model I used didn't allow back-to-back exposures without at least a 1-second delay between shots. With some lens focal lengths, that produces visible gaps in the star trails instead of smooth, continuous streaks.

Practical Matters

Star trails by themselves are visually interesting, but for a really successful photograph you also need to identify an interesting foreground to include in your shots. Once you've found your



▲ **PUTTING IT ALL TOGETHER** *Top:* This single, 180-second exposure captured at the Texas Star Party shows some star trailing. Note the longest trails are those closest to the celestial equator. *Middle:* Several frames combined in *Photoshop* start to reveal significant star trails but retain the same foreground brightness. *Bottom:* The final, color-tweaked image displays impressive star trails resulting from a set of exposures totaling 2.7 hours. The Milky Way's leading edge is clearly visible even in the combined image.

spot, it's time to begin capturing the frames you'll later assemble into a finished photo. As with any astronomical image, I recommend shooting in RAW format for the greatest amount of processing flexibility. Also bear in mind that the more frames you capture, the more images you'll have to combine later. That's why you want each individual exposure to be as long as practical. How long can you go?

Unfortunately, you can't determine the maximum exposure time from a simple formula because the upper limit is set by the brightness of your sky. The best approach is to take some test exposures with the lens stopped down a bit, starting at around f/8. Set your camera's ISO to 100 or 400 and take exposures of 30, 120, and 180 seconds duration to find out what looks best. Try to balance the exposure time and lens aperture setting so that you get noticeable star trails while at the same time the camera's histogram display shows the main hump more or less centered, or even shifted slightly to the left. If it's too far to the right, the brightest stars will be blown out and the trails will begin to lose their color.

The other consideration is how brightly illuminated your foreground is. If it appears overexposed in your test shots, then you may want to reduce the exposure time or record a separate, single foreground frame that you can blend into your final composition later.

The proper exposure time for your chosen foreground is a judgment call. You may want it to be a prominent part of the composition, or perhaps it works best as a silhouette. You can even try "painting" it with light to create a dramatic effect or help it show up better in your final image. Light painting is pretty straightforward. During one or more of your exposures, simply shine a light on the parts of the foreground you want to illuminate. For my Dry Tortugas image (shown on page 55) I fired a handheld camera flash repeatedly as I walked the length of the structure.

▲ **ALTERNATIVE SOFTWARE** *Star Stacker* is one of many helper apps available that can quickly transform a folder of star-trail images into a single image. The app even includes multiple options for different artistic effects that you can add to your image.

Some Assembly Required

Normally, *stacking* in astrophotography means aligning a set of images on the stars so that their light adds together to create a single image with an improved signal-to-noise ratio. In effect, the finished picture is simply a better version of a single, individual frame. However, when it comes to star-trail photos our goals are different and so is the approach. If we simply *summed* the frames together, the foreground would get disproportionately bright. If we *averaged* them, the stars trails would appear faint. Instead, we want each pixel in the assembled photo to be the brightest value found in the stack of individual frames. That way, each segment of the star trail contributes to the final image and the dark areas stay dark. We can accomplish this feat with image-processing software.

My tool of choice is *Adobe Photoshop*, though other image-editing software has similar capabilities. The first step is to place all the individual frames in a single folder on your computer to make the process easier. Next, select ***File > Scripts > Load Files Into Stack***. This will place all of your star-trail photos into a single *Photoshop* document, with each individual frame listed as a separate layer. Then, for each layer, set the blending mode to ***Lighten***. This is the key. As you work your way down the stack of images, you'll see the star trails gradually lengthen, segment by segment.

Don't try to modify each frame at this stage — create your stack first and then ***Flatten*** the layers into a single .psd file. Once you've created the stacked result, you're ready to start working toward your final version. You might want to lighten the picture or perhaps enhance the saturation slightly — the choice is yours. As chefs say, "season to taste."

If *Photoshop* isn't something you want to deal with, a quick app search will reveal several alternatives. I found one on the Apple App Store for macOS called *Star Stacker*. It adds your individual shots together and even includes a number of special effects that you can apply to your final image. An option for PC users is *Startrails* (**startrails.de**) to automate the process. There's nothing here that you can't do manually in *Photoshop*, but both are simple to use and do a great job.

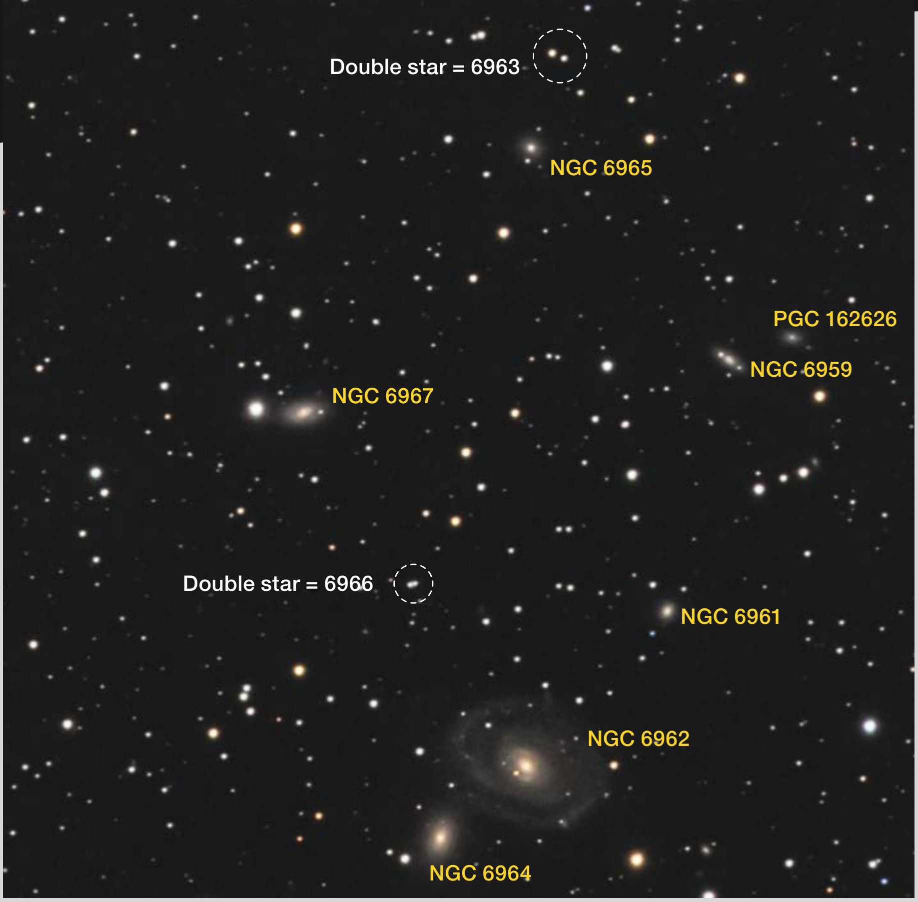
A camera, tripod, lens, cable release, and some imagination. That's really all you need to create a captivating star-trail image.

What are you waiting for?

■ Contributing Editor **RICHARD S. WRIGHT, JR.** is rarely more content than when watching the stars trail overhead while his imagination runs wild.

Ghostly Errors

A group of galaxies in western Aquarius challenges casual inspection.



▲ **GHOSTLY GALAXY GROUP** NGC 6962 is by far the largest member of this group of dim galaxies. However, it also exhibits the lowest surface brightness and is thus a pale glow in the author's 18-inch telescope. NGC 6962 is about 182 million light-years away.

GARY IMM

As a longtime deep-sky observer, I tend to gravitate toward dim and obscure telescopic targets. "Dim and obscure" certainly describes some of the nondescript collections of galaxies I scrutinize with my 18-inch f/4.5 Dobsonian reflector. Tough stuff? Bring it on.

One coarse clump of galaxies resides near the celestial equator in western Aquarius. Most of the individuals in the **NGC 6962 Group** are wisps of 13th and 14th magnitude. Even so, I keep returning to them in an effort to tease out more detail — or *any* detail at all!

I've been studying the NGC 6962 Group from the top of 6,100-foot (1,860-meter) Mount Kobau in the dry southern interior of British Columbia, just north of the 49th parallel. At my alpine perch, the group crests 41° above the horizon — not bad, though the seeing at 41° isn't reliably steady. The scope isn't always steady, either, as the Kobau summit is prone to powerful gusts of wind. And now, increasingly each summer, thick wildfire smoke often drifts overhead. On one occasion a few years ago, the wildfire itself threatened our camp. My "bring it on" bravado disappeared fast.

Sightseeing

If you enjoy star-hopping, you'll like my zigzag ramble to the NGC 6962 Group. Join me as I set out from 3rd-magnitude Theta (θ) Aquilae, close to the Aquila-Aquarius border. The roughly 10° hike from Theta passes several delightfully dim galaxies. Unless otherwise noted, all the fields described below materialize in my 18-inch Dob at 228×.

The zigzag starts with a ¾° southeastward hop from Theta over 66 Aquilae to 13.4-magnitude **PGC 64318**. This almost edge-on galaxy, measuring 1.7′ × 0.3′, appears slightly elliptical on a northeast-southwest slant. Continuing southeastward 1.9° passes **Σ2661**, an attractive, low-power double star comprising 7.9- and 9.2-magnitude components, 24.4″ apart. Only ½° farther is 13.5-magnitude **NGC 6900**, a face-on galaxy 1.0′ × 0.8′ in size. The puny puffball surrenders no detail.

After relishing NGC 6900, I push 1½° eastward to four stars outlining a quadrilateral 1¼° high and 1° wide. The asterism is dominated by 4.9-magnitude 69 Aquilae, which I'll come back to later. For now, I aim the scope at the quadrilateral's southern tip, marked by 6.1-magnitude 68 Aquilae (it comes with two modest companions), because this star shines 20′ southeast of 12.2-magnitude **NGC 6915**. Covering a gigantic (I'm kidding) 1.5′ × 0.9′ of sky, NGC 6915 is an easy, albeit featureless fuzz.

The northern tip of the quadrilateral is double-punched by **South 749**, which sports 6.8- and 7.5-magnitude stars 60.0″ apart. From that wide duo I cast 36′ eastward to hook two galaxies less than 10′ apart, aligned approximately north-south. The southern one, 13.5-magnitude **NGC 6922**, is a 1.3′ × 1.0′ face-on system. The northern one, 14.8-magnitude **PGC 64812**, is a 0.8′ × 0.2′ edge-on weakling. An 8.9-magnitude signpost, HD 195163, flickers 2½′ south of it. Trolling 19′ east-northeast from the galaxy nets another small fry: 14.0-magnitude **PGC 64864**, 1.2′ × 0.7′ in extent. And 7.5′ southeast of that guy, I reel in 13.9-magnitude **PGC 64880**, a roundish 0.9′ × 0.7′ glow.

From PGC 64880, a 20′ hop southeastward lands in the middle of a 12′-long row of three 9th-magnitude stars also trending southeastward. North of the three stars are two galaxies 4′ apart, oriented east-west: 12.4-magnitude **NGC 6926** and 13.4-magnitude **NGC 6929**. The former, a barred spiral

2.0′ × 1.4′ in size, is a north-south oval. The latter, 0.8′ × 0.7′, is a smudge a bit west of two extremely faint suns. South of the row-of-three is 13.4-magnitude **PGC 64910**, flanked by 14th-magnitude stars above and below. Officially 1.7′ × 1.4′, the face-on barred spiral is a decent specimen, yet only its central bulge shows.

Into the Group

Now I return to 69 Aquilae where I embark on an L-shaped star-hop covering 2° × 3°. The route trends eastward to 4.9-magnitude 70 Aquilae, then turns northward. I nudge the scope past 4.3-magnitude 71 Aquilae, cross into Aquarius, and stop at 5.2-magnitude 1 Aquarii. After that, I push 2° eastward to the NGC 6962 Group.

Anchoring the six-part set is 12.1-magnitude **NGC 6962**, a 2.9′ × 2.2′ oval glow oriented east-northeast by west-southwest. This "big" galaxy is flanked by 15th-magnitude suns east and west. Less than 2′ to the southeast is 13.0-magnitude **NGC 6964**. Its 1.7′ × 1.3′ shape is aligned north-south and is attended southeastward by a 14th-magnitude star. A line from NGC 6964 back through NGC 6962, extended 3′ northwestward, approaches 13.7-magnitude **NGC 6961**. An unimpressive 0.6′ × 0.5′ blur, NGC 6961 is designed for averted vision even in my 18-inch!

Three galaxies form a broad triangle about 7′ north of the anchor galaxy NGC 6962. The best of them is 13.1-magnitude **NGC 6967**. Measuring 0.9′ × 0.6′, NGC 6967 is elongated east-west, its eastern end close to a 10.9-magnitude star. Veteran observer and *S&T* Contributing Editor Steve Gottlieb, who has been observing this group for decades, notes that NGC 6967 is incorrectly listed in some catalogs as NGC 6965, and I've noticed the same wrong labeling in atlases.

Nudging the scope 6½′ west of NGC 6967 nails 13.7-magnitude **NGC 6959**. Possessing dimensions of 0.6′ × 0.3′, NGC 6959 is just a hazy northeast-southwest ellipse. But wait — it's accompanied westward by 14.8-magnitude **PGC 162626**, a similar 0.6′ × 0.4′ haze. The two hearty hazes cooperate with a 12.8-magnitude star to make a 1½′-wide triangle. A short row of three dim dots slants south of it. I'm knocked out.

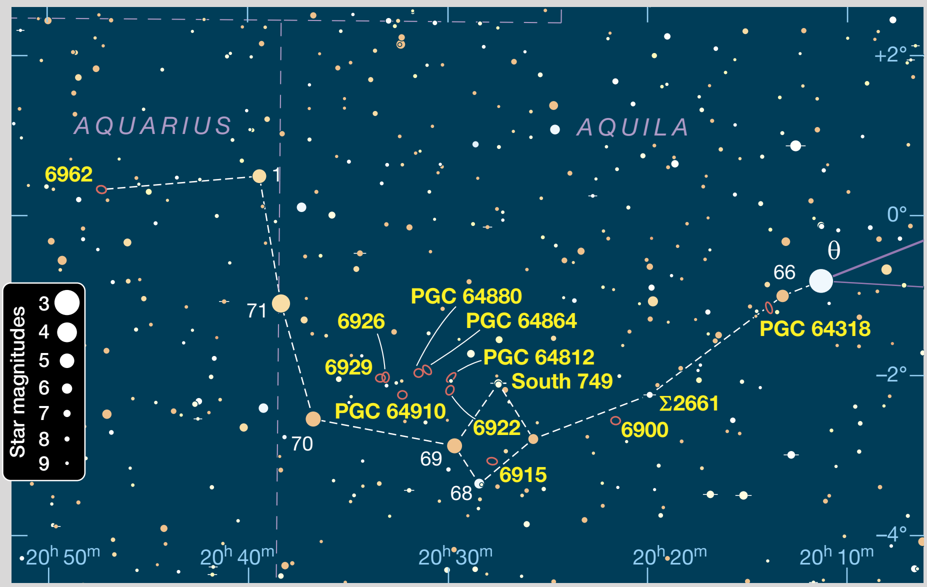
Establishing the group's northern point is the "real" **NGC 6965**. Again, averted vision is needed to consistently reveal this 14.0-magnitude, 0.6′ × 0.4′ patch. In addition to the mixup mentioned earlier, NGC 6965 is often charted and cataloged as **NGC 6963**. Gottlieb has commented that the misidentification originated in a faulty observatory bulletin more than a century ago. Worse, the 1885 discovery position for the phantom NGC 6963 corresponds to an insignificant binary star 1.5′ north of NGC 6965. There's no galaxy there — only the double star.

The group contains one other double-trouble target: Halfway between NGC 6962 and NGC 6967 is a blurry binary that was erroneously cataloged as a galaxy and assigned the label **NGC 6966**. Observing from California, Steve has resolved the extremely faint pair in an 18-inch reflector at 323×. His determined success remains an "unresolved" challenge for me.

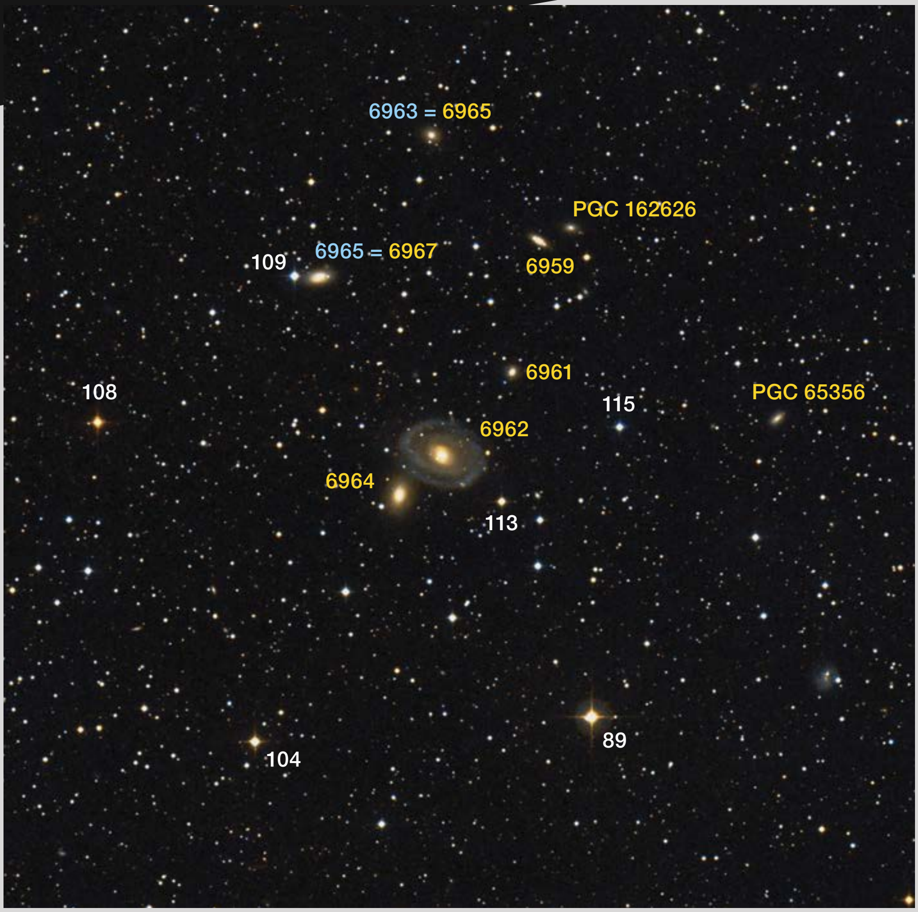
Targets En Route

Object	Surf. Brightness	Mag(v)	RA	Dec.
PGC 64318	12.5	13.4	20^h 13.9^m	−01° 09′
NGC 6900	12.6	13.5	20^h 21.6^m	−02° 34′
NGC 6915	12.4	12.2	20^h 27.8^m	−03° 05′
NGC 6922	13.7	13.5	20^h 29.9^m	−02° 11′
PGC 64812	12.6	14.8	20^h 29.8^m	−02° 02′
PGC 64864	13.7	14.0	20^h 31.0^m	−01° 56′
PGC 64880	—	13.9	20^h 31.5^m	−01° 58′
NGC 6926	13.3	12.4	20^h 33.1^m	−02° 02′
NGC 6929	12.8	13.4	20^h 33.4^m	−02° 02′
PGC 64910	14.2	13.4	20^h 32.3^m	−02° 15′

For both tables: Right ascension and declination are for equinox 2000.0.



▲ **CELESTIAL BORDER TOWN** The NGC 6962 Group is a community of galaxies located in westernmost Aquarius, next to Aquila. Star-hopping from Theta Aquilae passes many faint galaxies.



▲ **FAINT FIELD** The NGC 6962 Group is easy to miss. To ensure he doesn't overshoot the target, the author looks 1½° east of 1 Aquarii for a 14′-long "fence" of three 8th- and 9th-magnitude stars slanted northeast-southwest. They're outside the frame of this image, but you'll see them in the chart on page 59. The field of fuzzies lies ½° beyond the fence.

NGC 6962 Group

Object	Surf. Brightness	Mag(v)	RA	Dec.
NGC 6962	14.1	12.1	$20^h 47.3^m$	+00° 19′
NGC 6964	13.8	13.0	$20^h 47.4^m$	+00° 18′
NGC 6961	12.4	13.7	$20^h 47.2^m$	+00° 22′
NGC 6967	12.4	13.1	$20^h 47.6^m$	+00° 25′
NGC 6959	11.9	13.7	$20^h 47.1^m$	+00° 26′
PGC 162626	—	14.8	$20^h 47.1^m$	+00° 26′
NGC 6963	—	14.6, 15.3	$20^h 47.3^m$	+00° 31′
NGC 6966	—	14.7, ~15	$20^h 47.4^m$	+00° 22′
NGC 6965	12.4	14.0	$20^h 47.3^m$	+00° 29′
PGC 65356	—	13.9	$20^h 46.6^m$	+00° 20′
PGC 65347	13.2	14.1	$20^h 46.3^m$	–00° 13′
PGC 65398	12.5	14.4	$20^h 48.0^m$	–00° 11′
PGC 65333	11.7	13.9	$20^h 45.8^m$	+00° 11′

Outliers

The seven galaxies I've described so far are the core members of the group. In addition, I've bagged four outlying PGCs, all of them helpfully located near unremarkable but easy-to-find stars. Hopping 5½′ west-northwest of NGC 6962 takes me to an 11.5-magnitude star, and 4⅓′ west of it is an eighth galaxy, 13.9-magnitude **PGC 65356**, which is a 0.8′ × 0.5′ midget. The new total of eight objects fits within a circle of sky only ¼° in diameter, though it's difficult to clearly register all eight at the same time.

More outliers are scattered southward. First, I pick up 14.1-magnitude **PGC 65347**, a 0.7′ × 0.7′ nothingburger just northeast of the 6.8-magnitude star HD 197814. I also go for 14.4-magnitude **PGC 65398**, a slender edge-on 1.0′ × 0.2′ in extent, which lies immediately west-southwest of the 8.5-magnitude star HD 198125. Finally, I go 10′ southwest of NGC 6962 to the 8.9-magnitude star TYC 512-1318-1, then shift 17′ westward to capture 13.9-magnitude **PGC 65333**. (Along the way, a pallid fleck named PGC 65351 eludes detection.) The mighty PGC 65333, rumored to span 0.5′ × 0.3′, does a good imitation of a badly focused dot.

In total, I've pocketed 11 members of this loose-knit family. The little lumps of light aren't impossibly faint, but you may have noticed that the word "bright" doesn't appear anywhere in my descriptions. My roundup of the pale puffs and misty misidentifications reminds me of Edwin Hubble's closing comments in his seminal *Realm of the Galaxies*, published in 1936. "Eventually," wrote Hubble, "we reach the utmost limits of our telescopes. There, we measure shadows and search among ghostly errors of measurement for landmarks that are scarcely more substantial." The great measurer of celestial shadows is on my mind when I dive into the lumpy sky of western Aquarius.

■ Contributing Editor **KEN HEWITT-WHITE** has been observing the deep sky for more than five decades. The author would like to acknowledge Steve Gottlieb for his observations posted online.

A Handy Reference

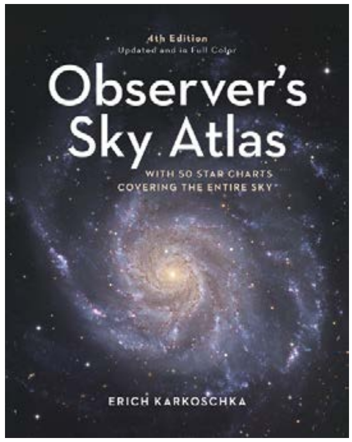
OBSERVER'S SKY ATLAS: *The 500 Best Deep-Sky Objects With Charts and Images, 4th Edition*

Erich Karkoschka
Firefly Books, 2023
144 pages, ISBN 9780228104100
US$39.95, hardcover

MOST OBSERVERS HAVE had trouble tracking down deep-sky objects at one time or another. Perhaps their target lies in a crowded region of the sky, or it doesn't look anything like the beautiful images online taken by the Hubble Space Telescope or talented astrophotographers. Wouldn't it be nice to have a sky atlas that also contained pictures of what deep-sky objects look like in binoculars or a small telescope?

The *Observer's Sky Atlas* by Erich Karkoschka is exactly that. First published in German in 1988 and translated into English in 1990, the atlas is now in its fourth edition (and, for the first time, in color). Along with the helpful pictures of deep-sky objects, the book features new star charts based on updated data from the European Space Agency's Gaia mission.

The Explanatory Notes section, which serves as an introduction, provides detailed information on how to use the atlas, with some Astronomy 101 thrown in along the way. It explains basic astronomical concepts such as resolution, directions in the sky, and stellar luminosity and colors, and it offers tips on averted vision and other observing techniques. This section also includes multiple charts, such as a color-magnitude diagram for all stars cataloged in the book as well as one that shows the distribution across the sky of the book's 500 objects. Altogether, the book features finder charts for 250 objects for binoculars and small telescopes; in-depth charts for 150 additional, slightly fainter objects; and a list of 100 still-fainter objects that might require larger amateur telescopes to spot.



The Star Charts section, which comprises the bulk of the book, offers spreads that focus on a specific region of the sky, ordered from north to south. Each spread has lists of observing targets on the left-hand page and charts of the targeted constellation on the right-hand page, surrounded by smaller, close-up charts of deep-sky objects found in the region of interest. Photographs of each noted object appear along the edges of both pages.

On the left-hand page, the author gives a general description and some catalog details about each target, including magnitude, size, distance, and celestial coordinates. Below that lie tables of information on the major stars in the constellation, followed by subsections on variable stars and binary stars. But the real showstoppers are the 532 images of most of the observing targets listed in the atlas, along with several overview photos of sections of the Milky Way.

> This book functions exceptionally well as a ready-made list of targets for observers using binoculars and small telescopes.

This book functions exceptionally well as a ready-made list of targets for observers using binoculars and small telescopes. The images of galaxies, nebulae, and clusters aid the observer in identifying each object in their scope, and the target lists make it easy to pick a constellation and start observing without extensive preplanning or in-depth knowledge of any particular region of the sky. The new color scheme also facilitates easier reading of the atlas under a red light in the field.

While visually crowded, the atlas is easy to use. The charts are divided by the northern, equatorial, and southern regions and then by right ascension. The index of deep-sky objects and binary stars, along with the grayscale bars on the edges of the pages, make it straightforward for observers to locate a specific chart or object, even in the dark.

The *Observer's Sky Atlas*, while useful to beginners, isn't an in-depth observing guide. Observers will need to know their way around their equipment and already have a sound base of basic astronomy terminology and knowledge, including grasping how to read a star chart. Curiously, the authors use "nebula" to refer to all deep-sky objects, including star clusters and galaxies, a practice that might confuse a beginner.

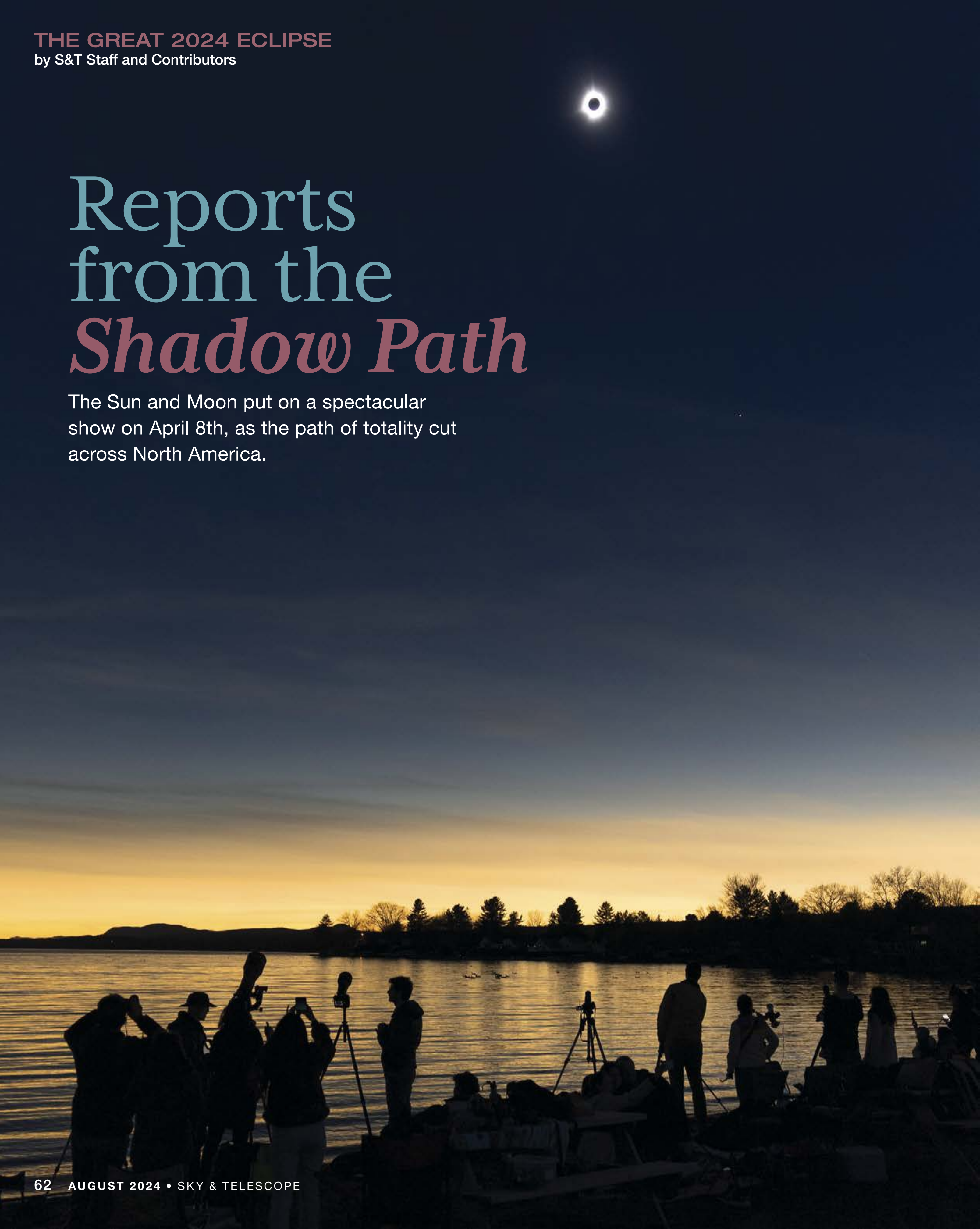
That aside, this atlas is an excellent resource for observers who already have a good foundation of knowledge but are still learning, which one might say is true for just about everyone.

■ **SABRINA GARVIN** is the editorial assistant of *Sky & Telescope.*

by S&T Staff and Contributors

Reports from the *Shadow Path*

The Sun and Moon put on a spectacular show on April 8th, as the path of totality cut across North America.



"What a sight to behold!" said Skylar Shaver, space physicist, after witnessing the total solar eclipse from Dardanelle, Arkansas. Millions shared her sentiment on April 8th this year, as immense crowds gathered throughout North America to watch the last total solar eclipse visible from the contiguous U.S. for the next 20 years.

The weeks leading up to the event were filled with trepidation. Cloud-cover models had predicted the best conditions would be in Mexico and Texas, but these forecasts turned out to be less accurate than hoped, leading many to scurry for backup plans. Some booked last-minute flights or jumped in the car and raced for clearer skies.

Clouds did scuttle some eclipse chasers' plans. But in the end, millions enjoyed views of the solar corona and dazzling prominences along much of the narrow path of totality. The corona displayed several long, bright streamers typical of those seen during solar maximum. And several prominences danced along the lunar limb. The staff and contributors of *Sky & Telescope* spread out over 4,800 kilometers (3,000 miles) to experience several minutes of darkness. Here are our impressions of this spectacular event.

◀ **LAKESIDE CLARITY** Dozens of observers were treated to an excellent view of totality along the shore of Lake Memphremagog, located at the border between the United States and Canada. Stan Honda recorded this image using a Sony α7S III camera with a 28-to-70-mm lens at f/2.8.

▲ **AWAITING CONTACT** *Sky & Telescope* News Editor Monica Young (third from right) watches the partial phases of the eclipse with her family under mostly clear skies in Mazatlán, Mexico.

Pacific Contact

The first of us to witness totality was Contributing Editor Bob King aboard the MS *Zaandam* in the Pacific Ocean, 160 km off the coast of Mazatlán, Mexico. The ship's captain had to radically change course in order to guarantee a crystal-clear view.

Shadow bands rippled across the ship's deck for many seconds both before and after totality. King told us:

I shuddered and choked back tears when the Moon quenched the last bead of sunlight to reveal the beautiful and strange sight

PEEKABOO VIEWS Variable clouds made views of totality a dodgy endeavor for observers on the *S&T* tour in Fredricksburg, Texas. But that didn't stop former Contributing Editor Johnny Horne from snapping this evocative portrait of the "diamond ring" just before second contact. He used a Nikon D850 paired with a 200-to-500-mm lens at 500 mm. Total exposure was 1/50 second at f/11, ISO 320.

AWAITING CONTACT: COURTESY OF MONICA YOUNG

▲ **CASUAL SNAPS** *Sky & Telescope* eclipse-cruise coleader (and former Editor in Chief) Rick Fienberg lies back to photograph the partial phases of the eclipse from the deck of the MS *Zaandam* off the coast of Mexico.

of totality overhead. Silky spikes of eerie silvery-yellow corona crowned the black disk of the Moon. People were shouting and screaming for joy, which for me only magnified the eclipse's tremendous emotional impact.

No one who saw totality will forget the brilliant, hot-pink prominence along the southwestern lunar limb. I've observed the Sun in hydrogen-alpha light many times, but this single, massive "tongue of flame" appeared far brighter and more vivid than any filtered prominence. Jupiter and Venus were obvious in the watercolor-blue sky.

Incredibly, totality seemed to last a long time — something I've never experienced before. And when totality had passed, I wanted to hug everyone, and proceeded to do so! I can't tell you how good that felt.

On shore, News Editor Monica Young was positioned with her family in Mazatlán, where high, thin clouds did nothing to mar the view:

Partial phases were clearly visible and created crescent shapes beneath palm trees and through the eclipse art my daughter and I had made. We waited breathlessly as the golden crescent in our eclipse glasses thinned — not least because I wasn't sure whether we would see the corona through the clouds. I needn't have worried! The corona was surprisingly bright, with several streamers framing the Sun. At the 5 o'clock position, a brilliant pink prominence appeared to leap off the edge of the Moon. Minutes became seconds, and the diamond ring reappeared.

Texas Totality

The Moon's shadow continued to race northeast and crossed the border into the United States, where several *S&T* staffers made their stands in various locations. Much like in Mexico, thicker clouds threatened to put a damper on the show in the very places that long-range predictions had suggested would have the best weather prospects.

Senior Editor Kelly Beatty reported that the attendees on *S&T's* tour to Fredericksburg, Texas, feared that a massive storm system would wipe out their viewing chances:

Rain was all but certain. But with each day came a slightly better forecast, and by the time we arrived at our private viewing site, the optimism was palpable as low clouds dissipated and revealed big swaths of blue sky.

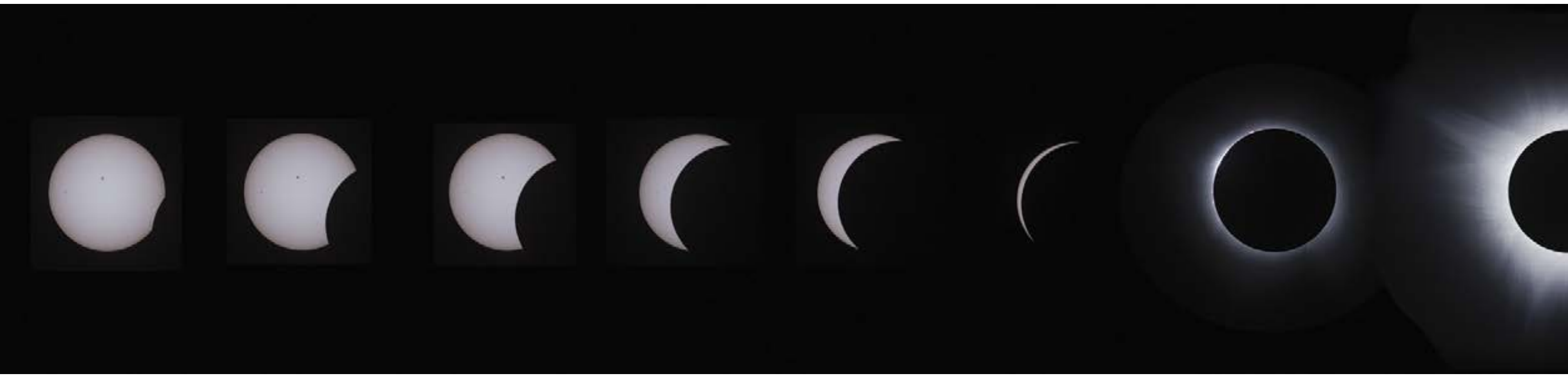
After nice early views of the partial phases, thicker clouds returned. The situation looked bad. Then, almost miraculously, a thinning overhead let us witness the first diamond ring, followed by veiled but still-dramatic views throughout totality.

All too soon, towering prominences on the western limb heralded the second diamond ring. And, with that, the cloudy curtain closed and ended the show, leaving nothing but impenetrable gray overhead.

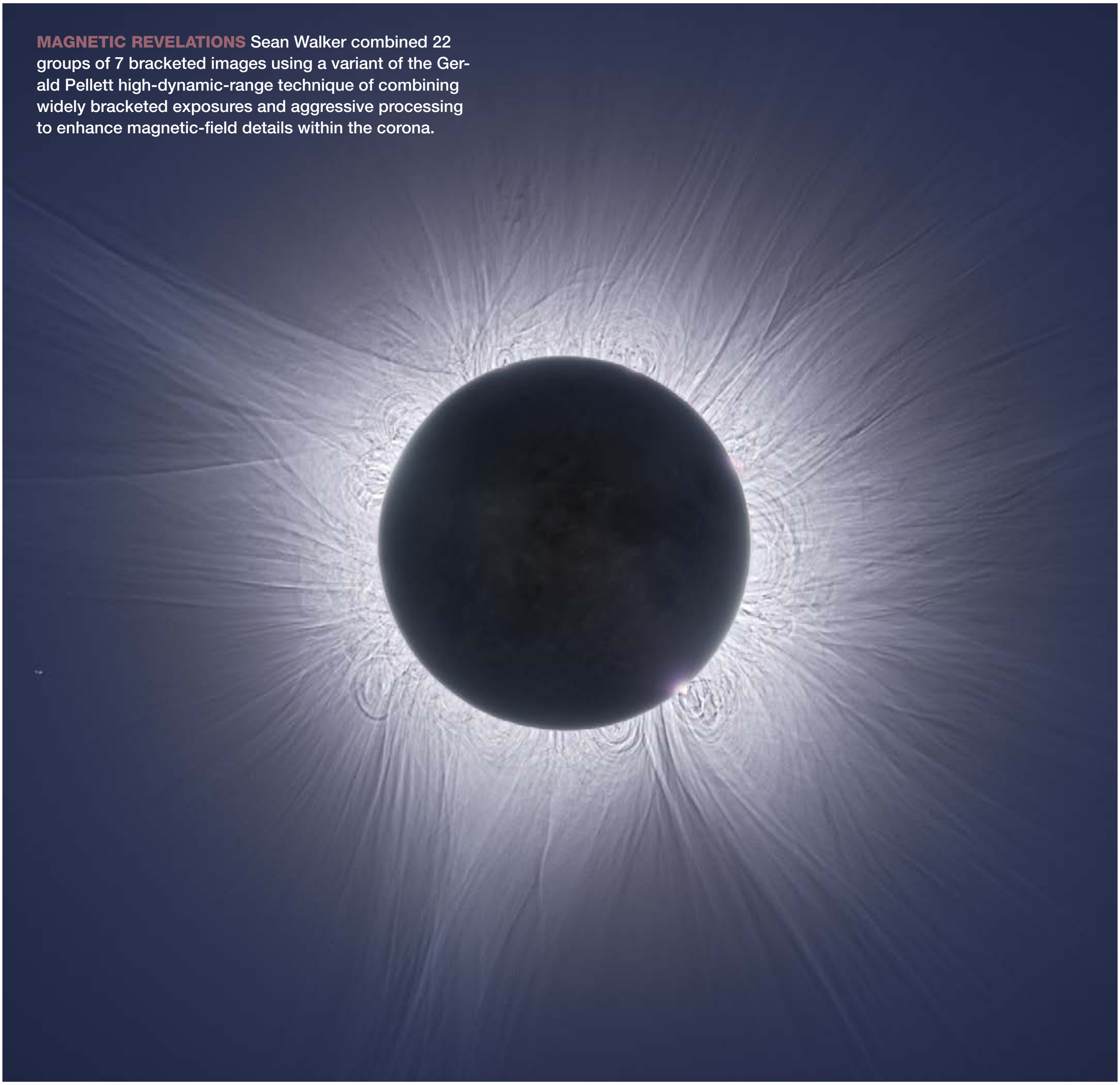
I still don't know what caused the clouds to part, but deep down we all knew that Mother Nature had done us a great favor.

Some 130 km to the west, the situation played out differ-

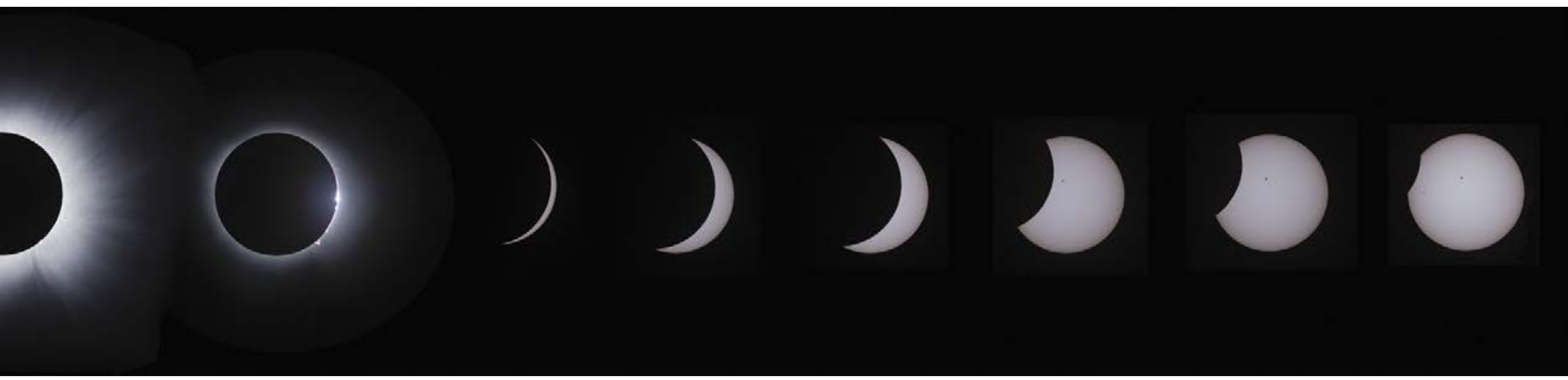
▼ **PERIODIC SEQUENCE** Stages of the eclipse from shortly after first contact (far left) through totality and nearing fourth contact (far right) as seen from Dardanelle, Arkansas. Each image was captured through an Astro-Physics 92-mm Stowaway refractor at f/5.3 with a Canon 70D camera.



CASUAL SNAPS: BOB KING; ECLIPSE STAGES: SEAN WALKER



MAGNETIC REVELATIONS Sean Walker combined 22 groups of 7 bracketed images using a variant of the Gerald Pellett high-dynamic-range technique of combining widely bracketed exposures and aggressive processing to enhance magnetic-field details within the corona.



ently. Observing Editor Diana Hannikainen, reporting from the off-site campus of Texas Tech University in Junction, explained that

> *the skies were clearing nicely, and anticipation buzzed in the air. And then, a quarter-hour before totality, calamity struck. Thick, menacing clouds rolled in and parked themselves in front of the Sun for about 20 minutes. I did catch a glimpse of totality, but it was fleeting. However, the whoops emitted by young, first-time eclipse-viewers as darkness rushed in, and their astonishment at the experience, will be a precious memory I'll hold on to forever.*

Observers fared better in Waco, Texas, where Contributing Editor Govert Schilling accompanied a group of 35 Dutch tourists to Woodway Park. They were in for a meteorological roller coaster of expectations, fears, and hopes:

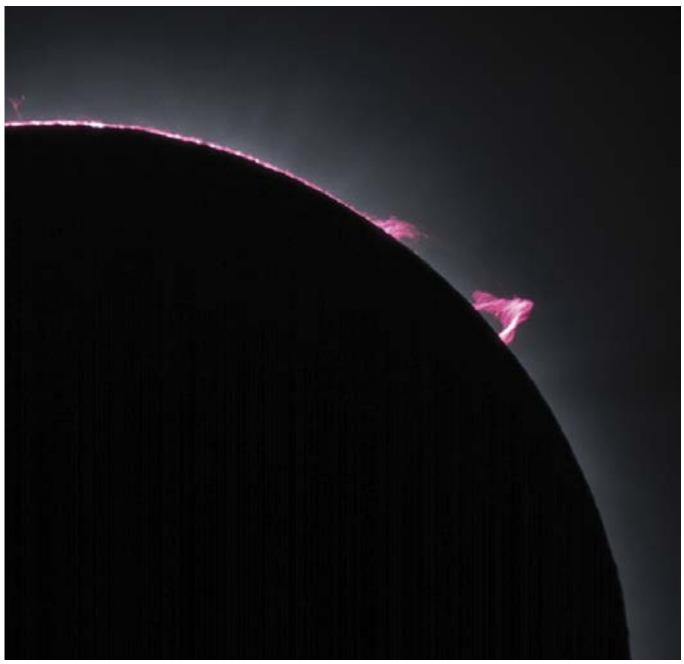
> *In the end, we observed the first half of totality under perfect conditions, while the second half was blocked by a thick cloud. Given the earlier, discouraging weather predictions for the area, everyone was excited to see the corona (and a couple of beautiful prominences) for at least as long as totality had lasted during the 2017 eclipse.*
>
> *Thanks to the clouds, this was probably the most exciting (and stressful!) eclipse of the 16 totals I have experienced so far. As participant Gitta Noordermeer told me well after third contact, "I am still not recovered from the emotions!"*

Just a few miles to the north, Science Editor Camille Carlisle attended the Texas Star Party's viewing event, where forecasts also looked bleak:

> *We spent the weekend anxiously comparing weather models. One forecast said we'd be skunked, another gave 50% cloud cover . . . Even on Monday morning, the forecasts weren't converging.*
>
> *But by 10 a.m., the clouds over the Latham Springs Camp and Retreat Center had become patchy. Conditions held steady as totality approached. About a half hour before second contact, barn swallows abandoned their normal leisurely flights and perched, huddled and tense, under the auditorium's eaves. Colors dimmed, dogs barked, and shadows faded.*
>
> *Then, with celestial drama, totality began! Jupiter and Venus flanked the brilliant corona — it was so bright near the lunar limb that I momentarily questioned whether totality had actually begun. A magnificent solar prominence appeared like a red curl near the 5 o'clock position. It was so large that it was easily visible with the naked eye.*

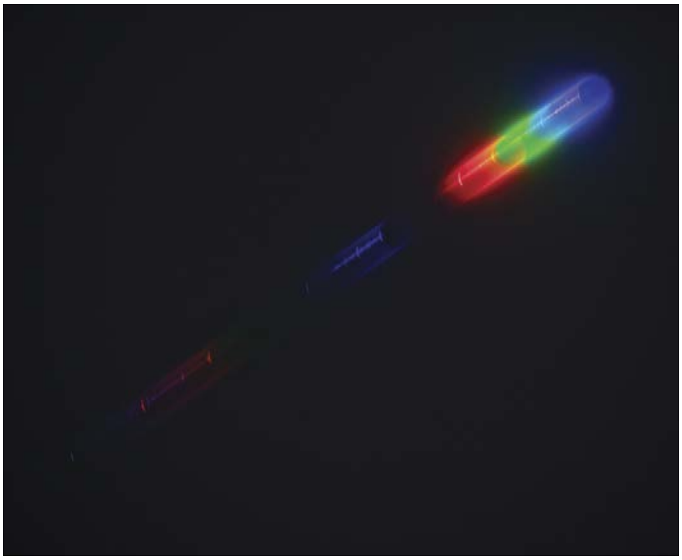
As the shadow moved farther into the U.S., observing conditions markedly improved. Associate Editor Sean Walker was with his family in Dardanelle, Arkansas to experience the event at the Ring family residence:

> *Weather predictions hardly a week before warned that Arkansas would be disappointed, yet the forecast improved each day for the five days leading up to the eclipse. The morning of the 8th broke with nary a cloud in the sky. About 1:20 p.m., we began to see crescent Suns through pinhole projectors, although the most*



▲ **DIAMOND AND PROMINENCES** *Left:* The diamond ring is seen moments before second contact. *Right:* The Moon's silhouette gave observers the rare opportunity to witness this extremely bright, triangular prominence with the unaided eye. North is to the left.

DIAMOND RING: STEVE GRIMSLEY; PROMINENCES: SEAN WALKER



▲ **SPECTRAL FLASH** The bright arcs are the prominent emission lines of hydrogen (deep red), helium (yellow), magnesium (green), and calcium (violet) in the chromosphere, revealed during the brief moments following second contact.

clever projection of these tiny crescents came from a mirror ball brought out by Brittany Breen. It cast hundreds of crescents into shaded areas.

Walker planned to photograph the eclipse using the high-dynamic-range technique he wrote about in 2020. (Find it on the *S&T* website at **https://is.gd/HDReclipse**.) Things were progressing nicely until his tracking mount lost power shortly before second contact. A power cord couldn't fix the problem, so he reworked his plans. Thankfully, the sky cooperated:

Some very thin clouds surrounded the Sun during totality, though they didn't detract from our spectacular view of a classic solar-maximum corona. Multiple streamers emanated from behind the silhouetted Moon, with a particularly long one from the northwestern limb. Not 15 seconds into totality, everyone's attention was drawn to the vivid pink prominence emerging on the southern limb.

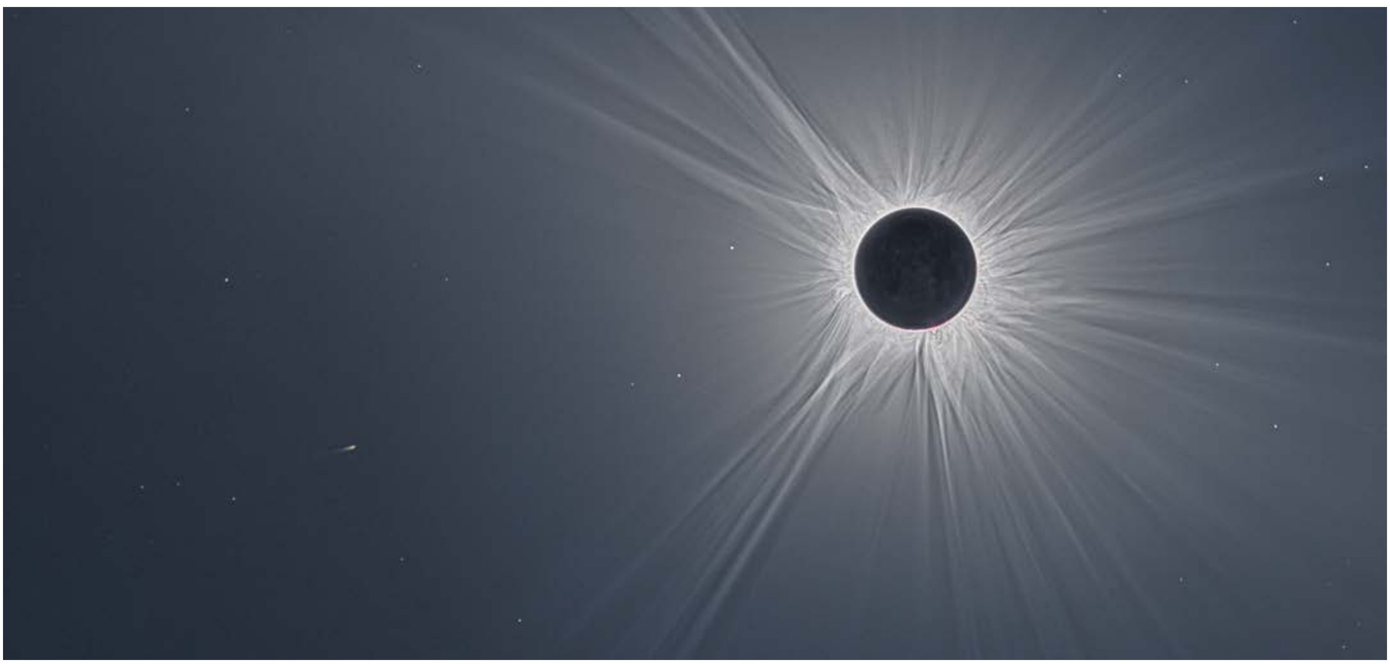
Despite the equipment issues, Walker managed to come away with more than two dozen bracketed sets of exposures taken during the 4 minutes, 12 seconds of totality, as well as sharp images of prominences, Baily's Beads, and the diamond ring.

Northern Reaches

Conditions were fair farther along the path until the border of western New York, where clouds blocked the view for many. Editorial Assistant Sabrina Garvin and her family were among them in Canandaigua. Huddled in their coats due to the sudden temperature plunge, they could still see some of the eclipse's effects, including the swath of shadow sweeping toward them from the southwest. The thick cloud cover enhanced the darkness of totality. "Streetlights with solar sensors lit up, and the birds, which had been cheery and talkative up until that point, fell silent," she said.

In northern Vermont, a very satisfied Senior Editor Alan MacRobert told us:

The day dawned clear blue from horizon to horizon over the



▲ **COMETARY PLUNGE** This deep, wide-field composite image captures the extended corona, dozens of nearby stars, and the Kreutz sungrazer comet SOHO-5008 (left). The comet was discovered only several hours before the eclipse and disintegrated not long after totality.

FLASH SPECTRUM: SEBASTIAN VOLTMER; WIDE-FIELD IMAGE: PETR HORÁLEK

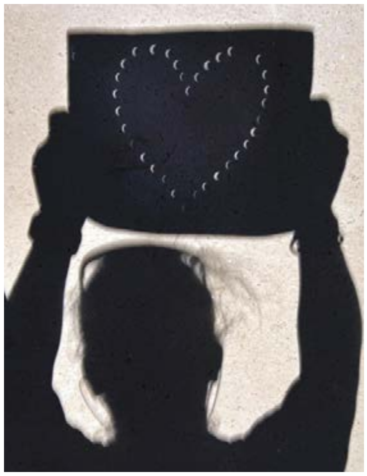
Northeast Kingdom region of Vermont. We set up early on a sports field at Vermont State College. Hour by hour, people poured in. Buses unloaded swarms of high-school students. One couple had flown from cloudy Texas, long touted as having the best clear-sky prospects.

The sunlight dimmed slowly at first, then faster as the landscape grew eerily silvery in the narrow crescent-shine. Shadows became weirdly sharp in one direction. Venus and Jupiter appeared through the deepening blue. The corona emerged some seconds before totality, then the last overpowering dazzle of the diamond ring rapidly faded right down and out! The crowd whooped and cheered.

The highlight of this eclipse for me will always be that great pyramid of brilliant pink loops on one limb, foreshortened and full of detail.

Our final report comes from Editor in Chief Peter Tyson, who despite expectations enjoyed perhaps the best land conditions along the entire route. As he told us:

I parked myself on a golf course in northeastern Maine by the Slice Restaurant, whose owners offered free parking and a warm welcome. Not a cloud in the sky, which is absurd for Maine at this time of year — and especially this year, when it's been cloudy or rainy for weeks on end.



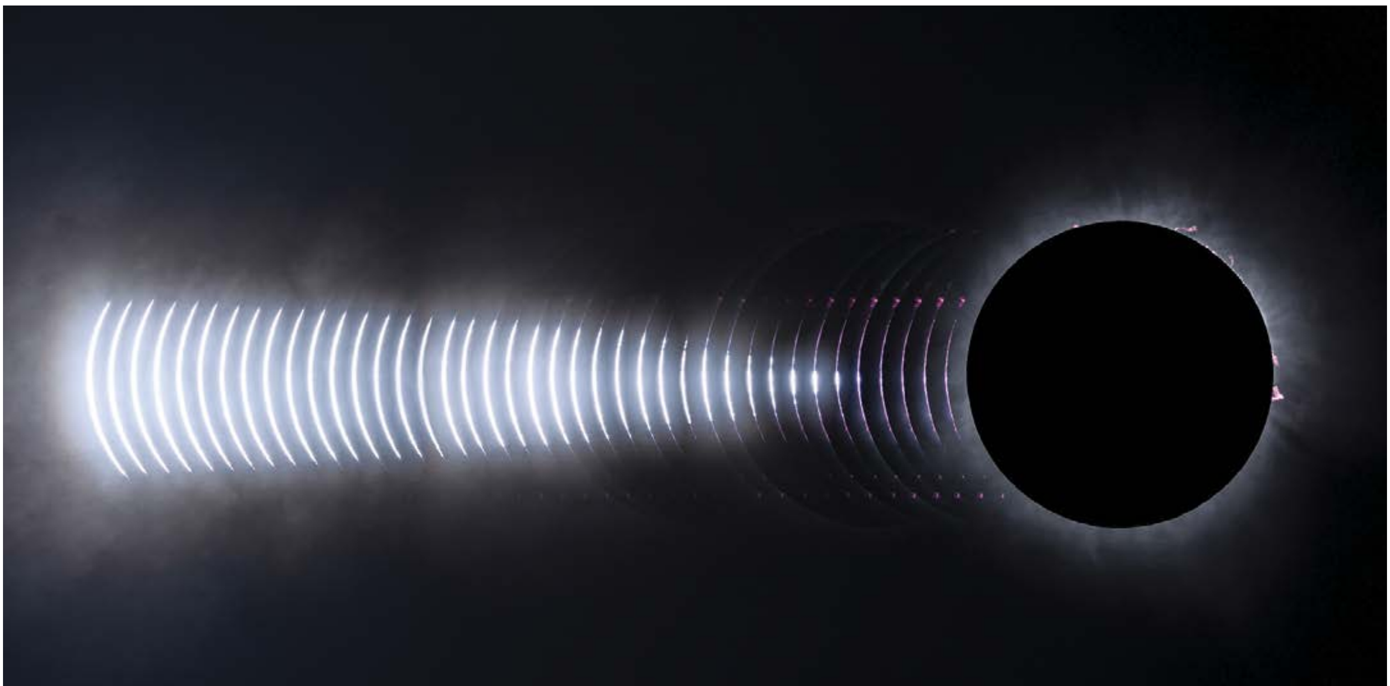
◀ **PINHOLE EMOTICON** An attendee aboard the MS *Zaandam* uses pinhole projection to express the excitement of witnessing the event halfway between first and second contact.

A crisp breeze blew, snow still about, but the temperature had risen to near 60°F by totality, so it was quite pleasant. Perhaps 100 people gathered, some with impressive cameras or scopes. We enjoyed 3 minutes 18 seconds of totality, which naturally felt like a minute. It all went so fast it was hard to keep up, but I savored the sudden twilight at second contact and a blazing diamond ring at third contact.

Most spectacular of all were the prominences, including a necklace along the lower limb like pink Baily's Beads, plus a huge prominence nearby like an upside-down V. V for Victory, you might say, having waited so long and traveled so far for this jaw-dropping celestial wonder.

Clear skies held throughout New Brunswick, Canada, and beyond. Partial clouds permitted some residents of Newfoundland to glimpse totality on the last landmass along the path.

And with that, the Moon's shadow slid off Earth and departed into space. It won't intersect our planet's surface again for another six months — this time in the form of an annular eclipse visible from South America. That event will make landfall on October 2nd at Easter Island before crossing the southern tips of Chile and Argentina. Will you be there?



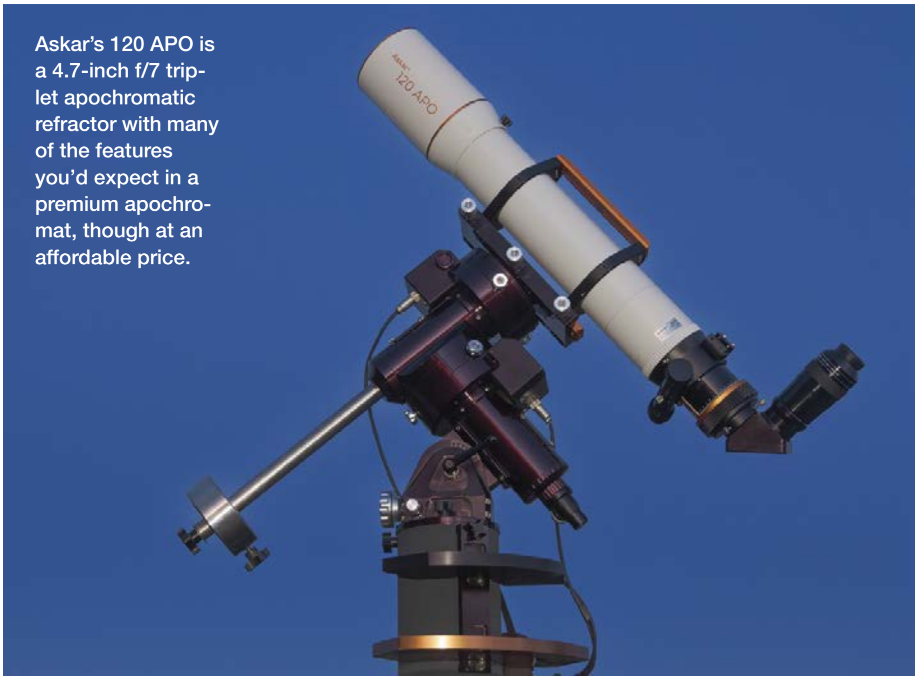
BAILY'S BEADS PROGRESSION This photo taken in Mazatlán, Mexico, combines 42 short exposures spaced one second apart as the final sliver of the photosphere disappeared behind the Moon. A later exposure near the end of totality (right) shows the inner corona.

HEART PROJECTIONS: BOB KING; SECOND CONTACT SERIES: CHIRAG UPRETI

RINGS AND BLING José Mtanous combined his images to emphasize many distinct features of the eclipse in one artistic composition. His composite highlights the many pinkish prominences visible throughout totality as well as lunar detail on the Moon illuminated by earthshine.

Askar's New 120 APO

This new refractor offers a generous aperture at a surprisingly attractive price.



Askar's 120 APO is a 4.7-inch f/7 triplet apochromatic refractor with many of the features you'd expect in a premium apochromat, though at an affordable price.

120 APO

U.S. Price: $1,499
www.sharpstar-optics.com

What We Like

Low Price

Usable with binoviewers

What We Don't Like

Threaded components can bind

Focuser doesn't rotate

IT SEEMS HARDLY a month goes by that the prolific company Jiaxing Sharpstar Optical Instrument Co. and its owner Michael Fong don't announce a new telescope or series of telescopes. Among the latest is its Askar APO series, a line of triplet-apochromatic refractors with one major advantage: price. At $1,499, the 120-mm (4.7-inch) aperture model I tested carries the same retail price as Sharpstar's own 80-mm in its Askar-branded PHQ line and the 94-mm in its EDPH series.

You get a lot of aperture for the money with the APO series. There has to be a catch. To see what it might be, I tested an early unit sent directly from Sharpstar in China, along with the optional 1× Flattener and 0.8× Reducer lenses for imaging. I was told the final shipping telescopes would differ from the early sample I tested only in a minor difference in the tube finish that isn't apparent in the photos here.

A Light Triplet

The APO line currently consists of four models: a 103-mm, the 120-mm I tested, plus a larger 140-mm and a massive 185-mm. All have triplet objective lenses incorporating one element of an undisclosed type of low-dispersion ED glass. All are f/7, with the exception of the 103-mm, which is f/6.8.

The 120 APO measures 722 mm long with its dew shield retracted, so it isn't quite airline carry-on compatible. An attractive feature of the scope is its relatively low weight for its aperture. The scope, with lens cap, tube rings, and mounting plates, weighs in at 6.6 kilograms (14 pounds), several pounds lighter than most other 120-mm triplet refractors I've used. This weight saving is accomplished without the cost of carbon-fiber tubes, keeping the price low.

My entry-level Sky-Watcher EQM-35 mount handled the 120 APO fine for visual use with just one counterweight

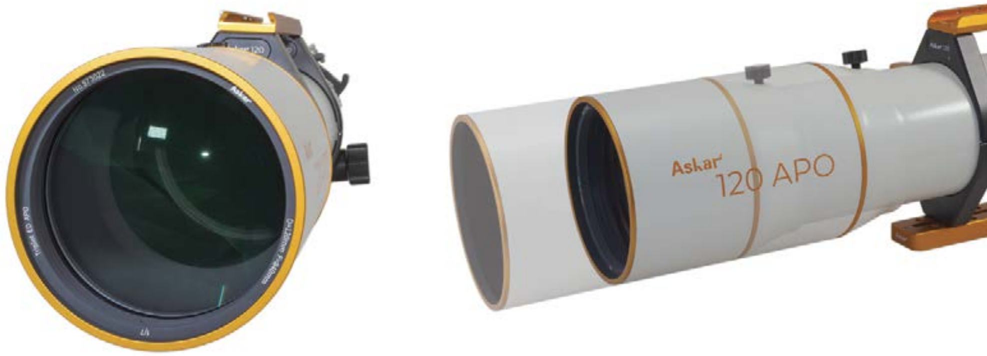
◀ The 120 APO features a machined aluminum tube with orange-anodized fittings and a metal lens cap. While an excellent soft-sided case is included, there's only room for the optical tube; the two photographic flatteners won't fit.

ALL IMAGES COURTESY OF THE AUTHOR

required to balance it. Part of the weight saving is in the tube rings, which are thinner than usual, though I found no issues with flexure in dozens of hours of guided astrophotos.

The telescope comes with tube rings attached to a Vixen-standard 290-mm dovetail bar. The top of the rings has a 210-mm handle machined with a Synta-standard channel to accept guidescopes — a welcome feature over the usual flat handles tapped with just bolt holes.

In addition, the focuser has not one but two universal finder bases, offering plenty of options for mounting accessories such as finderscopes and ride-along control computers. Users shouldn't need to buy additional mounting bars or finder bases.



▲ *Left:* The scope's 120-mm (4.7-inch) triplet objective is anti-reflection coated. Its tube interior is fully blackened with a ribbed section in the upper portion and three field stops all working together to produce good suppression of stray light. *Right:* The 9-inch-long dew cap retracts onto the tube but extends beyond the lens by 4 inches. It has a locking knob to secure it firmly in position.

The focuser on the 120 APO is a dual-speed, rack-and-pinion design that proved smooth and precise. Under the heavy load of a star diagonal and big Tele Vue 41-mm Panoptic eyepiece, the combination didn't creep out of focus or slip even when unlocked with the scope aimed straight up. However, I did have to tighten one of the bearing-adjustment hex screws on the focuser very slightly to improve the tension to prevent any slippage. Locking the focuser still allowed adjustments with the 10:1 fine focus knob, and I never found it slipped over long exposure sequences.

The focuser has a rear rotator convenient for both visual and photographic use. It has a scale marked in one-degree increments, useful for repeating the framing of images over multiple nights. I would have liked more than one index mark, as the single mark located near the rotator's lock knob is hard to see in some orientations. Also, the knob never completely locks the rotator. With a heavy eyepiece or binocular viewer off to one side, I found the rotator would still slowly turn on its own. I never encountered that problem with a camera attached, nor did rotating the camera cause a shift in focus. A warning: The rotator knob comes off with just a couple of turns and could drop into the snow or grass, never to be seen again!

An attractive feature of the 120 APO is its ability to work with binocular viewers, despite the long back focus requirements of the accessory's complex light path. The scope accomplishes this by having a 4-inch-long rear tube segment that unscrews, allowing the focuser to be reattached onto the now-shortened main tube.

▲ The bottom Vixen-standard dovetail bar is drilled with numerous holes for adjusting the ring spacing if desired. The rack-and-pinion focuser has a lock knob, tension screws, and M4-threaded holes for attaching electronic focusers.

▲ The slotted top plate accepts accessories with Synta-standard dovetail feet. The back of the tube has two additional finder bases. The 3.3-inch focuser offers 100 mm of travel and has graduated scales for focus position and rotation angle.

▲ *Top:* Removing the rear section of the main tube allows binocular viewers (a Baader unit is shown) to reach focus without needing a Barlow lens. *Bottom:* The extension tube is required for either of the photographic flatteners to reach focus.

However, that's where I ran into the main issue with the 120 APO's mechanics. The scope arrived with the focuser seized onto the rear tube section. As other reviewers have found, it took a pair of rubber strap wrenches to loosen the focuser and remove it. I also had the small M54-to-M48 rear adapters stick onto the flattener lenses.

The binding of thread-on components is an issue I've had with most Sharpstar and Askar telescopes and astrographs I've tested. Early in the testing, I applied a thin film of "anti-seize" lubricant to the threads of all the components, which kept the problem from recurring.

The only other issue I had was that in sub-freezing temperatures the camera rotator became quite stiff. When I turned it counterclockwise, it would begin to unthread from the focuser. Turning it slowly generally worked, but the grease used in the rotator mechanism is clearly not made for winter use. Still, the focuser itself worked well in both its coarse and fine motions in the cold, even under load.

Visual Performance

Once the telescope cooled off after about 40 minutes, the 120 APO passed my high-magnification star test very well, with just a trace of spherical aberration. I saw no sign of astigmatism even on sub-freezing nights when some lens cells can pinch optics. In focus, bright stars looked textbook-perfect, displaying round Airy disks surrounded by a first diffraction ring, with a hint of outer rings coming and going. All objects snapped into sharp focus. Bright targets Vega and Jupiter showed no false color in focus. The close components of Epsilon Lyrae, the Double-Double, were cleanly separated by dark sky.

Racking through focus revealed just a trace of a blue-cyan rim to the diffraction pattern outside focus and a pale yellow-magenta rim inside focus. This is a notch below the color correction found in the finest triplet apos, but far better than I was expecting for the price. I saw some false color only on high-contrast lunar features, such as crater rims and mountain peaks along the terminator. The chromatic aberration was present only when racking through focus but was absent in focus.

The 120 APO provides enough aperture for fine, high-magnification views. It soon became my scope of choice for planetary viewing. Jupiter was exceptional at 210× to 280× on nights of steady seeing. The scope revealed fleeting fine texture visible in and around the Great Red Spot and displayed Galilean-moon shadows as black ink drops etched onto the planet's cloudtops.

For great low-power views, removing the rear tube segment allows a binocular viewer to reach focus without the Barlow lens typically required in standard refractors. Twin Tele Vue 24-mm Panoptic eyepieces (yielding the widest field possible in a 1¼-inch eyepiece) provided 2° panoramic views of star fields. Nebulae and clusters seemingly floated in 3D space, and stars in clusters appeared to be at different distances. With this combination, views of the Double Cluster (NGC 869 and NGC 884) were particularly outstanding.

A good binocular viewer provides a superb, if costly, observing experience. That the

▲ Both flatteners are triplet lens designs, with the 1.0× model (shown above) being the more substantial of the two in size and weight (at 900 grams or nearly 2 lbs). Each screws onto the tube with M84 threads and presents M54 and M48 threads on the camera side, the latter with a step-down ring that accepts 48-mm filters, as shown.

◀▼ A single exposure of the Double Cluster with the 1.0× Flattener shows the full 2.4° by 1.6° field produced with a full-frame Canon R camera. The crop of the upper left corner (left) reveals the negligible level of aberrations typical of each corner.

120 APO accommodates the accessory is a great feature in its favor, though swapping out the tube segments is a little inconvenient. Also, threading the focuser back onto the shortened tube results in it ending up rotated some 90° compared to when it's installed on the full-length tube. The focuser itself doesn't have a rotation mechanism, so re-orienting the focus knobs requires turning the entire tube within the tube rings. Generally, I think you have to decide in advance if you're going to have a "binoviewer night" and configure the scope accordingly.

Photographic Performance

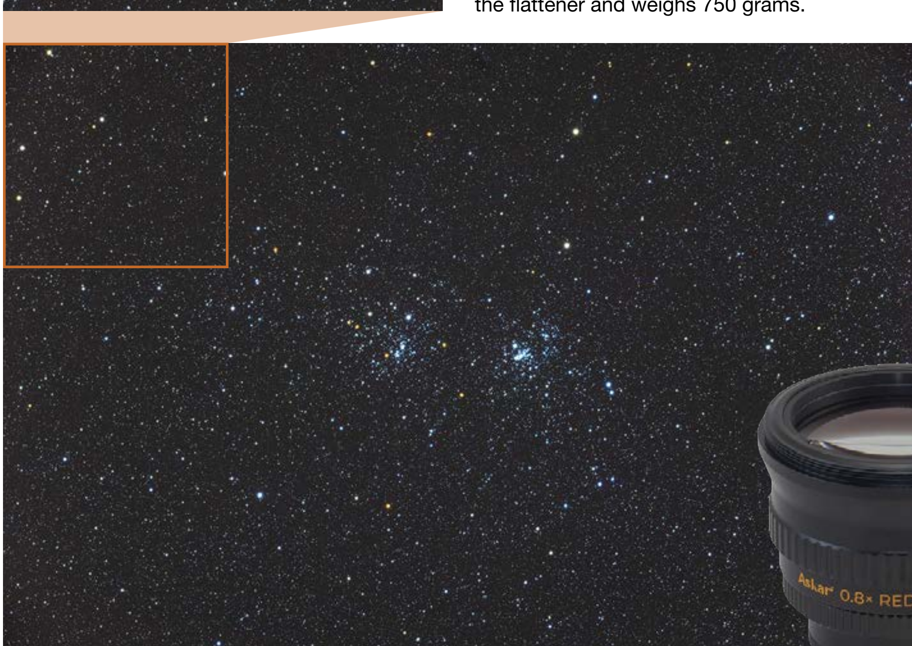
Without either of the optional flattener lenses, the 120 APO presents a field that is flat over just a 20-mm image circle, to be expected for an f/7 refractor. However, the 1.0× Flattener and 0.8× Reducer do their jobs very well. The 1.0× Flattener retains the scope's native 840-mm focal length at f/7, while the 0.8× Reducer yields 670 mm at f/5.6.

When either flattener was employed, I saw no sign of false-color halos on bright stars. Stars appeared sharp out to the corners of a full-frame sensor, with only the Reducer showing slight off-axis aberrations. I saw no evidence of de-centered or tilted optics; all corners looked the same. Vignetting was hardly noticeable with the 1.0× Flattener and minimal with the 0.8× Reducer.

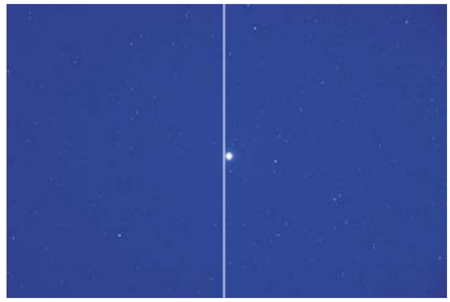
The field flatness was as good as I've seen in many years of testing apochromats, which almost always show some residual coma, astigmatism, or lateral chromatic aberration at the corners, even when used with their companion flatteners. With the 120 APO, you really have to pixel-peep to see any corner aberrations.

My only complaints with the two flatteners are that their adapter rings can bind, and that a camera ends up in a different orientation when switching between them. However, at only $199 each, the flatteners are a bargain and are both worth having for the photographic options they offer.

In short, I was impressed. As with its visual performance, I soon chose the 120 APO for a lot of my deep-sky imaging.



◀▼ The field of view with the 0.8× Reducer is 3° by 2° with a full-frame (36- by 24-mm) sensor. A corner blow-up shows a level of astigmatism so slight it may not be obvious on the printed page. The reducer is smaller than the flattener and weighs 750 grams.



▲ This crop shows the level of vignetting at the corners in images of Vega taken in twilight and with no flat-field correction applied. The 1.0× Flattener (left) shows very little corner darkening; the 0.8× Reducer (right) has only slight falloff at the extreme corners.

Recommendations

Anyone looking to upgrade from or supplement a 60- to 80-mm class apo would do well to consider the 120 APO. (An upgrade from a 100-mm scope won't offer so great a difference.)

However, the lighter and more affordable 120 APO provides sufficient aperture for fine planetary views, and a focal length suitable for capturing smaller deep-sky targets. The scope's relatively light weight makes it easy to carry out to the backyard and permits use with a smaller, more portable mount. Aging backs will appreciate that!

I can certainly recommend the Askar 120 APO. Apart from my minor complaints about the mechanics, I found no serious catches. I feel the scope is a terrific bargain for both visual observers and astrophotographers. Just be prepared to buy some strap wrenches to loosen its components!

■ Contributing Editor **ALAN DYER** is co-author with the late Terence Dickinson of *The Backyard Astronomer's Guide*. He can be reached through his website, **amazingsky.com**.

The Bucket-Seat Binocular Mount

Make an attractive yet robust observing tool.

▶ Lauren Wingert's bino-chair uses a car seat and a monitor arm to hold her 10-pound binoculars in a comfortable observing position.

WHEN LAUREN WINGERT inherited a pair of 25×100 binoculars, she also inherited a problem. There's no way you can hold 25× optics steady by hand, and when those optics weigh 10 pounds there's no way you can hold them at all for more than a minute or two. As Lauren says, "All you really want to do when holding them is set them down! They're nearly unusable without some sort of robust mount."

Binocular mounts abound, but few have a 10-pound capacity, and the ones that do are expensive. It became immediately clear that Lauren had another ATM project on her hands: building a mount for these immense binos.

Since the binoculars were free to begin with, she wanted to build a mount that was both stable and low-cost. Lauren says, "I had seen 'zero-gravity chairs' that used some sort of pipe-mount thing next to the chair. Those looked to be a pain to move in azimuth. Get up, move everything, reset." She wanted something that would rotate around the azimuth axis along with the chair.

Lauren found an adjustable gaming chair for about $100. It swiveled, reclined, and had metal armrests she could mount an arm on. For the arm she spent $40 on a computer-monitor mount rated at 30 pounds. Attaching it to the chair was a simple matter of bolting it to one of the armrests. And hey presto! She had a shaky mess. The chair arms flexed from side to side. The rotating ring wobbled. And worst of all, in order to recline the chair she had to tilt it forward first to disengage the ratchet. Try that with 10-pound binoculars hanging in front of your face and you'll increase your vocabulary.

The monitor arm worked like a charm. It had good up/down, tilt, and in/out motions while easily holding the binoculars' weight. It was just the chair that, shall we say, disappointed. Lauren kept her eye out for something else, and one day at work she noticed a car's bucket seat in storage. Her boss was happy to see it go, so Lauren took it home for free. And thus began the bino-chair do-over and a quest for stability. Lauren reports, "The idea of a more stable chair was appealing, but the whole thing became one engineering problem after another to overcome. It was a lesson in physics, stability, trial and error, do-overs, and multiple fixes."

The first order of business was to make the chair swivel. That was fairly easily accomplished by the use of a lazy-Susan bearing sandwiched between

▶ *Right:* A gaming chair used as a prototype swiveled and tilted — but it also shook, shimmied, and was awkward to use. *Far right:* Lauren tried tripod legs for extendable booms, but the weight of the binoculars made them bind.

ALL IMAGES COURTESY OF LAUREN WINGERT

▲ *Left:* Bracing rods between the chair and the monitor arm provide stability and vibration damping. Springs counter the extra lift of the monitor stand's internal springs. Lauren moved the nameplate from the top section to the lower section to cover the spliced length of metal pipearm (*middle*) added to extend the monitor arm's reach. *Right:* Lauren added a gyroscope in order to dampen rotational vibrations.

two slabs of thick plywood. Castors on the bottom let Lauren roll the chair out to her observing area in the backyard. She tried using three wheels so they would act like a tripod, stable on any surface, but quickly learned that the chair would tip over at certain angles. She needed four castors, which meant she also needed leveling legs to make sure she had solid contact on all four. Fortunately, she found a set with built-in levelers.

That left the binocular-holding arm. Inspired by her brother Brian's tripod-leg Dobsonian (*S&T:* Jan. 2023, p. 70), Lauren first tried mounting a tripod leg horizontally overhead. That would theoretically allow her to move the binoculars forward and back for comfortable viewing. Bolting the tripod leg to a big strap hinge attached to the top of the chair's headrest rods would let her raise and lower the binoculars for minor altitude adjustment, while the chair's tilt mechanism would allow for major adjustment.

Lauren quickly realized that the binoculars were just as heavy on the end of a horizontally mounted tripod leg as they were when hand-held. So she positioned the tripod leg with lots of overhang in the back and added counterweights. Alas, the weight prevented the chair from returning to its upright position. Lauren tried spring-loaded chest hinges rather than counterweights, but the springs weren't powerful enough. And even if they had been, the weight of the binoculars made the tripod leg's sliding rail bind, negating its value as an extendable boom. Plus, having the hinge behind her head meant that any up-down motion simply raised the binoculars away from her eyes. Lauren tried adding a vertical adjustment to the end of the tripod leg, but it was a lost cause.

She finally decided to abandon the tripod leg idea and raid the monitor arm from the old chair. With that decision, her luck immediately changed: The arm's mounting bracket matched the chair's arm mount holes nearly perfectly. She kept the hinge on top and folded it backward to tie into the monitor-arm mounting bracket for additional support, using a threaded rod between them. She also added a support piece from the top of the monitor arm's lower segment to the headrest bolts.

The monitor arm mounts to the tilting part of the car seat, so the binoculars stay in observing position no matter whether the back is reclined or not. But with the arm mounted behind the observer there wasn't enough arm length for Lauren to get behind the binos. More fixing! So she had to lengthen the monitor arm with a section of pipe.

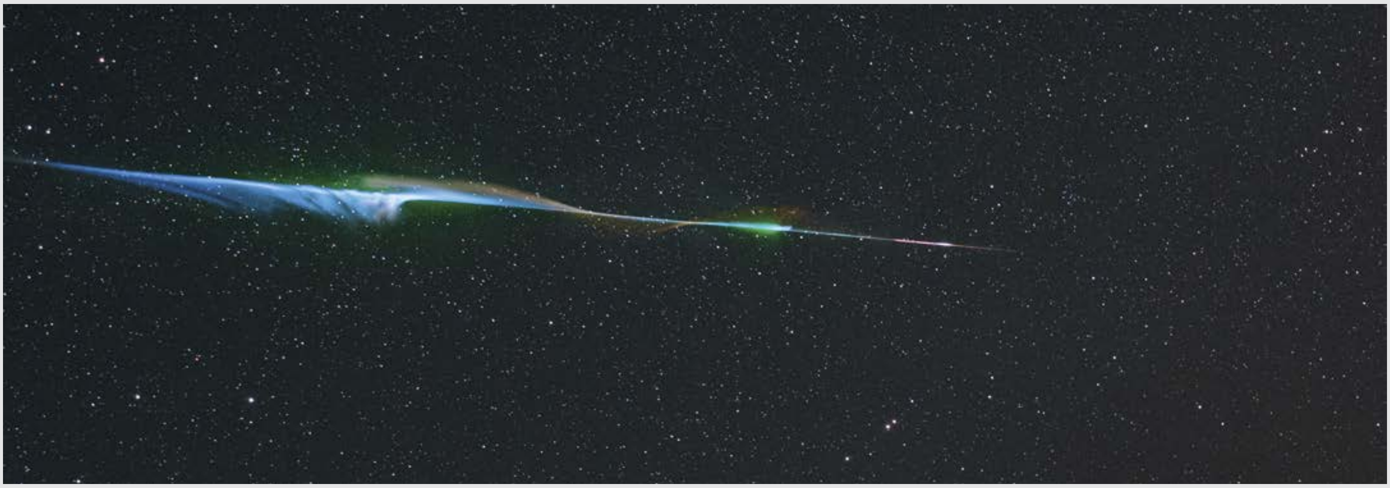
Finally, the bino-chair was ready to test! Of course you know what's coming. As Lauren wrote in an email, "Problems! There was flex in the plywood itself. There was heartbeat / breathing / body sway / looseness in the lazy Suzan — these all worked together to make very subtle, nearly imperceptible vibrations. Those vibrations traveled along the monitor arm like a tuning fork! The outer end where the binos sat endlessly moved in tiny vibrations."

To fix the plywood flex, Lauren replaced the 12-inch lazy Susan with a 20-incher. She unbolted all the monitor arm supports and added rubber dampening at all the connection points. She doubled the thickness of the binocular mounting plate. She even added a gyroscope to provide rotational stability.

Another test night provided more positive results. As Lauren reported to me the next morning, "It didn't catch fire." It did, in fact, perform quite well. It's now one comfortable observing chair!

■ Contributing Editor **JERRY OLTION** thinks persistence and ingenuity can prevail in just about any ATM project.

DUSTY SAILS
Vikas Chander
Gum 17 (center) and Gum 15 (upper right) in Vela are two of the brighter H II regions of a much larger molecular cloud that permeates the area. North is to the right.
DETAILS: *Takahashi Epsilon E-160ED reflector and ZWO ASI6200MC Pro camera. Total exposure: 25⅓ hours through Hα and RGB filters.*



△△ COLORFUL TRAILS

Michael Kleinburger

While photographing the summer Milky Way on Hochkar Mountain in Austria on the night of July 15, 2023, a fast, bright meteor blazed across the field, leaving a persistent train of ionized gases in its wake.

DETAILS: *Nikon Z 6 camera and 50-mm lens. Total exposure: 60 seconds at f/2.8, ISO 400.*

△ CELESTIAL SNAIL SHELL

Drew Evans

This very deep exposure reveals the intricate patterns of dust and stars in the arms of M100, a grand-design spiral galaxy in Coma Berenices. Several background galaxies also dot the field.

DETAILS: *Celestron EdgeHD 11-inch Schmidt-Cassegrain and ZWO ASI2400MC Pro camera. Total exposure: 21¼ hours through light pollution and UV/IR blocking filters.*

▷ GALILEAN TRANSIT

Dan Llewellyn

The yellowish moon Io (bottom right) cast its dark shadow on the Jovian cloudtops on November 5, 2023. To its left, the Great Red Spot appears paler than the Southern Equatorial Belt, unlike its appearance in recent years.

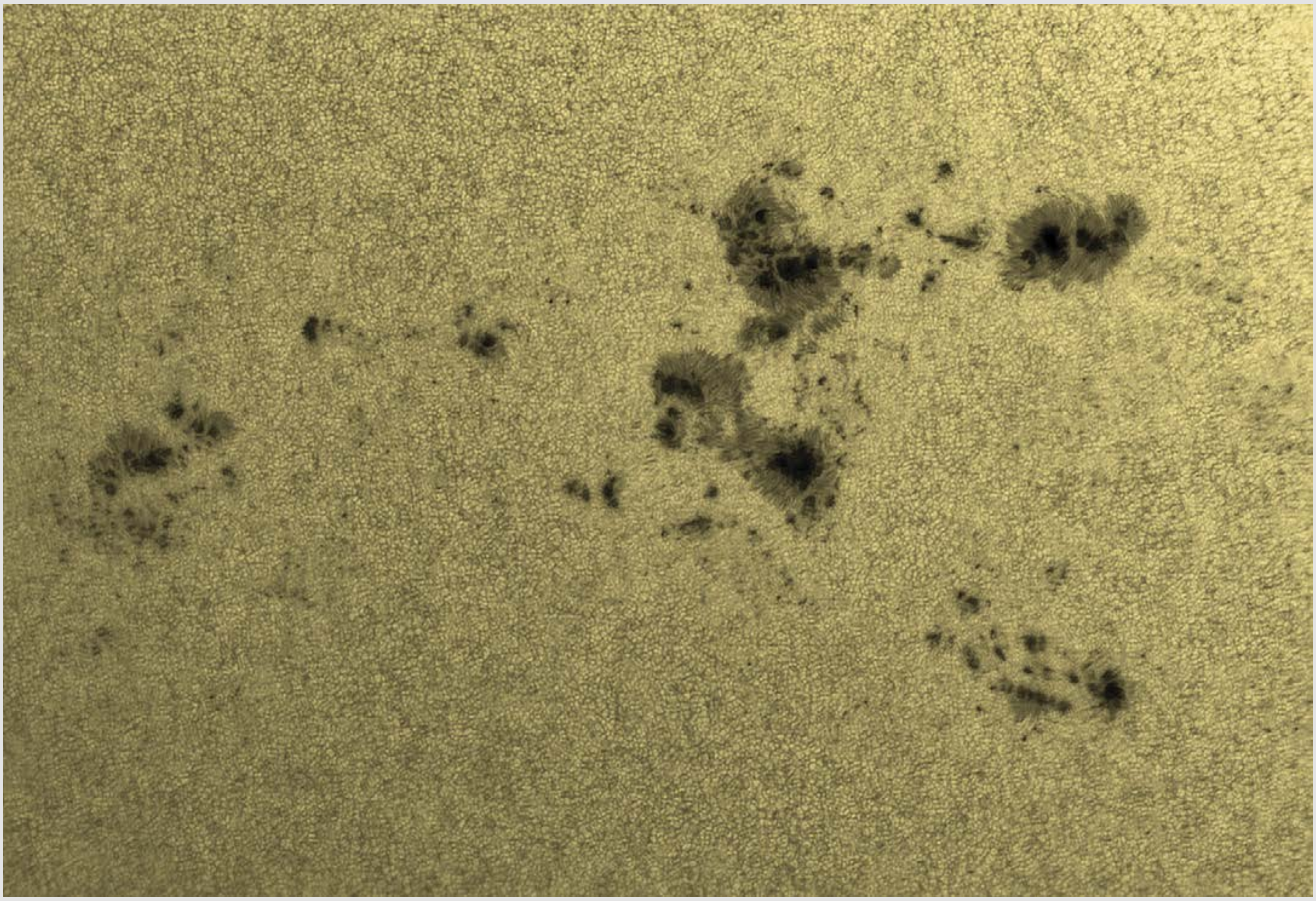
DETAILS: *Celestron C14 Schmidt-Cassegrain and Player One Mars-C II camera. Stack of more than 8,000 frames.*

▽ WIDESPREAD SPOTS

Chris Schur

Several large sunspots make up Active Region 3645, as seen on April 19th. Each displays a delicate halo of flocculent penumbrae. The entire field is riddled with countless light and dark convective cells known as granules.

DETAILS: *Explore Scientific AR152 refractor and ZWO ASI183MM camera. Stack of multiple video frames through Baader Herschel Wedge and solar continuum filter.*



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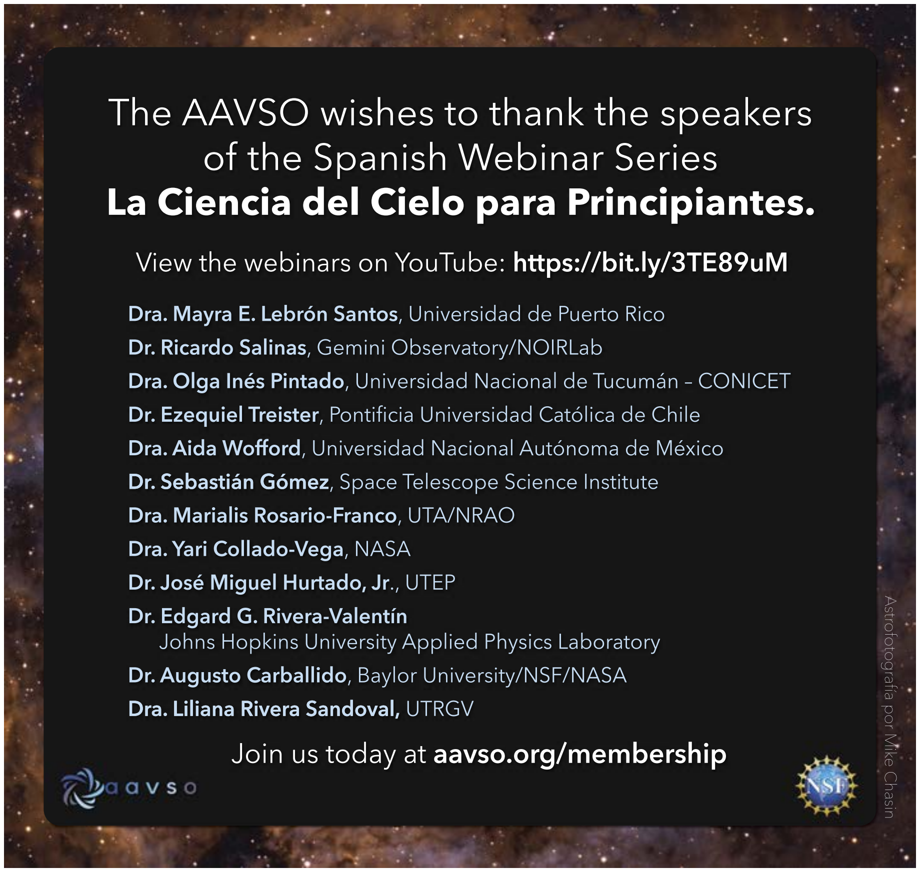
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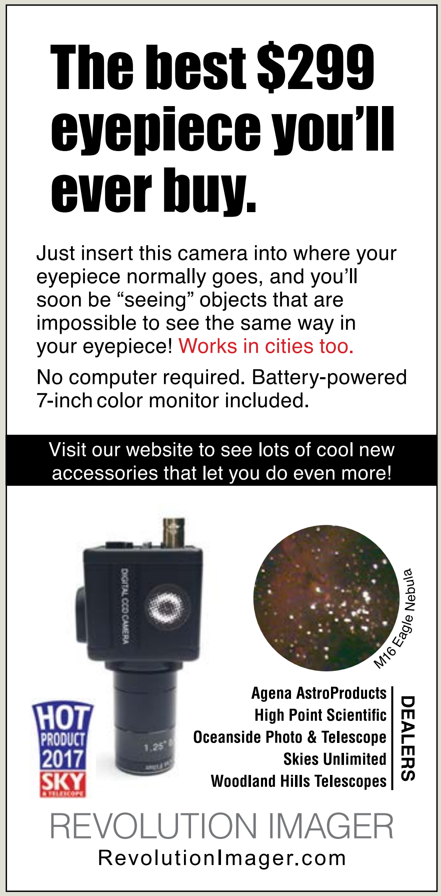

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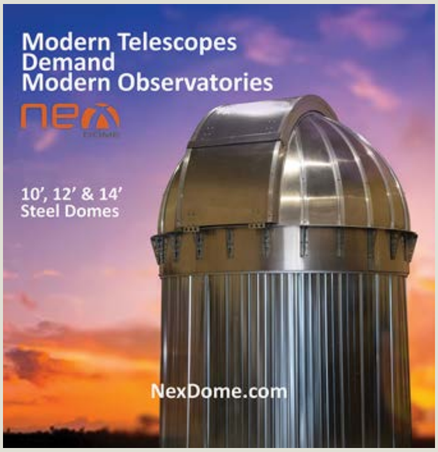

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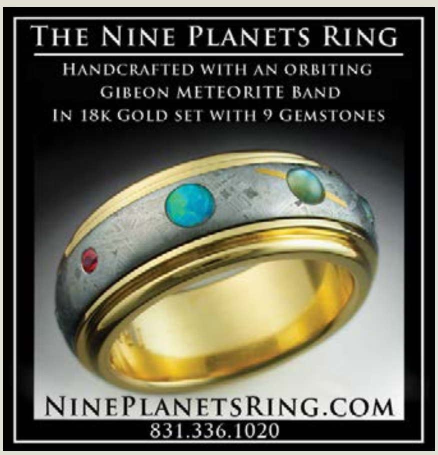

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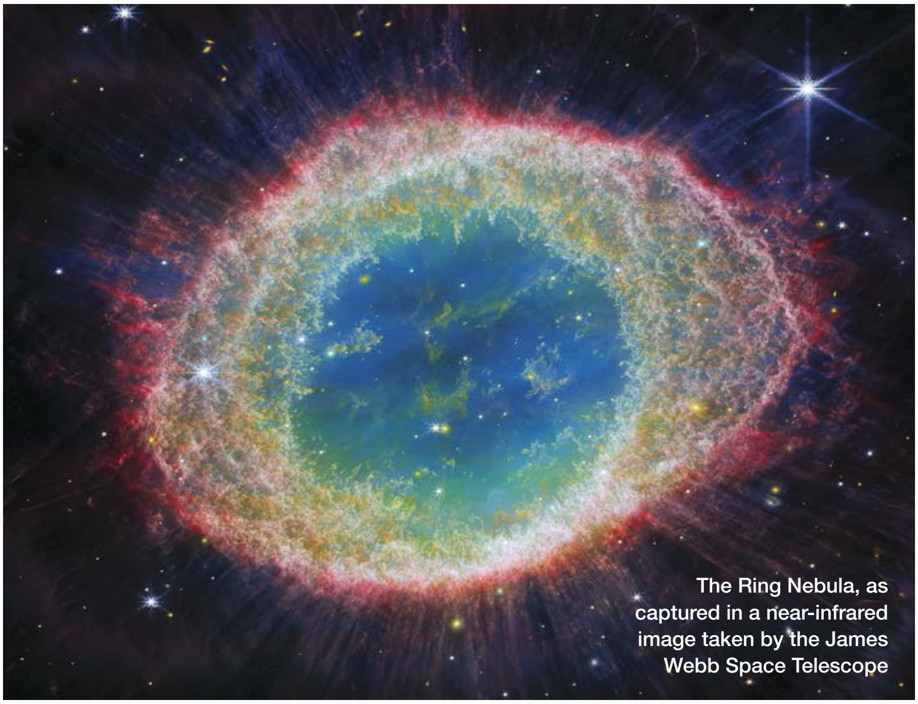
A Lesson in Proper Outreach

What not to say to a 6-year-old just getting excited about astronomy



The Ring Nebula, as captured in a near-infrared image taken by the James Webb Space Telescope

LIKE MANY *S&T* READERS, I enjoy doing outreach. Our club, Westchester Amateur Astronomers, is frequently asked to have members spend a few hours under the stars with eager adults and children, introducing them to the wonders and beauty of astronomy.

One clear and pleasant Saturday night a few years ago, I found myself surrounded by a group of about 15 adults and five children, members of a local Audubon Society. We were at a small nature preserve north of New York City, and it was a perfect evening for viewing. Mars, Jupiter, and Saturn were visible well above the horizon, and the brightest summer objects were on display in Bortle 4–5 skies.

I did what many outreach hosts do: I oriented to north by finding the Big Dipper and using its "pointer stars" to locate Polaris. I talked about the procession of the constellations across the night sky due to Earth's rotation. I identified the brighter constellations and the Milky Way and then used my 8-inch Celestron CPC 800 to show planets and celestial objects in detail.

As usual, Saturn's rings drew gasps and cries of "they're not real" from many in the group. Everyone had certainly seen the rings in high-quality images, but there's still nothing like having their actual reflected photons land on your retina for the first time. The group was keen to hear scientific and historical details. I encouraged and answered many questions. When M31, the Andromeda Galaxy, poked over the horizon, we even got to talk about the size and expansion of the universe.

Everything went well until I got to M57, the Ring Nebula. Its surreal, smoky improbability always motivates me to explain how stars evolve — how they enlarge as their hydrogen fuel is consumed and blow off their outer layers, with the remaining hot white dwarf energizing the expanding nebular gas. Then I said, "In about 5 billion years the Sun will expand beyond the Earth's orbit. The Earth will be incinerated."

There was stirring in the back of the group, and a young boy maybe six years old suddenly cried out, his voice full of terror, "What's going to happen to the Earth? Will we all be burned up? I don't want that!" His father gently tried to explain that this event wouldn't happen for 5 billion years, but that only seemed to increase his anxiety. At his age, 5 billion years and next year must be indistinguishable.

The moment was both humorous and upsetting. We certainly didn't want this enthusiastic child to worry about something that could never affect him or us, or to spoil his enjoyment of the evening. Eventually he calmed down, but I'm not sure his concerns were really ameliorated.

Child psychologists tell us that children develop their understanding of time slowly over a period of years, learning incrementally how to differentiate past, present, and future and grasp the pace of existence. Soon this boy will comprehend that it's pointless to have a personal concern about something that will happen at an almost unimaginable future time.

Yet, I wonder if his child-like fear for the fate of our planet is a more authentic sentiment than the easy denial that comes from our adult comprehension of "5 billion years." Maybe we should be just as upset as he was for Earth's destiny, not in 5 billion years but in the next few decades.

Meantime, if there are young children in the crowd at the next outreach, I'll leave out that bit about our planet getting fried!

■ A retired physician, **LARRY FALTZ** is a former president of WAA, a lifelong astronomy enthusiast, and an *S&T* subscriber for half a century.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