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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

APRIL 2026

How AI Is Reshaping Astronomy

Page 62

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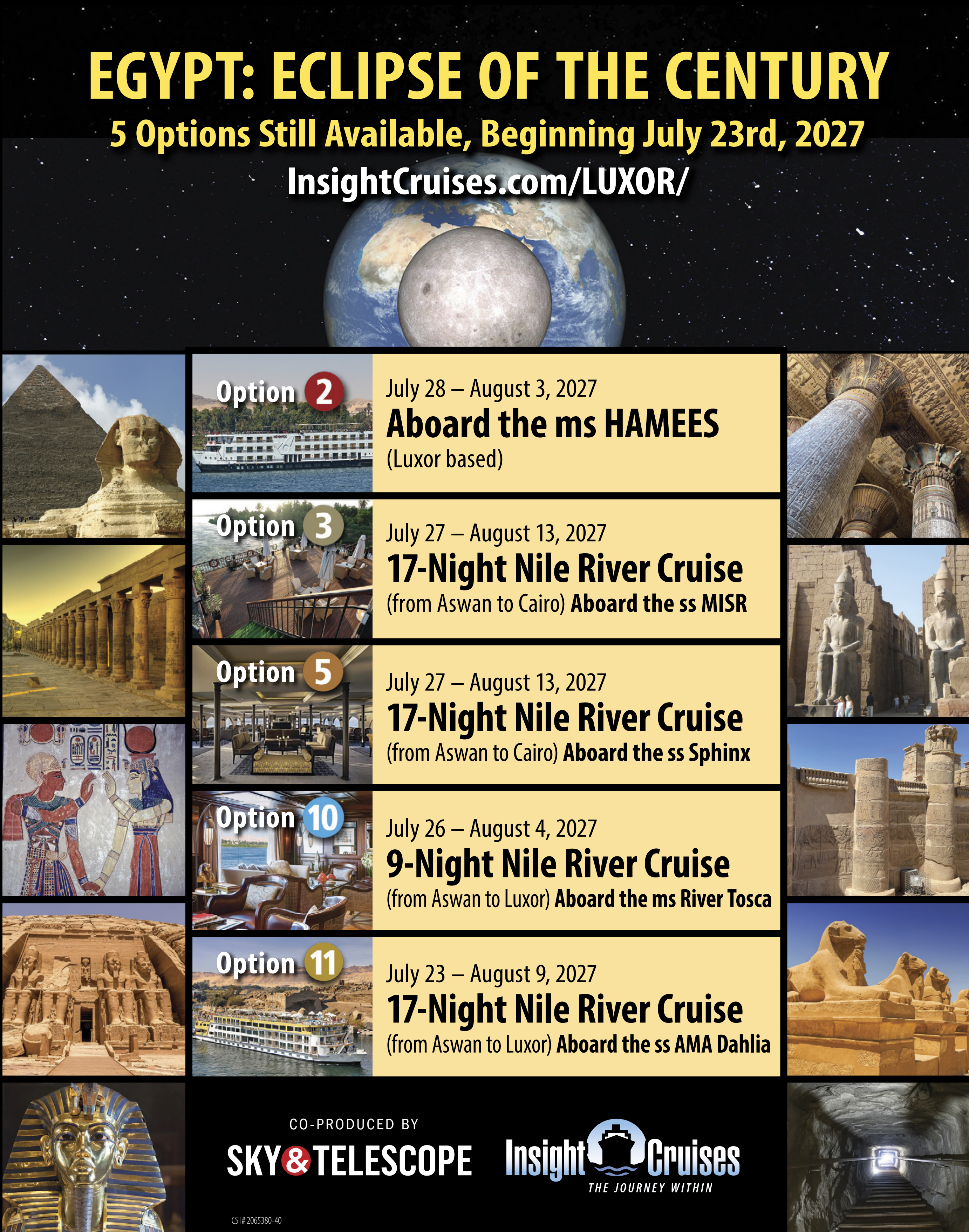
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Artist's concept of an artificial intelligence network
PHOTO: NICOLLE FULLER / SAYOSTUDIO

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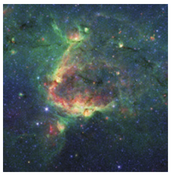
Unraveling AI

I'M SURE IT HASN'T ESCAPED anybody's attention that artificial intelligence has been much in the news lately. It certainly hasn't escaped the notice of astronomers, who have always been keen to explore new technologies. We touched on AI's use in amateur astronomy in our November issue (page 64). On page 62 of this month's magazine, News Editor Monica Young now takes us on a thought-provoking deep dive into how AI is impacting astronomical research. She has done a sterling job of unraveling the complexities not only of AI's technical aspects but also of the underlying reasons behind how and why scientists are turning to AI for their work.



▲ Astronomers used AI to identify massive newborn stars

NASA / JPL-CALTECH / UNIVERSITY OF WISCONSIN

All this talk about AI sometimes leads people to ask us how we're using it editorially. So I would like to take this opportunity to underline that we at *Sky & Telescope* do not use AI to generate the content that we are bringing you, our readers. The work that you hold in your hands — the stories, the illustrations, and their interweaving on the page — has all been created and curated by real, live human beings. We are all passionate about what we do and how we do it, and this will not change.

We do use AI tools in ways that don't replace creative talent and that permit us to keep a tight rein on accuracy, however. For example, we sometimes use an AI software platform to transcribe recorded interviews, instead of spending hours typing out the transcripts ourselves. But we check the transcription against the audio recording for accuracy before publishing a quote. This tool has been an industry standard in science journalism for several years now — even before the current AI boom.

And now, on to some staffing news. Last month we were saying a fond farewell to Gary Seronik. This month, I'd like to welcome our new associate editor, Meg Thacher, into the fold. Meg comes to us from a distinguished career teaching astronomy and writing at Smith College in Northampton, Massachusetts. She's also been a freelance science writer for many years. She's handy with a red pen and with observing gear. We're all looking forward to working with her!

I'm also extremely pleased to announce Sean Walker's promotion to Senior Editor, a much-deserved recognition for his many years of tireless and superb service to the magazine. Sean joined the *S&T* staff in February 2000 as Ad Production Coordinator. In the years since, he has worn many hats and had many titles. We've all benefited from his sharp insights and enormous expertise in all things astrophotography and equipment-related, as well as his fine storytelling voice.

Welcome, Meg! Congratulations, Sean!

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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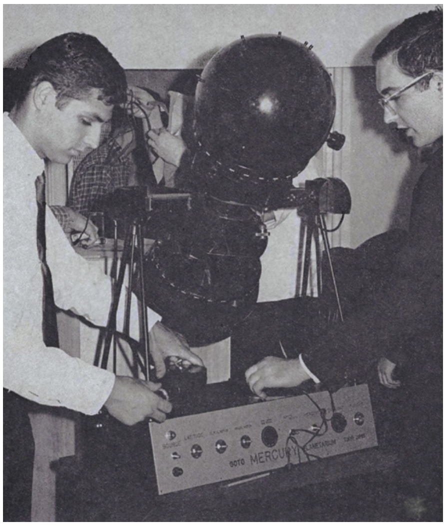


◀ George Lovi (right) adjusts the Goto Mercury projector at the Brooklyn Children's Museum with Mark Levine (left), who would later become the director of the Vanderbilt Planetarium on Long Island.

BROOKLYN CHILDREN'S MUSEUM, BROOKLYN AVENUE AND PARK PLACE

Planetariums Around the World and Back in Time

Sam Storch's "One Hundred Years in the Dark" (*S&T:* Oct. 2025, p. 28) took me back to the mid-1960s, when I had the privilege of being a very young planetarium lecturer at the Brooklyn Children's Museum in New York.

We had a Goto projector, a 5-meter (16-foot) dome, and a complex control board without any computers. We presented programs about (future) Moon landings, space walks, and the "Christmas Star" and tried to keep it interesting for the visitors who wandered in. We tweaked rheostats, flashbulbs, rotating tube projectors, acetate filters, reel-to-reel tape players, and a temperamental 8-mm film projector, all while trying to tell a story in an entertaining manner. It was a terrific experience that started my career as a science communicator.

I got to rub elbows with people like George Lovi (*S&T*) and Joel S. Levine (NASA). What a wonderful way to be immersed in something I loved and continue to treasure!

Mitchell B. Kramer
Middlebury, Vermont

Sam Storch told me about Mitchell B. Kramer's letter. As it turns out, on page 291 of the November 1967 issue of *S&T*, there's an article that Joel S. Levine wrote about the Brooklyn Children's Museum and planetarium, which featured the image of George Lovi at left. At that time, Levine was chairman of the department of astronomy and space science at the Brooklyn Children's Museum, as well as the director of the Brooklyn College Observatory.

Joe Rao
New York City, New York

I thoroughly enjoyed Sam Storch's article. As a university student, I had the privilege of working at the Johannesburg Planetarium on the weekends. At the time, the planetarium had a Zeiss projector from the 1930s. There was something about that old Zeiss that was magical. Mechanically, it was a work of art. With just a few switches, we could transport our audience to any place on Earth at any date or time.

The stars were more realistic than those of any of the modern planetariums I've visited around the world. After showing people the wonders of the sky, I loved bringing them gently back to Earth by leaving the projector rotating, bathed in colored spotlights. The stately turning of the body, the gentle swinging of the mechanical shutters, and the colored shadows of that "giant ant" on the dome were mesmerizing. It was the perfect way to end an experience that I hope sparked a lifelong love of astronomy.

Hugh Selsick
London, United Kingdom

I was very fortunate that in 1973, Joseph A. Foran High School in Milford, Connecticut, was built near me with a planetarium featuring an excellent Goto projector. With it, we students got to know the sky so well that we could easily spot tiny light leaks coming from the projector. We created and presented our own public programs incorporating the sky, music, and other projectors. All those skills became useful later in life.

During the live programs, if one of the star fields was stuck closed, we'd open it with a red plastic light saber! And we'd squirt water on the viewers during simulated thunderstorms. On trips to other planetariums, we would always proudly compare our superior stars to theirs. Seeing a recorded program on those trips instead of the actual projected sky was disappointing.

Foran's planetarium has just been renovated into a digital theater, which is more versatile. But I hope students will still be empowered to use it themselves. And with the sky there now horrible, I hope they'll still show the public what they're missing.

Harold Moritz
East Haddam, Connecticut

I enjoyed the outreach and planetarium articles in the July and October issues, as I have experience with both.

It started years ago at the Strasenburgh Planetarium in Rochester, New York. While there, I designed the special effects and ran shows that brought the universe to life. Presenting to an audience was a never-ending pleasure.

Later, I brought that same spirit to Grand Canyon National Park. On the rim of that vast chasm, I operated telescopes and shared my knowledge with visitors from around the world. There was something magical about watching them look through a telescope for the first time. I hope planetariums continue to motivate visitors to seek, enjoy, and preserve our night skies.

Paul Braiman
Lake Arrowhead, California

After receiving the October issue, I was pleased to find a familiar venue in its pages. Sam Storch's article reminded me of my childhood in New York. After my first solar eclipse as a little tyke, I had the privilege of experiencing my first star show at the Hayden Planetarium on a field trip as an elementary-school student from Brooklyn. I have since relocated to California and made sure my children enjoyed a similar experience by frequenting the Morrison Planetarium in San Francisco during the ’80s and ’90s. Planetariums are excellent primers for an introduction to the study of the heavens.

Clarence G. Underwood
Esparto, California

I enjoyed learning how people have created increasingly realistic starscapes in Sam Storch’s article. I was slightly perplexed, however, by his claim that “no other invention of humanity has ever been able to imitate” the sight of a star-filled sky. A quick internet search suggests that virtual-reality headsets may also fit the bill. It would be interesting to hear how skywatchers of all ages rank that experience when compared to a modern planetarium show.

Joshua Roth
Arlington, Massachusetts

Sam Storch’s article was an amazing piece. I particularly enjoyed the part that discussed alternatives to traditional planetariums.

For those who truly wish to engage with the stars indoors, it’s possible to bring them into your home. After moving into our current house 23 years ago, we contacted a local star-painting service (Stellar Vision, Inc., **stellarstars.com**) to have the Southern Hemisphere’s sky painted on our bedroom’s ceiling as a reminder of our life in New Zealand. We even have a comet or two for added enjoyment.

For those of us who live in the oft-clouded-over Pacific Northwest, the ceiling is a pleasant reminder of what awaits for us out there. Twenty-three years later, it’s still shining on!

Richard Molitor
Bothell, Washington

Sam Storch writes that the Royal Eise Eisinga Planetarium in Franeker, the Netherlands, housed an orrery from 1774 to 1781. In fact, amateur astronomer and wool comber Eise Eisinga spent those seven years building his impressive mechanical model of the solar system, which is still fully functioning 245 years after its completion. Actually, it’s the oldest working planetarium in the world. In 2023, it was awarded World Heritage status by UNESCO.

Govert Schilling
Amersfoort, the Netherlands

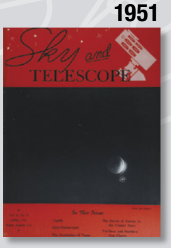
FOR THE RECORD

- In the Test Report of the Sky-Watcher Heliostar 76 (*S&T:* Dec. 2025, p. 68) the filter bandpass is 0.05 nanometer, or 0.5 angstrom, not 0.5 nanometer.
- Victor van Wulfen, referenced in “Exploring Sidney van den Bergh’s Reflection Nebulae” (*S&T:* Jan. 2026, p. 14), wrote the Clear Skies Observing Guides (**clearskies.eu**).

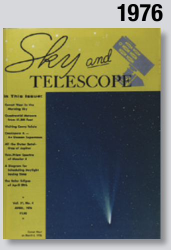
SUBMISSIONS: Write to *Sky & Telescope*, 1374 Massachusetts Ave., 4th Floor, Cambridge, MA 02138, USA, or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

75, 50 & 25 YEARS AGO by Sabrina Garvin

1951



1976



2001

April 1951

Venus Viewing “Except for part of the Northeast, the occultation or close conjunction of Venus and the moon appears to have been well observed. . . .

“At Milwaukee, Wis., the occultation caused some excitement, for although Herbert W. Cornell had told the *Milwaukee Journal* about it in advance the newspaper did not print anything, ‘perhaps because we had been having such wretched weather,’ writes Mr. Cornell. ‘Then, for a change, we had a clear western horizon and both newspapers, the *Journal* and the *Sentinel*, were flooded with phone calls as to ‘what is happening to the moon?’ We were called up in a hurry to explain all about it, and both papers published pictures that their staff photographers took.”

April 1976

Daytime Comet “As hoped, Comet West became a fine object in the morning sky during early March for Northern Hemisphere observers. It had a long tail and brilliant nucleus, and many amateurs rated this the finest comet since 1969i (Bennett). It may have been even better, as Comet West is one of the few on record that became bright enough to be visible in the daytime without optical aid. . . .

“Reports from Australia and New Zealand showed a steady brightening as the comet neared the sun. . . . It may have been as bright as magnitude –1 on February 21–23, when glimpsed just before setting in evening twilight . . .

“Passing the sun, Comet West reappeared in the morning sky, to be widely observed at dawn on February 29th by amateurs who had favorable conditions. . . . [In] early March the head of Comet West was about 1½ magnitudes brighter than expected.”

April 2001

Black Holes “Astronomers have long been convinced that black holes exist. . . . In the last few decades astronomers have found abundant [indirect] evidence of black holes’ presence in many places. . . . It would be nice actually to see a black hole directly and settle the matter for good.

“Speaking at the January meeting of the American Astronomical Society in San Diego, several researchers . . . have done just that. . . . The astronomers paired up neutron-star systems and black-hole systems that had the same rates of gas inflow, [resulting in] a clear sign that event horizons do exist in the black-hole systems. [Infalling] material continuously plowed into the [neutron] star’s surface, [but where] the object was expected to be a black hole, the same [material] vanished.”

Eighteen years later in 2019, Alan MacRobert’s wish to “see” a black hole would come true when the Event Horizon Telescope released the first-ever image of a supermassive black hole’s shadow: **https://is.gd/BHImage**.

RED PLANET

Lightning Sparks Detected on Mars

▲ A towering dust devil, imaged from above by the Mars Reconnaissance Orbiter, casts a serpentine shadow.

FOR DECADES, scientists have suspected that there's lightning on Mars. However, definitive evidence proved elusive. Now, a team of researchers has finally directly detected electrical discharges in the Martian atmosphere.

These sparks are nothing like the miles-long, wrath-of-the-gods lightning we experience on Earth; instead, they look more like the faint electrostatic discharges that occur when rubbing a sweater on a dry day. They occur when electrified dust grains collide in midair, a process known as *triboelectrification*.

The evidence comes from an unlikely instrument: a microphone on NASA's Perseverance rover, which has been roaming Mars since February 2021. The microphone's primary purpose is characterizing winds and atmospheric turbulence, along with diagnosing technical issues on the rover itself.

But in September 2021, a dust devil passed directly over the rover, and the microphone recorded its winds. Baptiste Chide (University of Toulouse, France) worked with colleagues to analyze that data, publishing results in *Nature* in 2022. In the audio, they noticed intriguing clapping sounds, initially attributing them to dust grains striking the microphone's membrane. But the researchers later realized the mysterious sounds resembled miniature shock waves, produced when winds electrically charge suspended dust particles that then collide.

When Chide reviewed the recordings, he found a second signal from electromagnetic interference that arrived a few milliseconds before the shock wave. The find was equivalent to seeing lightning before hearing thunder. "These are two independent signals, and that was the confirmation of the discharge," Chide says.

By analyzing the delay between the near-instantaneous electromagnetic signal and the slower acoustic shock wave, Chide and colleagues calculated the distance of each event from the microphone, enabling them to gauge the discharges' intensity. In the Novem-

EXOPLANETS

Webb Telescope's First Look at Habitable-Zone Planet TRAPPIST-1e

THE TRAPPIST-1 SYSTEM hosts seven Earth-size planets orbiting a red dwarf 40 light-years away. A few of them reside in the star's *habitable zone*, where liquid water could exist on the planetary surface — if the planets have the right atmosphere.

Astronomers have used the James Webb Space Telescope (JWST) to rule out the possibility of an atmosphere on the system's three innermost worlds: TRAPPIST-1b (*S&T:* Aug. 2023, p. 8), TRAPPIST-1c (*S&T:* Nov. 2023, p. 9), and the habitable-zone planet TRAPPIST-1d (*S&T:* Jan. 2026, p. 10).

Now, they've turned their sights to the next one out, TRAPPIST-1e. However, the findings, published across two papers in the September 10th *Astrophysical Journal Letters*, are inconclusive. The exoplanet might have a nitrogen-rich atmosphere with traces of methane — but the data are also consistent with no atmosphere at all. The host star's activity contaminates the data, making it difficult to distinguish between the different scenarios.

The JWST data include four transmission spectra from June, July, and October 2023. Taken while the planet crossed in front of its star, these spectra capture the host star's light as it passes by the planet and through whatever sliver of atmosphere the world might have (*S&T:* Dec. 2024, p. 34).

Despite stellar activity, the astronomers were able to rule out a puffy, hydrogen-dominated atmosphere. They instead found that the data best match an atmosphere with heavier molecules, more like Earth's or Titan's. That atmosphere would be nitrogen-dominated, and the data favor the presence of methane, too.

Yet the spectrum is also consistent with a bare rock or an atmosphere obscured entirely by clouds.

"I do wonder whether we are hitting the end of the road for transmission

NASA / JPL-CALTECH / UNIV. OF ARIZONA

ber 27th *Nature*, they write that the most energetic of the sparks released 40 millijoules — comparable to the energy generated by a car's spark plug.

Hearing the mini-thunderclaps is rare for multiple reasons. Mars has terrible acoustics. The low atmospheric pressure and the high concentration of carbon dioxide attenuate sound waves at high and middle frequencies, severely limiting how far those waves can travel. In that environment, two people standing together "would have to scream to hear each other," Chide says. The thin air also can't support long transmissions of lightning; they die off quickly.

But the rarefied Martian atmosphere also explains why these tiny lightning flashes strike in the first place. The air's composition and low pressure, on average less than 1% of Earth's at sea level, make it easy to ionize gas and produce a discharge in midair.

Such tiny sparks might seem underwhelming to a casual observer, but they may prove important in dust-storm forecasts, chemical investigations of life, and future exploration of the Red Planet. Chide's team is planning to further examine analogous events in their lab on Earth.

■ JAVIER BARBUZANO

Read more here: skyandtelescope.org/MarsLightning.

TELESCOPES

Thirty Meter Telescope Considers Move to Spain

THE PROPOSED Thirty Meter Telescope (TMT) promises to become the most advanced telescope in the Northern Hemisphere. However, the project has encountered significant roadblocks, from funding uncertainties to local resistance on Mauna Kea, the preferred construction site in Hawai'i that's also sacred to native communities.

Now, the telescope might find a new home on La Palma, one of Spain's Canary Islands. In July, the Spanish government offered to host the telescope, with an investment of up to €400 million ($470 million) to help cover some of the project's costs. In a brief statement posted on November 11th, the TMT announced that it is officially considering the move.

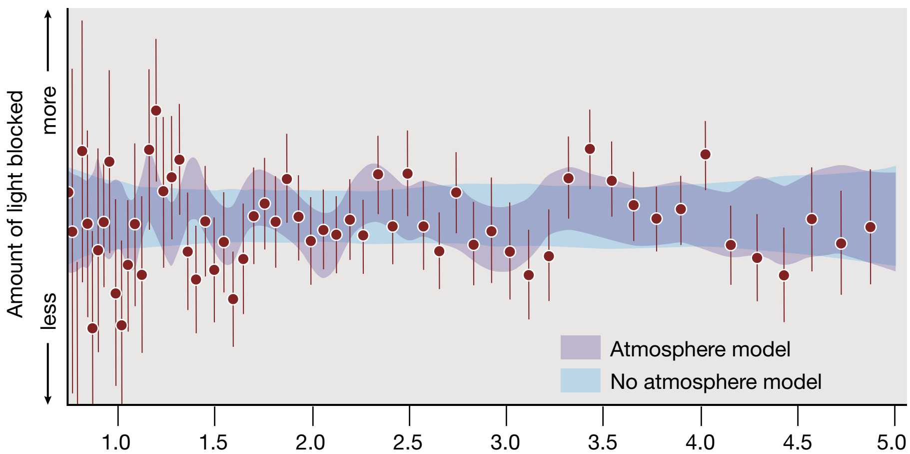
If built, the TMT would play a key role as the only one of three next-generation megascopes to be located in the Northern Hemisphere. The Giant Magellan Telescope (GMT), also U.S.-led, is being built in Chile. Both projects require federal funding to cross the finish line; however, the White House's 2026 budget request forced the National Science Foundation (NSF) to back only the GMT.

▲ An artist's concept shows the dome of the Thirty Meter Telescope.

The Spanish government had already expressed interest in hosting the TMT on La Palma back in 2019, after protests halted TMT's construction on Mauna Kea. A 2016 survey found that La Palma's lower altitude and warmer, wetter climate would require most observations to be almost 20% longer. But the NSF's recent decision prompted Spain to step forward again.

"Faced with the risks of this major international scientific project coming to a standstill, the Spanish government has decided to act," says Diana Morant, the Spanish Minister of Science, Innovation, and Universities, "with a redoubled commitment to science and major scientific infrastructures for the benefit of global knowledge." La Palma may well promise a new path forward for the beleaguered observatory.

■ ARIELLE FROMMER



◀ This plot compares JWST data with computer models of TRAPPIST-1e with an atmosphere (purple) and without (blue).

spectroscopy in general," says Ignas Snellen (Leiden Observatory), who wasn't involved in the research. "The overwhelmingly large noise and systematic effects associated with the star could be too much for this task."

But the team still has hope: They've scheduled 15 additional JWST observations of the planet's transits back to back with the innermost planet, TRAPPIST-1b. Since the transmission spectrum of airless TRAPPIST-1b will only show stellar noise, it will help calibrate TRAPPIST-1e's spectrum.

"We are pushing the limits of JWST," says team member Ana Glidden (MIT). If this method works, the observations could — for the first time in history — confirm an atmosphere on a terrestrial planet beyond the solar system.

■ ARIELLE FROMMER

Read more: skyandtelescope.org/TRAPPIST1e.

TMT: TMT INTERNATIONAL OBSERVATORY; SPECTRUM OF TRAPPIST-1E: NASA / ESA / CSA / STSCI / JOSEPH OLMSTED (STSCI)

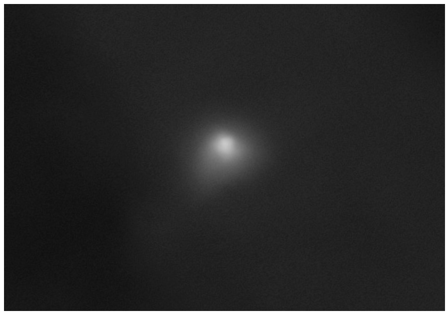
COMETS

3I/ATLAS: Interstellar Comet Update

THE INTERSTELLAR COMET 3I/ATLAS reemerged from behind the Sun last November, allowing Earth-based telescopes to observe it again after its closest brush with our star.

During that time of *perihelion* is when comets change the most. The comet was hidden behind the Sun from Earth's perspective during this time, but instruments at Mars had a better view. On November 19th, NASA released the highest-resolution images taken around the time of perihelion. That data release, including images from the half-meter telescope on the Mars Reconnaissance Orbiter, was delayed due to the U.S. government shutdown.

"Boy, were they ready for this event!" said Nicky Fox (NASA), associate administrator of NASA's Science Mission Directorate. She spoke at a press conference announcing the results of observations from spacecraft at Mars and beyond, which "pushed our science instruments beyond their normal capabilities."



▲ The HIRISE camera on the Mars Reconnaissance Orbiter snapped this photo of Comet 3I/ATLAS from 30 million kilometers (20 million miles) away.

Images obtained by the European Space Agency's ExoMars Trace Gas Orbiter between October 1st and 7th also provided vital information on the comet's exact position. Triangulating between observations from Earth and Mars improved the precision in its predicted location by a factor of 10.

Analysis of new publicly available data will help astronomers understand the comet's trajectory, the size of its nucleus, and the composition of gases in its coma — all of which will help us understand a frozen fossil from the earliest period of planet formation.

Once the comet reemerged from the Sun's glare, amateur astronomers monitored its evolving tail while it was still too close to the Sun for major observatories to risk pointing at. They captured images of multiple tails that had spouted during perihelion.

"It's doing the things comets do," says David Jewitt (University of California, Los Angeles). "All these things are consistent with a comet nucleus of typical size or smaller, sublimating in sunlight and blowing out dust particles."

■ **DAVID L. CHANDLER**

Find updates at **skyandtelescope.org/3IATLASupdates**.

THE SUN

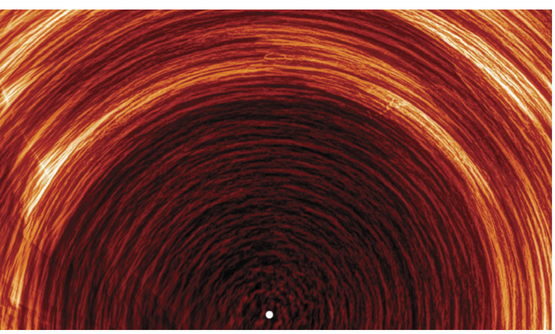
Solar Poles' Appearance Surprises Scientists

UNIQUE VIEWS of the Sun's poles from the European Space Agency's Solar Orbiter are showing how a "conveyor belt" moves within our nearest star. The craft obtained its first glimpse of the poles last year (*S&T:* Oct. 2025, p. 12). Now, new analysis of those data has implications for the 11-year solar cycle that drives sunspots, particle eruptions, and other activity.

The reset button for that cycle depends on movements within the Sun called the *meridional flow.* That flow carries plasma poleward along the surface; once at the poles, the plasma sinks deeper within the Sun and travels back toward the equator. The speed and strength of that flow determines when our star's activity cycle begins anew and may even help determine the next cycle's strength.

In previous studies, scientists tracked the motion of magnetic features across the Sun's visible surface, finding that the meridional flow slows as it travels away from the equator.

But those studies came from a glancing view of the poles. Solar Orbiter is following a trajectory that's becoming increasingly tilted relative to the Sun's equator, granting it direct polar views. The spacecraft's unique angle tells a different story to Lakshmi Pradeep Chitta (Max Planck Institute for Solar System Research, Germany) and colleagues.



◀ This image of the region around the Sun's south pole (white dot) combines eight days of extreme-ultraviolet observations to show tracks of bright spots in the chromosphere.

Chitta's team tracked bright spots in the *chromosphere*, the layer just above the visible surface. These spots trace the motions of giant plasma bubbles on the Sun's roiling visible surface, known as *supergranules* (each of which spans two or three Earths). Using those observations, the team found that the plasma is moving just as fast near the poles as near the equator — about 10 to 20 meters per second (22 to 45 mph).

Chitta and colleagues do note, though, that while the Solar Orbiter is tracking movements of features in the chromosphere, previous studies tracked magnetic features on the visible surface itself. It could be that there's a magnetic gradient, so that the field travels at a different speed higher in the Sun's atmosphere than at the visible surface.

The study, published in the November 10th *Astrophysical Journal Letters*, provides a first look at Solar Orbiter data. There's much more to come as the spacecraft's orbit continues to tilt, with ever-improving views of unexplored territory on the Sun.

■ **MONICA YOUNG**

COMET 3I/ATLAS: NASA / JPL-CALTECH / UNIV. OF ARIZONA; SOLAR ORBITER: ESA & NASA / SOLAR ORBITER / EUI-TEAM

STARS

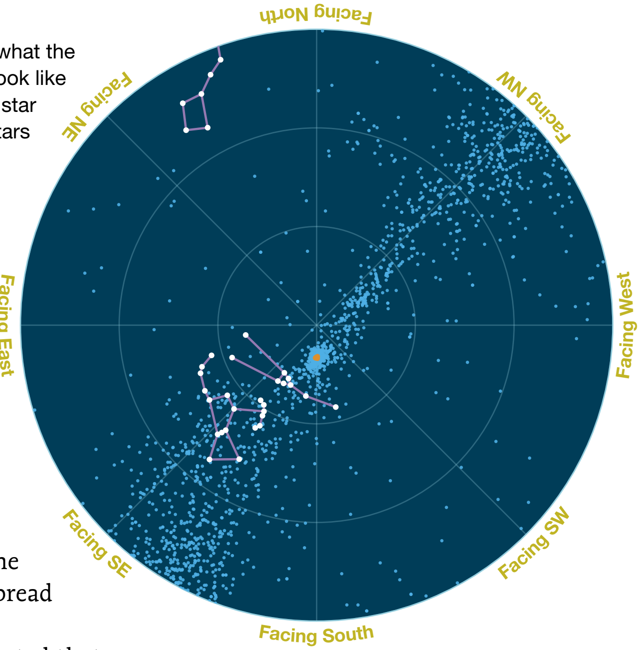
Meet the Seven Sisters' Lost Siblings

THE PLEIADES STAR CLUSTER is part of a much larger complex that stretches across the entire sky, a team of astronomers finds in a new study.

We know the brightest members of the Pleiades have been capturing our imagination since the Stone Age — but they're just the tip of the iceberg. The team identified more than 3,000 stars that formed together with the Pleiades but now span nearly 2,000 light-years, sprinkling across the entire sky.

"We are calling this the Greater Pleiades Complex," says Luke Bouma (Observatories of the Carnegie Institution for Science), who together with the team lead Andrew Boyle and Andrew Mann (both University of North Carolina, Chapel Hill) published these findings in the November 20th *Astrophysical Journal*.

Open clusters like the Pleiades are notorious for losing their stars. Such clusters form in a single burst out of a giant cloud of gas and dust, but multiple forces start to tear them apart almost as soon as they're born. Astronomers think that after a few hundred million years, most open clusters have fully dissolved, their stars mixed unrecognizably with the rest of the Milky Way. The Pleiades, at 446 light-years from Earth, are thought to have formed about 100 million years ago, so it's not surprising that some of the members are already spread across the galaxy.



▶ This simulated star map shows what the Greater Pleiades Complex would look like over Pasadena, California, if every star were visible. The seven Pleiades stars are in orange (at center), while the other members are blue. The Big Dipper, Orion, and Taurus are overlaid in white and purple.

Astronomers already suspected that a few nearby stellar groups are related to the cluster. Now, the team shows that these groups indeed have properties in common with clear cluster members.

Boyle and colleagues combined 3D motions from the Gaia mission and stellar-rotation rates from the Transiting Exoplanet Survey Satellite for some 8 million stars, folding in data from other ground-based telescopes. The team then pinpointed which stars among those millions share motions, chemical abundances, and — most importantly — ages with the Pleiades.

The result shows that astronomers can trace the complex birth of open clusters over millions of years through to today, says Henri Boffin (European Southern Observatory, Germany), who was not involved in the study. "It's an exciting development."

■ JAN HATTENBACH

Read details of the discovery at skyandtelescope.org/PleiadesComplex.

ANDREW BOYLE / UNIVERSITY OF NORTH CAROLINA, CHAPEL HILL

IN BRIEF

First Private Space Telescope Launches

A small space telescope the size of a mini-fridge could mark big changes in astronomy. SpaceX launched 140 payloads on November 28th, which included a CubeSat named Mauve. Unlike other space observatories, Mauve is owned by a private company — the UK-based Blue Skies Space — and that means its data will be private, too. The ultraviolet-to-visible spectra of Milky Way stars that it provides will be available only to researchers who subscribe. From low-Earth orbit, Mauve will observe large swaths of ultraviolet sky for three years using a 13-cm telescope and spectrometer. Mission objectives include monitoring stellar activity as well as its impact on any exoplanets. The Mauve science team, made of researchers who joined the program early on, has already constructed a survey program with a set list of targets. As science operations start up in early 2026, those targets and the full science program will be shared publicly. Annual subscriptions will then provide researchers access to all data within the program. Thus far, the company says 10 institutions have signed up.

■ DAVID DICKINSON

Read more at **skyandtelescope.org/mauve**.

Solar Observatory Celebrates 30 Years

The Solar and Heliospheric Observatory (SOHO) has far exceeded its nominal three-year lifespan, having now spent more than 30 years observing the Sun. As a joint European Space Agency and NASA mission, SOHO launched on December 2, 1995. Since then, it has viewed our star with few interruptions, spanning almost three 11-year solar cycles (Cycles 23, 24, and now the ongoing Cycle 25). With the 12 instruments it carries onboard, the mission has revolutionized the study of our tempestuous Sun and the space weather it creates. (All mission data are free to access online.) For example, SOHO observations established that, even as ultraviolet radiation doubles and then wanes again throughout the course of a solar cycle, at the same time, our Sun's *total* energy output varies remarkably little (only 0.06%). Poring through SOHO data for *sunquakes* (primarily acoustic waves that make our star ring like a bell), solar scientists have studied flows of plasma within the Sun. In addition to helping us understand the Sun itself, the spacecraft has also become a crucial asset for real-time monitoring of space weather. Its Large Angle and Spectrographic Coronagraph (LASCO) monitors solar eruptions known as *coronal mass ejections*. LASCO has even enabled the discovery of more than 5,000 sungrazing comets. Having used mission data to produce more than 7,000 scientific publications and mint 250 doctorate theses, a generation of solar physicists has grown up with SOHO.

■ DAVID DICKINSON

Sprite Surprises

Simultaneous observations of this atmospheric phenomenon yield unexpected results.

ON APRIL 22, 2025, my wife, Deborah Carter, and I were at the annual Texas Star Party at Prude Ranch near Fort Davis, Texas, when Will Young of **DeepSkyDude.com** alerted us to possible sprite activity that night. At that time, a massive storm system would pass some 100 to 160 km (60 to 100 miles) away. This was the perfect distance for seeing these large-scale electrical discharges that occur above thunderstorms, some 50 to 100 km high in the mesosphere. While scientists seem to understand the basic mechanisms for generating sprites, other aspects of their behavior are poorly understood, making them even more fascinating to observe and study.

We began our watch around 9 p.m. We were all standing side by side on the ranch's upper field when at 9:38 p.m., Deborah and I saw a ray of light thrust up from the horizon like lightning. It happened so fast, we couldn't be sure if it was a sprite. Deborah, who was looking directly at it, likened it to a needle-sharp, silvery beam. I caught it out of the corner of my eye, appearing as a slightly wider and paler pillar of light.

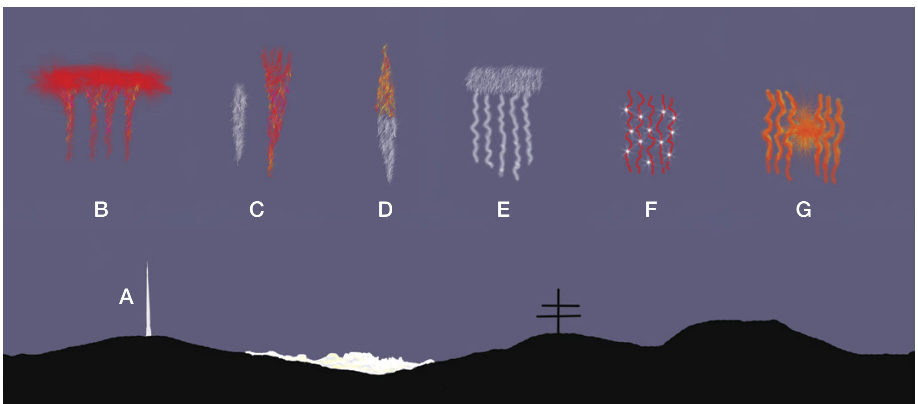
Eight minutes later, we were stunned to see a remarkable display of what can be best described as either a hedgerow of bright carrots or a bloom of jellyfish above the storm clouds. This time, both of us were looking directly at the phenomenon. We saw it as four streams of fibrous filaments capped by a broad arc of diffuse light. To me, the entire display looked electric red, while Deborah saw it more amber colored, like the dying embers of a campfire. I didn't expect to see such vivid colors. I also found it surprising how much detail I could perceive, especially considering that the sprites flashed into view so quickly. I knew that video recordings of sprites last only milliseconds, and yet the visual image seemed to linger in my mind's eye for much longer — like a residual afterimage.

A third episode of sprite activity occurred a few minutes later. It was yet another stunning display of a sharply defined phenomenon: two carrot-shaped sprites appearing side by side. The preceding one, the one at right, was taller than the other and appeared bright red; the shorter one was pale gray. Curiously, Deborah saw only one sprite, not two — she said it was shaped like an Olympic torch with a grey handle that tapered toward the horizon, topped by an amber flame that narrowed toward the zenith. Perhaps she saw a different, though simultaneous, sprite.

Four minutes later, we saw yet another different display. To me, this sprite looked more like a phantom box jellyfish, its numerous tentacle-like tendrils spiraling down from the head. This time, Deborah saw the phenomenon as red, while I saw no color at all. Lowell Observatory astronomer Brent Archinal, who had joined us, also saw no color. It turns out both Brent and I saw the display using our peripheral vision while Deborah was looking directly at it. She saw the jellyfish's tendrils, but not the head; she also saw the tendrils sparkling, which we did not. It's possible that the head was dimmer than the tendrils and required averted vision to see.

Deborah alone saw the last sprite, which snapped forth in a bizarre, H shape — with the vertical bars of the H comprised of about three sprite streamers on a side, separated by a horizontal glow midway between them. That glow had some short, faint tendrils extending above and below it. She said it was a remarkable sight and a grand way to end the display.

The profound differences in our visual sightings makes me suspect that what the eye-brain system perceives depends on where the light hits our eyeball (either in the central, color-sensitive fovea or the peripheral, low-light-sensitive retina), as well as the color sensitivity of one's eyes and contrast effects with the color of the background sky. Such simultaneous observations warrant further study, especially on how the eye-brain system works in response to the same stimuli.



A SMORGASBORD OF SPRITES This illustration shows the various sprite displays described in the text: (A) Deborah Carter's silvery needle; (B) Deborah and the author's hedgerow; (C) the author's two "carrots"; (D) Deborah's Olympic torch; (E) the author and Brent Archinal's box jellyfish; (F) Deborah's sparkling tendrils; and (G) Deborah's H.

STEPHEN JAMES O'MEARA

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


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Image: NGC 6891, a bright, asymmetrical planetary nebula in the constellation Delphinus, the Dolphin. (NASA)


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WHITE DWARF WARFARE by Ajay P. Manuel

star wars: The Chandrasekhar–Eddington Clash

How ego, genius, and modern physics combined to help us realize how stars die.

For all its logic and rigor, science remains a human endeavor that oscillates between objectivity and ambition. The trajectory of scientific progress is defined by observations as much as by the egos that interpret them.

One such case occurred in the 1930s, when a brilliant young Indian astronomer, Subrahmanyan Chandrasekhar, found himself at the center of a quiet storm brewing in the halls of the Royal Astronomical Society in London. Across from him stood the revered British astronomer, Sir Arthur Stanley Eddington. Their camaraderie temporarily set aside, the two men found themselves opposed in one of the century's great scientific debates.

It was a confrontation between generations, cultures, and philosophies of science, and at its heart lay a deceptively simple question: What happens when a star dies?

Emergence of a Prodigy

That question had its roots in recent developments in the study of stars. By the turn of the 20th century, telescopes had allowed their handlers to map the world beyond our solar system, capturing everything from the birthing grounds of stars to faint galaxies in the farthest reaches of the universe. Stars were no longer divine lanterns or static candles on the night sky, but physical bodies governed by the very same laws of nature found on Earth. Nevertheless, the mechanisms driving their birth, life, and death remained a mystery.

Then came the *Hertzsprung-Russell diagram* (see facing page). Formulated independently by Danish astronomer Ejnar Hertzsprung in 1911 and American astronomer Henry Norris Russell in 1913, the diagram plotted the relationship between a star's luminosity and its color. Hotter stars appear blue or white, and they are clustered on one end of the diagram, while cooler stars appear yellow, orange, or red and are grouped on the other. This, in turn, allowed astronomers to

▲ **WHEN STARS COLLIDE** During the early 1930s, the brilliant young Indian theorist Subrahmanyan Chandrasekhar (at left) found himself at the center of a very public dispute with Sir Arthur Stanley Eddington, the renowned British expert on stellar interiors. The two men stood opposed in one of the century's great scientific debates, sparked by a simple question: What happens when a star dies?

classify stars by their temperature, enabling the development of models that could infer the stages of a star's life cycle.

The study of stellar evolution had truly arrived. During this era, the prevailing theory of this process was observed primarily through the lens of gravity. Astronomers believed that gravitational forces dictated a star's development, transforming its temperature, density, and brightness over time. The Hertzsprung-Russell diagram characterized this evolution, suggesting that stars transitioned from cooler, less dense states to hotter, denser forms as they aged.

Among the many bright minds eagerly following these developments was a teenage Subrahmanyan Chandrasekhar. Born in 1910, he became the latest addition to a family that represented an emerging intellectual elite in India. His uncle was Chandrasekhara Venkata Raman, who later won the Nobel Prize for Physics in 1930 for his discovery of the scattering of light. It is possible that this heritage weighed on and even inspired Raman's young nephew, who displayed extraordinary mathematical ability. Chandrasekhar threw himself into the academic arena by enrolling at Presidency College in Madras, India, in 1925. The college granted access to a global network of correspondence, and he used it to great effect.

Astronomy wasn't alone in its revolutions. *Quantum mechanics* — the branch of physics that describes the strange behavior of matter and light at atomic and subatomic scales — was in its ascendancy. Albert Einstein's theories of relativity had likewise provoked controversy a decade earlier.

Chandrasekhar eagerly stepped into this maelstrom. Intrigued by the riddle surrounding stellar evolution, he questioned the true endgame of a star's life. His curiosity set him on a journey in 1930 from Madras to Cambridge, England, where he would meet his future opponent: Eddington.

The Keeper of Cosmic Order

A living legend by then, Eddington was among Britain's greatest astronomers and a household name. Here was the man whose eclipse expedition in 1919 had confirmed Einstein's prediction of gravitational deflection of starlight passing the Sun, cementing the reality of relativity in the public imagination. More than a scientist, Eddington was also a philosopher of cosmic order. At the University of Cambridge, he had risen to prominence as the foremost interpreter of the stars and a towering authority in stellar evolution.

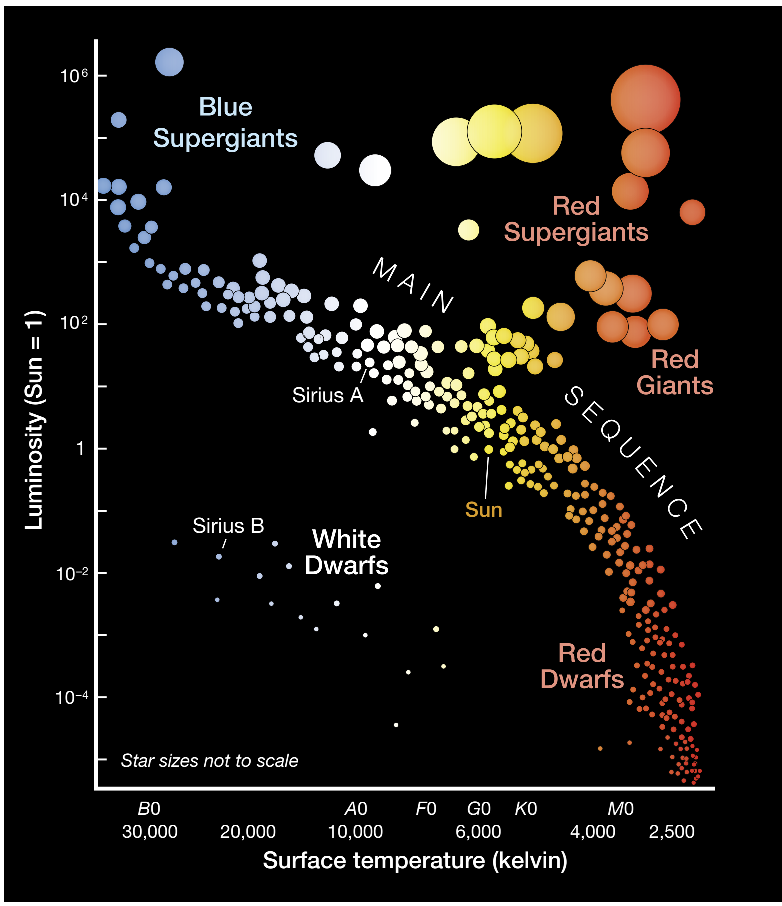
In 1920, Eddington proposed that stars obtain their energy from the fusion of hydrogen into helium. He would follow this with his 1926 book, *The Internal Constitution of the Stars,* in which he described stars as self-regulating thermodynamic systems and raised the possibility that heavier elements could be produced through continuous fusion. With Eddington's theory, a new picture emerged on the nature of stellar evolution, one in which gravity alone — as believed earlier — could not account for the life and luminosity of the stars.

For Eddington, the life of a star was all about maintaining a delicate balance. He described gravity as drawing matter together, tending to form globes of enormous size. Opposing the force of gravity was the outward flow of radiation, which he described "... like a wind rushing outwards and distending the star." This outward pressure counterbalanced the inward pull of gravity.

It seemed that Eddington had figured it all out, but troubling anomalies emerged. Astronomers had observed a distinct class of small, faint stars with very high surface temperatures. These stars, though not particularly luminous, were white in color. The first of these discoveries was Sirius B, the companion to the brightest star in the night sky, Sirius A. Astronomers had determined that, despite being so faint, Sirius B was nearly three times hotter than its more massive companion. Here was a rare combination: a star so hot yet so faint.

Armed with this knowledge and combined with Sirius B's orbital behavior, astronomers deduced that the star was roughly the size of Earth and nearly as massive as the Sun. This was a staggering result: Sirius B was an object that seemed to compress matter to an unimaginable density and defied the conventional understanding of how stars sup-

▼ **LIGHT AND HEAT** The Hertzsprung-Russell diagram is a scatter plot showing the relationship between the luminosities and temperatures (related to color) for all types of stars. (When this relationship was first published graphically in 1914, the x-axis plotted spectral class rather than temperature.) A newly formed star, whether a dwarf or massive, begins its life along the main sequence, then moves to other groupings as it ages and evolves.



ported themselves. Worse, there were more than just one of these "white dwarfs." This confounded Eddington. His equations (based on classical physics) couldn't explain how such dense objects resisted further collapse.

Thankfully, 1926 also saw the advent of quantum mechanics and the concept of *electron degeneracy pressure* — that is, electrons' distaste for sharing the same space. This counterforce to gravity's inward pull arises not from fusion's energy but from the quantum-mechanical nature of electrons themselves. Ralph H. Fowler, a physicist and colleague of Eddington at Cambridge, applied this knowledge to white dwarfs, stating that even when these stars had exhausted their nuclear fuel and cooled, the degeneracy pressure of electrons kept the crushing force of gravity at bay.

For the first time, astronomers had built a bridge between quantum physics and stellar structure. Fowler's extrapolation of quantum mechanics meant that a star of any mass would retire peacefully as a white dwarf in its final stage until all its energy was radiated into space. For Eddington, this was a fitting conclusion to a troublesome matter and wholly in line with his belief that stars acted as long-lived engines of harmony and stability.

Unfortunately, he would soon meet the young man from India who had arrived at a very different conclusion, ultimately tipping the balance of his worldview.

The Limits of Stability

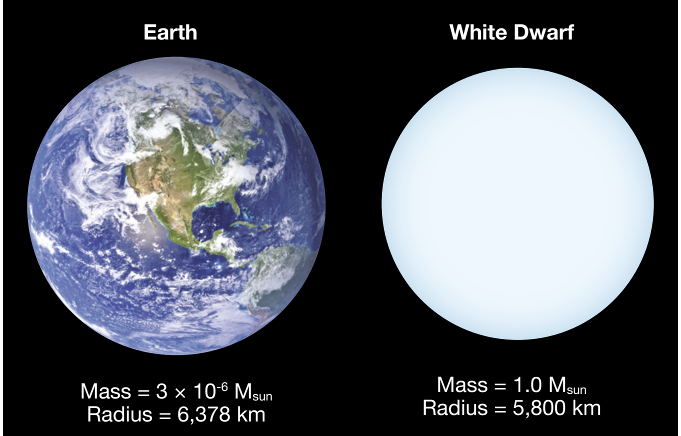
Chandrasekhar's voyage to Cambridge would take two weeks. There, aboard the steamship *SS Pilsna,* the endless expanse of water and passage of time were the onboard entertainment. But Chandrasekhar embraced the isolation, for traveling with him were Fowler's recent papers on incorporating electron degeneracy pressure to resolve the mystery of white dwarfs.

During the long days at sea, he diligently pored over this new approach. He recognized Fowler's triumph in calculating a relation between the density and the mass of a white dwarf, a result that agreed with the scant observations available at that time. But a subtle omission caught Chandrasekhar's notice: Fowler's calculations were based on Newtonian mechanics and did not account for the effects of Einstein's theory of relativity. This opened another avenue of inspection into the nature of stellar death.

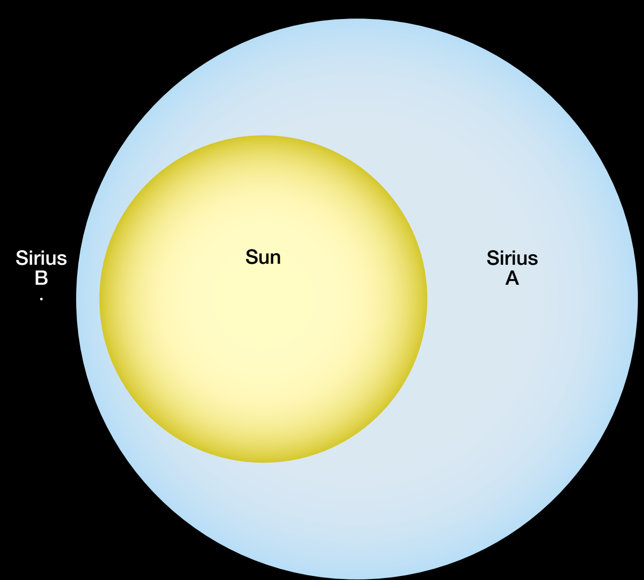
Fowler had concluded that every finite-mass star has a finite radius, with a density proportional to the square of its mass. This meant that the more massive a star was, the more tightly compressed it became, and, by extension, more massive white dwarfs would compress to smaller sizes and therefore be fainter. For Chandrasekhar, this line of thought corresponded with the fact that astronomers had not observed white dwarfs much more massive than the Sun. For if such stars did exist, their extreme compactness and low luminosity would have made them exceedingly difficult to detect with the telescopes of the time.

At the same time, this logic begged a relativistic question: If the cores of the most massive white dwarfs were so dense, wouldn't the electrons moving within these cores reach speeds comparable to the speed of light, if not greater? The 19-year-old student had stumbled onto something that would truly challenge the very foundations of stellar physics.

As the *Pilsna* powered toward England, Chandrasekhar redid Fowler's calculations while accounting for relativistic effects. What he discovered was startling: There was a limit to how dense a star's core could become. White dwarf matter became more compressible as mass increased. As a result, increasing density outpaced growth in mass — in fact, density approached infinity even as the mass reached a finite value.



▲ **NO COMPARISON** A typical white dwarf is an extremely dense object — essentially the hot, dense core of a dead star — that compresses roughly the mass of the Sun into a sphere no larger than Earth.



▲ **THE DOG STAR** Sirius A in Canis Major is the brightest star in the night sky. Its companion, Sirius B, is a white dwarf that's almost exactly the Sun's mass, slightly smaller than Earth in size, and has a surface temperature of 25,000 kelvin (45,000° F).

BEATRIZ INGLESSIS / *SKY & TELESCOPE* (2)

Chandrasekhar knew what this meant: A critical mass threshold determined the end state of stars.

By the time he disembarked in England, Chandrasekhar had derived the maximum mass a white dwarf could have before collapsing under its own gravity. His initial estimate for this maximum was 0.91 times the Sun's mass. (This result used the atomic constants and mean molecular weights of stellar material accepted at the time; following a revision of the latter values, Chandrasekhar's estimate became 1.44 solar masses.)

Electron degeneracy pressure could indeed counterbalance the force of gravity, but only for white dwarf masses below this limit. For anything greater, no known force could prevent a star from imploding. Its fate would be to collapse into something denser and darker than science had yet imagined.

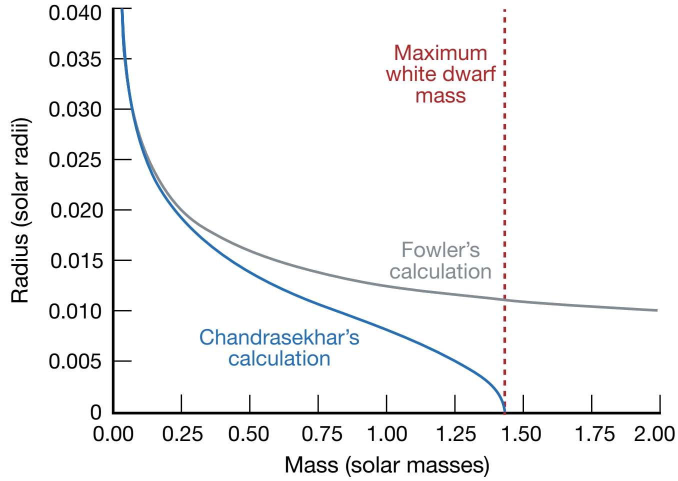
All that Chandrasekhar had to do now was convince the great minds at Cambridge of the same.

Differences of Opinion

Cambridge in the early 1930s was a world capital of theoretical physics. Fowler took Chandrasekhar under his wing and soon delved into the young man's results. To the new arrival's surprise, Fowler was unconvinced, ultimately growing so skeptical that he refused to sponsor Chandrasekhar's work for publication by the Royal Astronomical Society in London. Despite this unwillingness, Chandrasekhar remained resolute that his conclusions were valid. He pushed ahead and, in 1931, published "The Maximum Mass of Ideal White Dwarfs" — without Fowler's approval — in the American *Astrophysical Journal.*

Contrary to Chandrasekhar's expectation, his paper received almost no response from the scientific community. Very few seemed interested in his work, and gradually, he felt the weight of isolation in the academic climate at Cambridge.

But there was a silver lining in all this. Through Fowler,



▲ **STABILITY'S LIMIT** Fowler's calculations (gray line) showed that the radius of a star only reaches zero for an infinite mass, but Chandrasekhar discovered that stars above a certain mass lose their fight against gravity (blue line) and collapse in on themselves.

Chandrasekhar also met Eddington, who admired the young Indian's intellect. During the three years it took to obtain his PhD, Chandrasekhar met frequently with Eddington — they would often meet in Chandrasekhar's room in Trinity College to discuss his research. Over this period, the work of Cambridge's newest prodigy took on greater significance as a debate simmered between Eddington and another prominent British astrophysicist, Edward Arthur Milne. The two were at odds over the nature of stellar interiors.

Milne proposed modifications to Eddington's favored model, which held that the interiors of stars remained stable and continuous entities that did not experience abrupt transitions between the classical gas and quantum-mechanical

HALLOWED HALLS The University of Cambridge in England — actually a cluster of colleges (Trinity College is shown here) — was the nexus of theoretical physics during the 1930s.

degenerate states. Milne argued otherwise, that to account for certain observed features, such as the surface temperature and density of stellar matter, stars should have a central core of degenerate material surrounded by nondegenerate gas.

Chandrasekhar immensely admired both Eddington and Milne. He saw the issue as a purely scientific disagreement and decided to solve the problem. Chandrasekhar's relativistic corrections to Fowler's degeneracy model directly touched on the debate between Eddington and Milne. His calculations showed that electron degeneracy pressure could only support a star up to a certain mass. Above this limit, degeneracy pressure alone could not balance gravity. Instead, the inclusion of relativistic corrections demonstrated that the entire core of such stars would not become *purely* degenerate, contradicting Milne's proposition that all stars might have degenerate cores.

Eddington was pleased with this result, but Chandrasekhar's earlier deductions on the existence of the critical mass also meant that the white dwarf stage was not the finale for a high-mass star. This was not a favorable outcome for Eddington. The seeds of conflict between student and mentor were now set in motion.

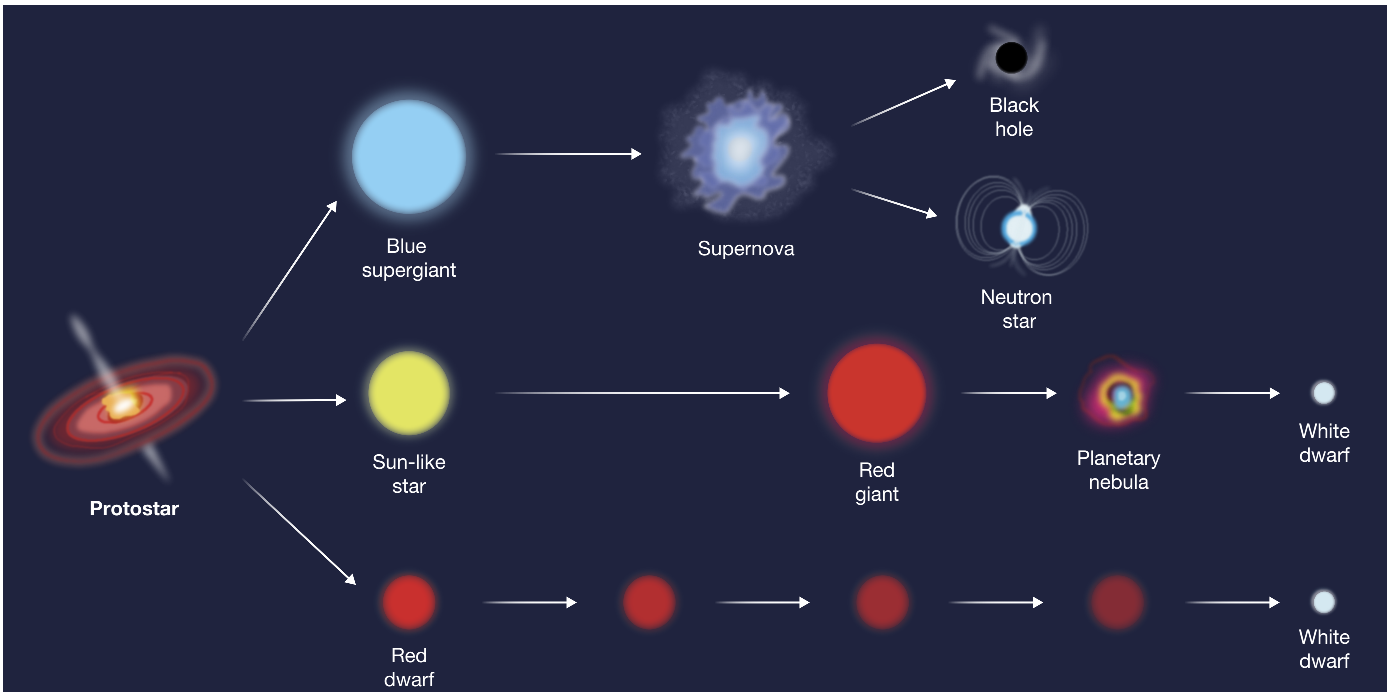
Science and the Shadow of Ego

By 1934, Chandrasekhar had become well known within the Royal Astronomical Society. He felt his take on the Milne-Eddington conflict was mathematically inescapable. Eddington, who regularly visited Chandrasekhar during this period, presented himself as trying to understand the young scholar's work and its resolution of the debate on stellar interiors.

Personally, though, Eddington was unhappy. Chandrasekhar's conclusions had shattered his belief in the eternal stability of stars. Previously, the question of what happens when stars die did not trouble Eddington, for he believed that they were not destined for catastrophic collapse. Now, his mentee had demonstrated that, at the end of their lives, stars would collapse into something Eddington found to be philosophically and aesthetically unthinkable: an object of infinite density. Thus, Eddington resisted.

On January 11, 1935, Chandrasekhar presented his paper, "The Highly Collapsed Configurations of Stellar Masses" at a Royal Astronomical Society meeting in London. Fowler chaired the session, and Eddington sat in the audience. Chandrasekhar read his findings, describing the limit that dictated the death of white dwarfs with masses greater than 1.44 times that of the Sun. Looking at his audience, Chandrasekhar felt euphoric, even relieved. His work was finally getting the recognition it deserved. But what happened next became legend.

As Chandrasekhar retired from the stage, Eddington rose to speak, not to commend but to condemn. Chandrasekhar knew that Eddington was scheduled to deliver his own remarks on degeneracy pressure but was caught entirely unaware when his mentor used the opportunity to discredit his work. Eddington expressed, in a tone both patronizing and dismissive, his disagreement and displeasure with Chandrasekhar's conclusion. "I think there should be a law of Nature to prevent a star from behaving in this absurd way," he countered. "The formula is based on a combina-



A STAR'S LIFE Astronomers now realize that the final state of a star depends on its initial mass. Stars like the Sun will become white dwarfs, while more massive stars will end their lives as neutron stars or black holes. Dwarf stars, those less massive than the Sun, can last for 100 billion years or more.

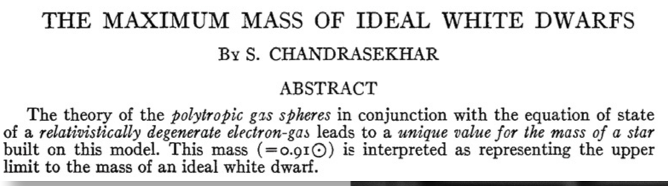
BEATRIZ INGLESSIS / *SKY & TELESCOPE*

tion of relativity mechanics and non-relativity quantum theory, and I do not regard the offspring of such a union as born in lawful wedlock."

The room fell silent. Chandrasekhar sat dumbfounded and humiliated. Afterward, the young theorist was comforted by his peers, saying, "It was too bad, too bad," but their reassurance made the matter more painful. Eddington had publicly dismantled years of labor — not on grounds of bad physics but on philosophical discomfort. Few dared to contradict Eddington, such was his authority and stature.

The 1935 meeting demonstrated that, even in science, reason could be subverted by emotion. Annoyed that Eddington hadn't expressed his feelings on the matter earlier, Chandrasekhar was equally confused as to why his mentor had encouraged him to pursue his work in the first place. Was this essentially a setup by Eddington so that he could discredit him in public? These thoughts ran through Chandrasekhar's mind, but he ultimately resolved to fight the good fight. A direct, observational test that could prove his reasoning did not exist at that time, so he focused on the physics at its heart.

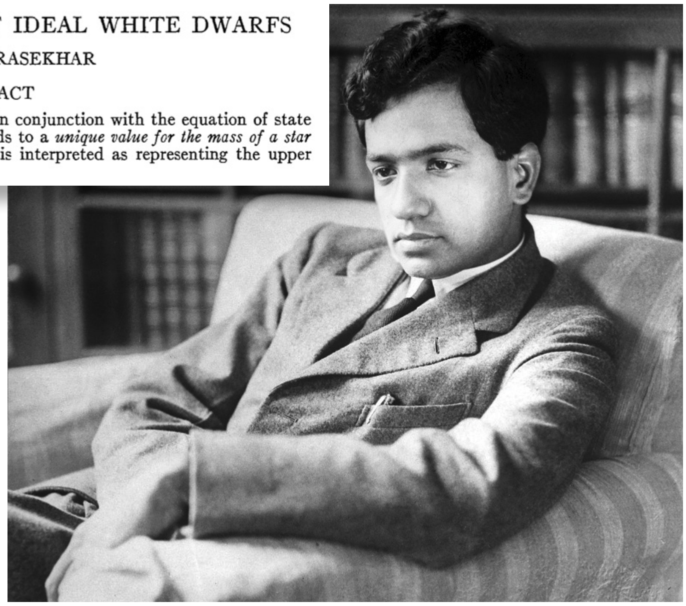
Chandrasekhar reached out to luminaries, including the legendary physicists Leon Rosenfeld, Niels Bohr, and Wolfgang Pauli. These three men had each made fundamental, interconnected contributions to the development of quantum mechanics and the new wave of modern physics of that era. All three agreed with Chandrasekhar's conclusions and stated that there was no ambiguity in his results. These private remarks were reassuring but did little to change the status quo. Further discussions with Eddington only led to a dead end.


THE MAXIMUM MASS OF IDEAL WHITE DWARFS

By S. CHANDRASEKHAR

ABSTRACT

The theory of the *polytropic gas spheres* in conjunction with the equation of state of a *relativistically degenerate electron-gas* leads to a *unique value for the mass of a star* built on this model. This mass ($=0.91\odot$) is interpreted as representing the upper limit to the mass of an ideal white dwarf.



▲ **SEMINAL WORK** The title page of Chandrasekhar's game-changing 1931 treatise, which described how relativistic effects in the degenerate cores of white dwarf stars defined an upper limit for their mass. Not long after completing his PhD in England, Chandrasekhar was wooed by both Harvard and Yerkes observatories. He chose the latter, spending virtually his entire career (from 1936 until his death in 1995) at Yerkes and the University of Chicago.

TITLE PAGE OF ARTICLE: *ASTROPHYSICAL JOURNAL*; CHANDRASEKHAR: HANNA HOLBORN GRAY SPECIAL COLLECTIONS RESEARCH CENTER, UNIVERSITY OF CHICAGO LIBRARY

From Opposition to Legacy

After their very public clash, the careers of Chandrasekhar and Eddington diverged dramatically. The latter continued to fervently explore cosmology, gravitation, and the philosophical underpinnings of relativity. He also continued his attacks on Chandrasekhar at subsequent conferences and meetings.

For the brilliant Indian theorist, England and Cambridge were a shattering experience. In the nearly two decades that followed, the Chandrasekhar limit would not be spoken of. Even the once-supportive Fowler distanced himself from the controversy. Disillusioned and depressed, Chandrasekhar redirected his attention toward other areas of research. The young visionary who had glimpsed the death of stars turned away from them altogether.

Over time, however, the scientific community gradually recognized and appreciated the very real implications of Chandrasekhar's work. His efforts drew support from the emerging fields of radio astronomy and nuclear astrophysics, alongside the work of prominent physicists such as Robert Oppenheimer and Fritz Zwicky, who explained that massive stars beyond the Chandrasekhar limit must collapse into neutron stars or black holes.

These validations grew even stronger when the first confirmed neutron star and black hole were identified in 1967 and 1971, respectively. Nearly 50 years after his momentous presentation, Chandrasekhar would be awarded the Nobel Prize in 1983 for his work on stellar structure and evolution.

Ultimately, Eddington's rigid philosophical stance delayed acceptance of the most profound concept in modern astrophysics for many years. By the time observers found the first evidence of neutron stars and black holes, Eddington had passed away. Chandrasekhar's limit became the cornerstone of stellar-evolution theory and shed light on how stars die.

The very public dispute between Chandrasekhar and Eddington revealed something essential: Even the purest pursuit of knowledge is shaped by the interpretations of its seekers. Eddington erred in his unwillingness to let go of an old vision of the universe. Chandrasekhar triumphed in his loyalty to reason over reverence and became a symbol of perseverance. His efforts and contributions to astronomy and physics now serve as a reminder that truth in science often waits patiently for recognition.

Today, Chandrasekhar's humble persistence forms a major legacy of modern astrophysics — while the stars, impartial as ever, bear silent witness to his long journey from Madras to the cosmos.

■ With an enduring passion for stories of the cosmos, **AJAY P. MANUEL** has become a science writer, aspiring author, and comic-book artist. "Dreams are like passing clouds," he muses. "They are never set in stone."

A Tour of Short-Period Binary Stars

Here's a selection of close binaries for backyard telescopes.

Double stars are often considered a consolation for the backyard observer, something to pass the time while waiting for the next new Moon outing to a dark-sky site. But not for me. I'm amazed to see two stars through the telescope, whereas my finderscope or a low-power eyepiece shows only one. And I'm impressed with their variety of colors, difference in magnitudes, and tightness of separations. Some of them — the *binary stars* — have components that orbit each other, and for an even fewer number, their orbital positions are predicted to change in a timespan short enough that we can actually observe that movement.

When I started my astronomy journey in my mid-40s, I bought an amateur-made 12.5-inch f/7 Dobsonian, which I would wheel into my backyard each clear night. My first observation was a shadow transit of Jupiter's moon Io — and being able to observe change in the supposedly changeless sky captivated me. I spent many nights admiring a variety of targets in the eyepiece, from open clusters to galaxies and nebulae. And then, I discovered binary stars. And I became fixated with observing them.

I bought an equatorial platform to help keep objects in the field of view longer while using high magnification. Next, I built a roll-away shed so I wouldn't have to wheel the telescope from the garage each session. I pursued ever more

▶ **PHYSICAL DOUBLE IN URSA MAJOR** This view of the iconic Big Dipper asterism shows the short-period binary star HU 628, also designated Iota (ι) Ursae Majoris, setting over the Great Sand Hills of Saskatchewan, Canada. (See the finder chart on page 23.) Unlike optical double stars, which are random alignments in the sky, binary pairs are gravitationally bound in orbit around each other.

ALAN DYER

My Favorite Close Binaries

Object	RA	Dec.	Mag (A, B)	Spec (A)	Sep	PA	P (yrs)	Distance (l-y)
STF 3121 A, B	09^h 17.9^m	+28° 34′	7.9, 8.0	*K*0	0.2″	305°	34.2	56.3
HU 874 A, B	10^h 11.6^m	+13° 21′	6.9, 7.9	*F*6	0.1″	282°	18.0	210.7
HU 628 B, C	8^h 59.2^m	+48° 03′	9.9 (B), 10.1 (C)	*M*1	0.8″	192°	39.4	47.3
HU 575 A, B	14^h 42.6^m	+19° 29′	9.8, 10.1	*M*0	0.5″	20°	51.7	70.4
BU 648 A, B	18^h 57.0^m	+32° 54′	5.3, 8.0	*G*0	0.9″	212°	61.2	48.5
STF 2272 A, B	18^h 05.5^m	+02° 30′	4.2, 6.2	*K*0	6.7″	117°	88.4	16.6

Position angles and separations are calculated for January 2026. Right ascension and declination are for equinox 2000.0. Magnitudes are visual.


HU 628 (Iota Ursae Majoris)

obscure and challenging binary pairs that were not plotted in star atlases, printing several ream's worth of supplemental finder charts.

As I soon found out, binary stars with short orbital periods often have less than 0.5″ separation. If I were to trace any movement in these close pairs, then I would need greater optical resolution. I decided to replace the 12.5-inch in the shed with the 20-inch f/5 Dob that I had been using for my monthly new-Moon outings. I installed tracking motors on the scope, so now I could select a target from planetarium software and slew to it rather than print out endless charts for star-hopping. I did all these so as to sketch binary pair orbits and eventually witness an actual change in the components.

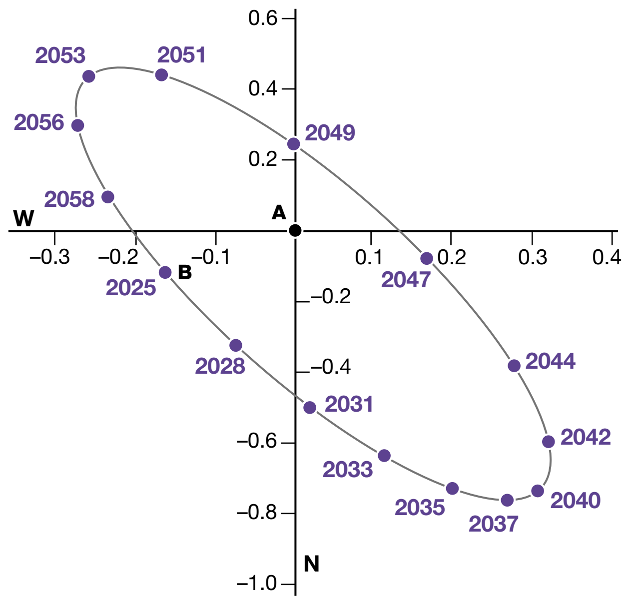
Readers may already be familiar with the short-period pairs Sirius B or Porrima, also known as Gamma (γ) Virginis. Here, I'm going to share my favorite selection of other short-period binaries that amateurs can access with backyard telescopes. I've selected targets for this project from the *Sixth Catalog of Orbits of Visual Binary Stars* (**https://is.gd/wds_orb6**), maintained by the U.S. Naval Observatory in Washington, DC. I specifically chose pairs with a minimum separation of 0.2″. This is just below the Dawes limit for my 20-inch scope's maximum resolving power (the Dawes limit is determined by dividing 4.56 by the aperture in inches). I whittled the list further by selecting targets accessible only from my observing latitude of 37° north and limiting the binaries' orbital period to no more than 120 years — longer than a human lifetime but enough range to capture pairs that have highly eccentric orbits, with relatively wide *apastron* (farthest distance between components) and close *periastron* (nearest distance).

In addition, I chose pairs whose orbits are graded in the *Sixth Catalog* as either 1 or 2 (with 1 being definitive and 9 being indeterminate), so there's more certainty in future predictions of the orbital paths. Some of the stars I've selected are visible in small apertures, from about 6 to 10 inches, while others will require apertures 12 inches and up. Double-star observing is all about seeing and contrast, so make sure you tackle these targets under pristine conditions.

Let's start our tour.

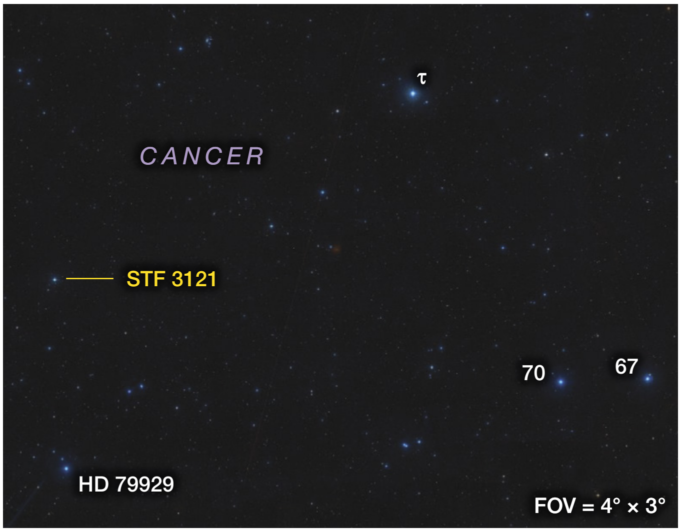
▲ **BINARY ORBIT DIAGRAMS** These illustrations of apparent orbits depict the secondary component (B) revolving around a fixed primary (A). The X and Y axes represent the components' separation in arcseconds. The plots are adapted from Stelle Doppie – Double Star Database (**www.stelledoppie.it**). North is down and west to the left in all orbit diagrams.

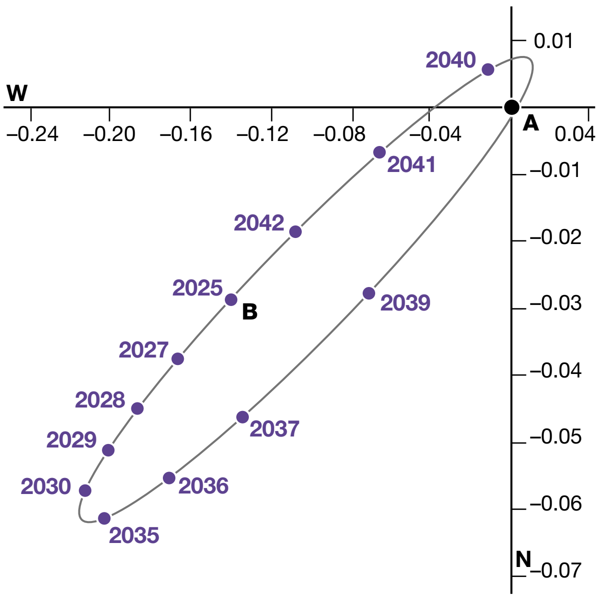
▶ **HOME IN ON THE BINARIES** Use the following images from the STScI Digitized Sky Survey to help guide you to the exact locations of the objects featured in this article. North is up in all finder images.



STF 3121 A, B

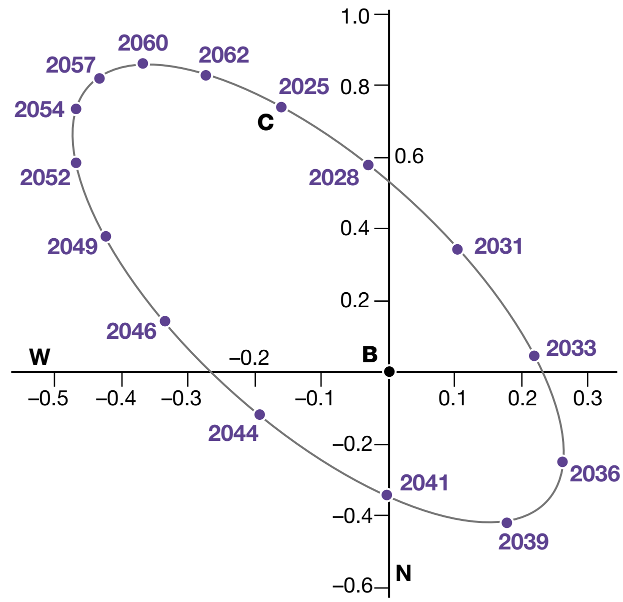
This pair, which had a 0.9″ separation when Wilhelm Struve discovered it in 1832 with the 9-inch Dorpat refractor in Estonia, is currently within the reach of an 8-inch telescope. The primary component (A), also designated as the variable star IP Cancri, is of spectral type *K*0, with a magnitude range too shallow to affect observations of the secondary (B). The pair has a 34.2-year period and a grade-1 orbit. I observed it in May 2021 with my 20-inch at 530× when the binary's separation was 0.4″ and noted the two light-yellow-orange stars clean and well split, with practically no difference in brightness. The pair's *position angle*, or PA, given in degrees, refers to the orientation of B relative to A and is measured eastward from north. Observers can follow STF 3121 as it widens to apastron in 2038, with its PA oriented to the northeast.





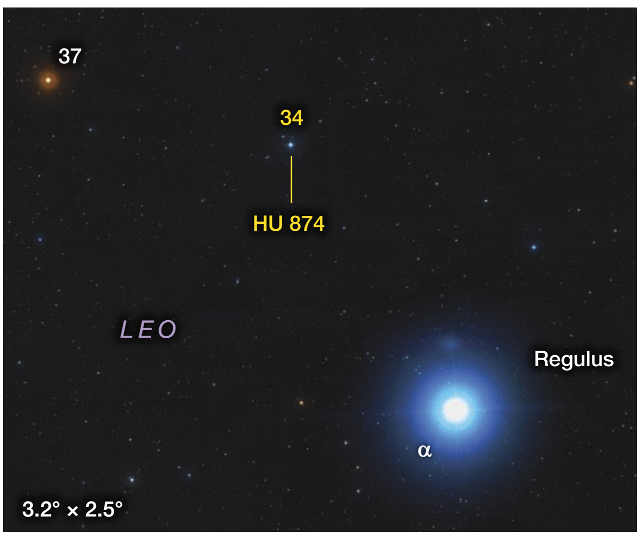
HU 874 A, B

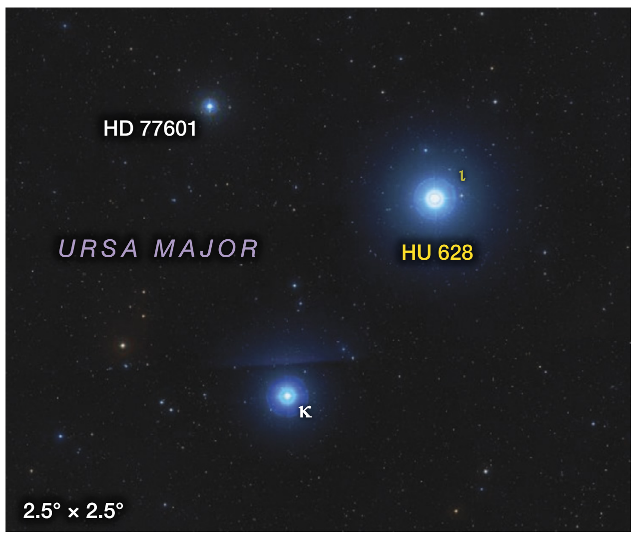
Also designated 34 Leonis, HU 874 lies about 1½° north-northeast of 1.4-magnitude Regulus, Alpha (α) Leonis. HU 874 has an 18.0-year period and presents in the eyepiece as nearly edge-on. When I observed it in May 2021, it was about halfway from periastron and I needed 1,067× magnification to get at best a notched elongation of the unequally bright stars, though it was difficult to tell which was the primary. Since then, the separation has steadily increased, and by 2033 it will approach apastron at 0.23″, perhaps just enough to get a hairline split in the telescope.



HU 628 B, C

This binary is a part of the triple star system HJ 2477, also called Talitha, Iota (ι) Ursae Majoris, at the forefeet of the Great Bear. It consists of a nearly equal pair of 9.9- and 10.1-magnitude stars. American astronomer William Hussey discovered it in 1903 using the Lick Observatory's 36-inch refractor, when its separation was a generous 0.9″. Currently at 0.8″, the secondary is coming off apastron and will make a quarter turn in position angle from south to east by around 2034, tightening to 0.2″ along the way. It will continue to be a very tight pair until after 2045, when observers will find its PA oriented to the west and starts heading toward apastron around 2057.

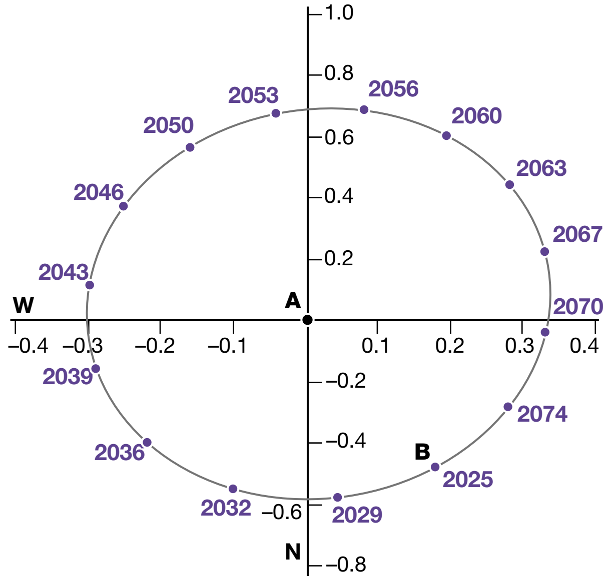


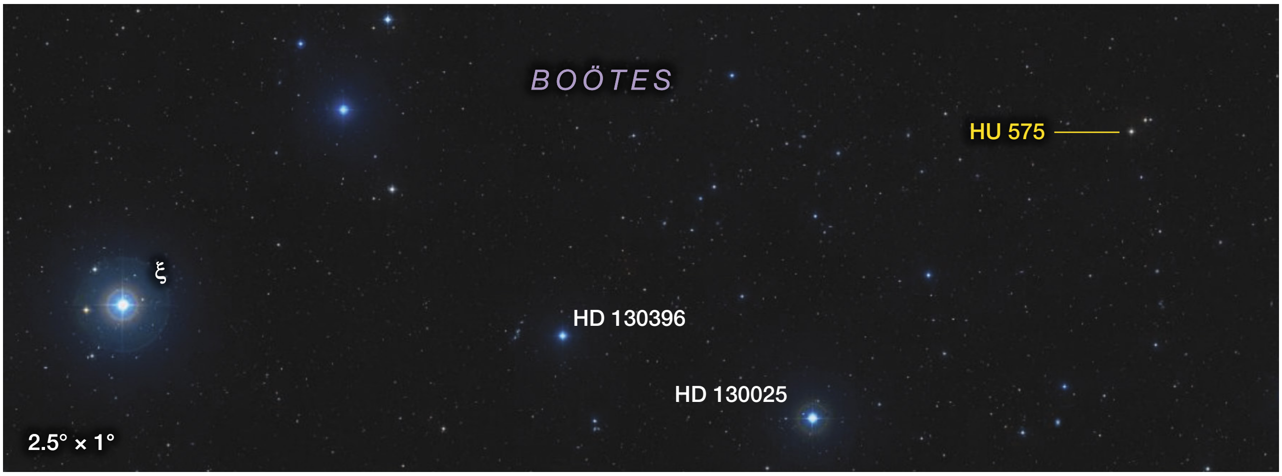


FINDER CHARTS THROUGHOUT THE ARTICLE: POSS-II /STSCI / CALTECH / PALOMAR OBSERVATORY (6); ORBIT DIAGRAMS: S&T ILLUSTRATION BY LEAH TISCIONE (6), BASED ON DATA FROM STELLE DOPPIE (WWW.STELLEDOPPIE.IT)

HU 575 A, B

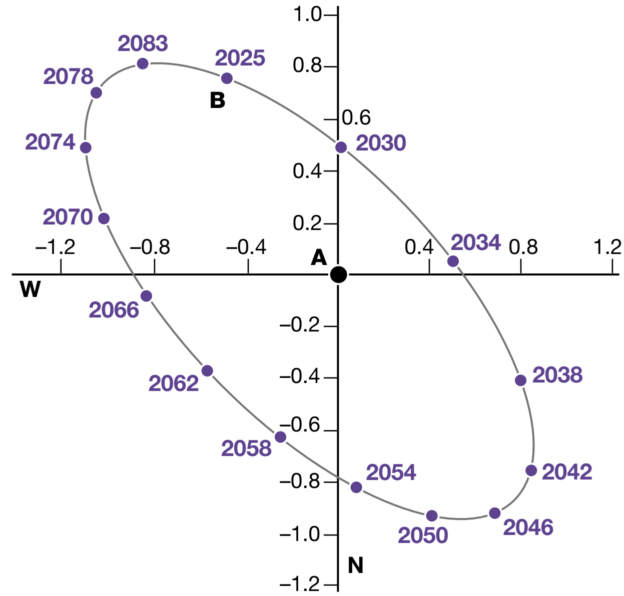
This pair, located 2° west-northwest of Xi (ξ) Boötis, is challenging but rewarding to follow. It has an out-of-round, grade-2 orbit with a 51.7-year period and is currently at 0.5″ separation angled to the northeast. By 2030, splitting the binary will be a bit easier, when the separation will be 0.6″ and the stars will be aligned due north. By 2042, the separation will be 0.3″ with the PA nearly due west, and then the pair starts turning to the south. I observed HU 575 in April 2020, when A and B were only about 0.34″ apart. At 1,067×, I gave it a rating of two exclamation points and noted the "small, faint, but definite split of these orange-red, nearly-equal-brightness stars."





BU 648 A, B

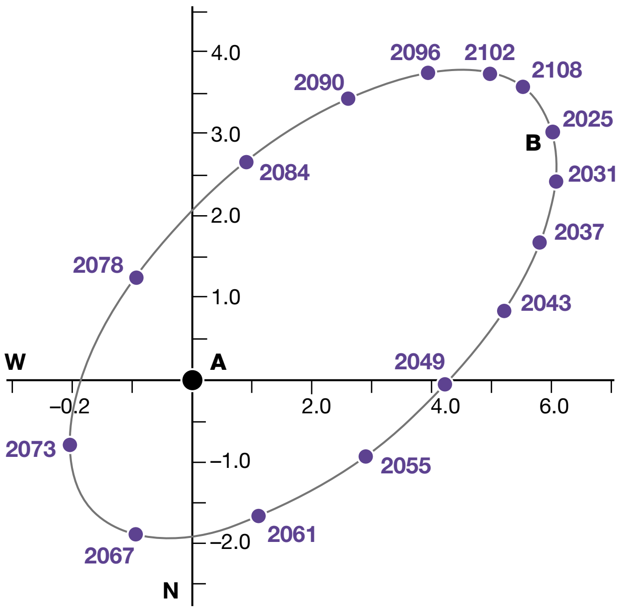
Also designated HD 176051, BU 648 lies roughly a third of the way from Gamma (γ) Lyrae to M57, the Ring Nebula. A 6-inch aperture can split this binary now, but within the next five years its separation will get tighter so you'll need larger aperture to resolve the pair. With a 61.2-year period, BU 648's A and B are now separated by 0.9″ and can be easily split despite their 2.7-magnitude difference in brightness. By 2035, the stars will close in to around 0.6″, and B will swing from its current south-southwest PA to nearly due east. By 2045, the pair will be separated by 1.2″ with the PA turning to the northeast. Challenge yourself and start observing it now so you can follow B's movement through the years.

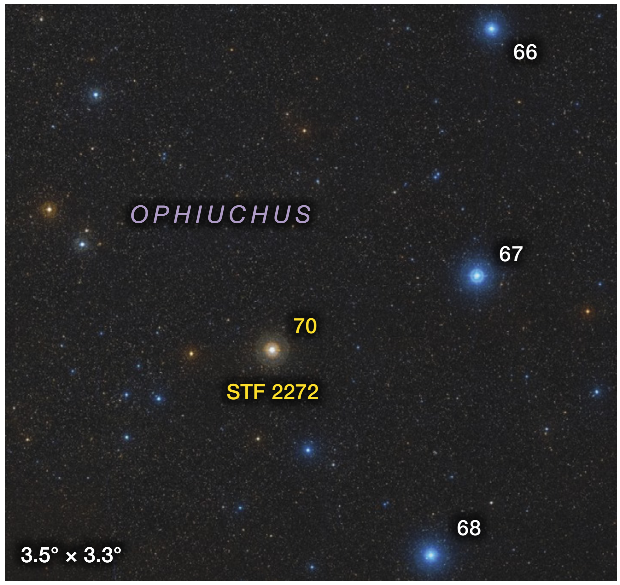


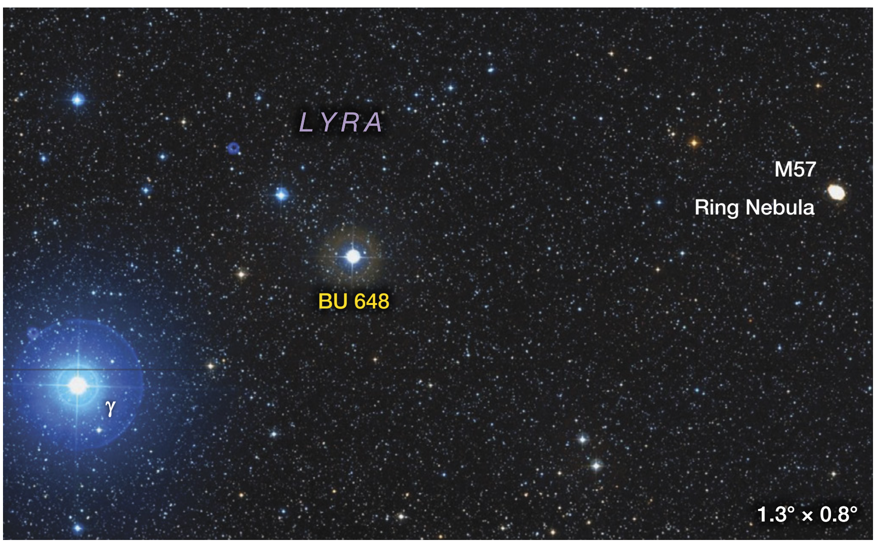
STF 2272 A, B

Also known as 70 Ophiuchi, STF 2272 is situated about 5½° east-southeast of Beta (β) Ophiuchi. The pair has a beautiful, cream-white primary and a light-orange secondary with a brightness difference of 2 magnitudes between them. It's an easy pair with a generous 6.7″ separation, making it accessible to a variety of apertures. As the system is only 16.6 light-years away, it presents a wide separation in the eyepiece. The binary has an 88.4-year period and is currently coming off its apastron, with the PA angled to the southeast. This will tighten to 4.3″ by 2049, with the PA oriented due east.

This is probably the easiest short-period binary one can find, and an excellent double star to show during a public outreach event. Because 70 Ophiuchi truly is gravitationally bound, younger people can potentially be inspired to follow its orbit throughout their lifetimes.







Bear in mind that when observing short-period binaries, you don't expect to see the component stars to be moving in real time! The fastest binary pair discussed here still takes 18 years to complete its orbit. Nevertheless, the components' relative positions change enough over a few years for a telescope observer to confirm orbital motion. It's a rewarding visual experience. Happy touring!

MARK MCCARTHY lives and works in the San Francisco Bay Area, where he tries to make the most of the bright skies. You can follow his observations at **https://is.gd/Mark_McCarthy_observing_blog**.

FURTHER READING: For more binary pairs for backyard telescopes, see the May 2019 issue, page 22.

 by Ron Brecher

Selective Processing in *PixInsight*

Here's how to modify areas of an astrophoto without affecting the entire picture.

Most people have first-hand experience with masks. Whether it's for a costume party, a doctor's visit, protecting an edge while painting a wall, or using a stencil, we all use masks in everyday life. Many amateur astronomers are familiar with aperture masks that block off part of the light entering a telescope, often to stop down its objective so as to sharpen the view in unsteady conditions. Regardless of the application, all masks have one thing in common — they conceal (or protect) some parts of an object while revealing others.

Masks also play an important role in astrophotography, allowing some image elements to be preserved while others are adjusted. For example, you could make a mask to allow

▲ **TARGETED ENHANCEMENTS** Many different masks were used to process this image of the spiral galaxy NGC 7331 in Pegasus last year during the peak visibility of supernova SN 2025rbs, seen to the upper right of the galaxy's core. The masks were used to isolate features based on brightness, hue, degree of saturation, and more.

ALL IMAGES ARE COURTESY OF THE AUTHOR

you to work selectively on the stars' colors, brightnesses, sizes, or shapes, while preserving other elements like galaxies and nebulae. They're also useful for selective sharpening of areas or shielding brighter parts of deep-sky objects from noise reduction that's needed elsewhere in a picture.

Let's look at some of the various mask-making tools available for image processing and how to use them to enhance your own astrophotos. I use the software *PixInsight* (**pixinsight.com**) for deep-sky image processing, though the same principles apply for other image-processing software packages, such as *Adobe Photoshop* (*S&T:* May 2010, p. 72).

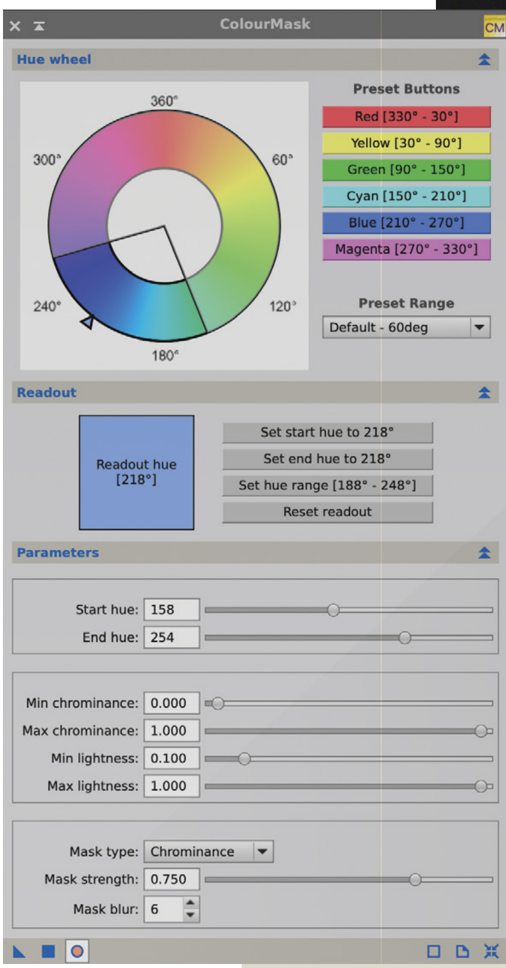
Masking Basics

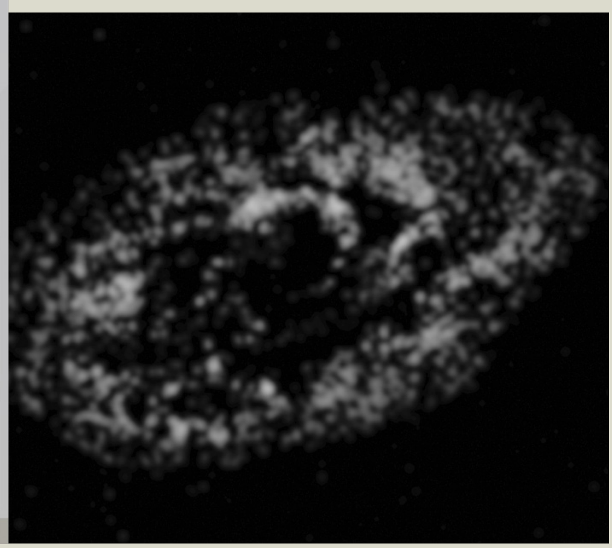
I like to think of the mask-making process as if I were stenciling a label on a box. First, I'd make the stencil from a piece of chipboard by cutting holes for the letters where I want the paint to go through. Then, I'd affix the stencil on to the box and spray paint onto the areas of the box exposed by the stencil. After removing the stencil from the box, I'd keep it in case I have other similar uses for it in the future. The same steps are involved in using masks during deep-sky image processing.

In *PixInsight*, masks are usually created from stretched, grayscale versions of the photos they are intended to modify (typically performed in the software with the ***HistogramTransformation*** found in the pulldown menu at ***PROCESS > IntensityTransformations)***. The mask then needs to be open in the program (in a window called a *view*) simultaneously as the image it's intended to modify. For a mask to work on a target picture, it needs to be the same pixel dimensions as the working image. A simple rule to keep in mind when making a mask is that the areas in black protect the region of an image it covers, while areas in white will be affected by any adjustments applied to the image. With both the mask and working photo open, select the target image view by left-clicking on it, and then you can apply any process intended for the region of interest. Once a mask is in place in the targeted picture, the protected areas will appear red in its view.

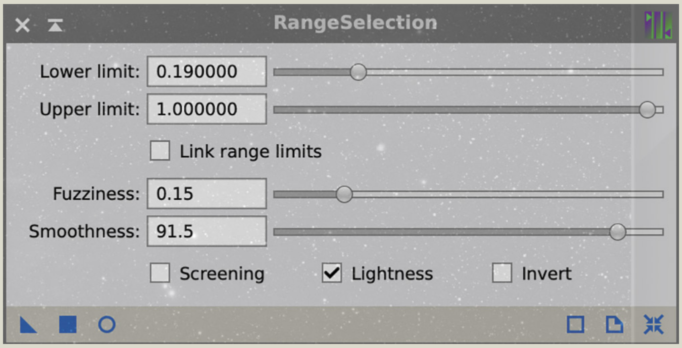
There are several mask-making tools included in the standard release of *PixInsight*. My favorites are ***ColourMask***, ***RangeSelection***, and ***StarMask*** found in the pulldown menu ***PROCESS > MaskGeneration***.

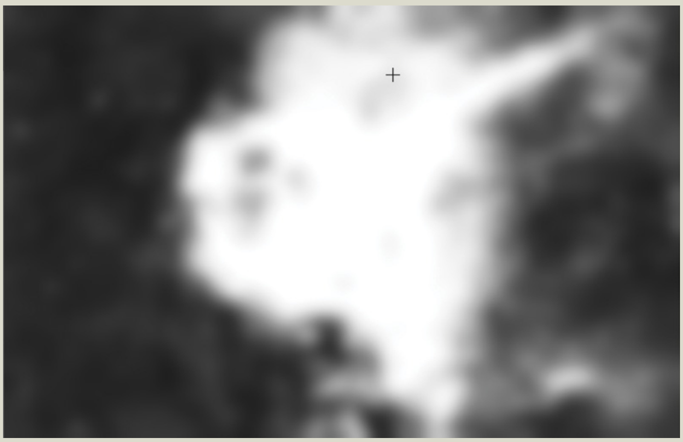
ColourMask lets you make masks based on a specific range of hues. It also has a ***Real-Time Preview*** button (the open circle at lower left of the process window) that lets you see changes in the mask immediately as you adjust the process settings. I often start by choosing the desired color range using the ***Readout*** settings. Then I'll change the ***Mask type***, ***Mask strength***, and ***Mask blur*** settings to generate one that best suits my intentions.



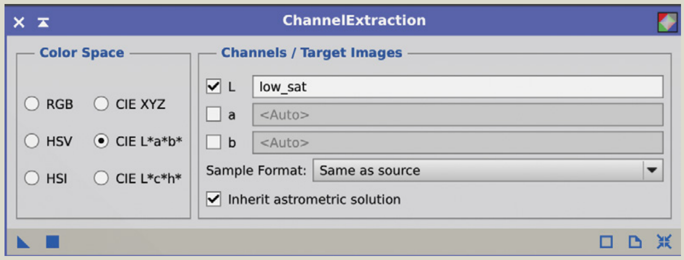


▶ **HUE SELECTION** The ***ColourMask*** process allows you to select a range of colors to generate a mask that targets particular hues for special processing. In this example, the bluish spiral arms of M33, the Triangulum Galaxy, are selected, producing the mask seen at lower right.





▲ **BLACK AND WHITE** ***RangeSelection*** makes it easy to prepare smooth masks with just a few controls. Adjust the ***Lower limit*** and ***Upper limit*** sliders, in which Black is 0 and White is 1. Then increase the ***Smoothness*** of the mask with the ***Fuzziness*** slider. Click the circular ***Real-Time Preview*** at lower left in the window to see how adjustments affect the appearance of the mask.



▲ **CHANNEL AS MASK** This example shows the ***ChannelExtraction*** process employed to create a lightness mask. Simply open the process, select ***CIE L*a*b**** in the ***Color Space*** area, then uncheck the ***a*** and ***b*** boxes before dragging the caret at the bottom-left corner onto the target view. The resulting grayscale image is then available for use as a mask.

RangeSelection creates masks based on the brightness of different parts of an image selected using the ***Lower limit*** and ***Upper limit*** sliders. I often use the ***Smoothness*** slider to average the edges of the selection, and the ***Fuzziness*** slider also provides a smooth transition in the mask where dark and light areas meet. These range masks are helpful for isolating the brighter parts of an image to work on while protecting darker regions, with the specific selections controlled by the tool's settings. This process also has a helpful ***Real-Time Preview*** function at lower left in the process window. I suggest experimenting with the ***Screening***, ***Lightness***, and ***Invert*** check boxes, and once you've dialed in a mask appearance that you like, close the Real-Time Preview and apply the process to the image. A new view is created showing the mask, which you can rename to reflect how it's used. I typically use ***RangeSelection*** to select large structures such as galaxies or expansive nebulae for adjustment while shielding the background.

The ***StarMask*** process is self-explanatory, though in addition to selecting only stars for color adjustments, an inverted star mask can protect your stars from unwanted artifacts caused by other tools (notably ***HDRMultiscaleTransform*** and ***LocalHistogramEqualization***). I usually test the process on a small preview containing stars of various brightness and sizes and then experiment with the tool settings until I achieve an appearance that I want for the resulting mask. However, there are better alternatives discussed below.

The ***ChannelExtraction*** process (found at ***PROCESS*** > ***ChannelManagement*** > ***ChannelExtraction***) is a good tool for making a mask based upon the brightness of the pixels in the original image. It works equally well on nonlinear and linear images, though linear images must first be stretched to make an effective mask. The tool produces a monochrome image matching the original for brightness. This type of mask is sometimes called a *lightness* or *luminance mask*. I often use these during the final tweaks to color saturation, where the brightest pixels often need a color boost.

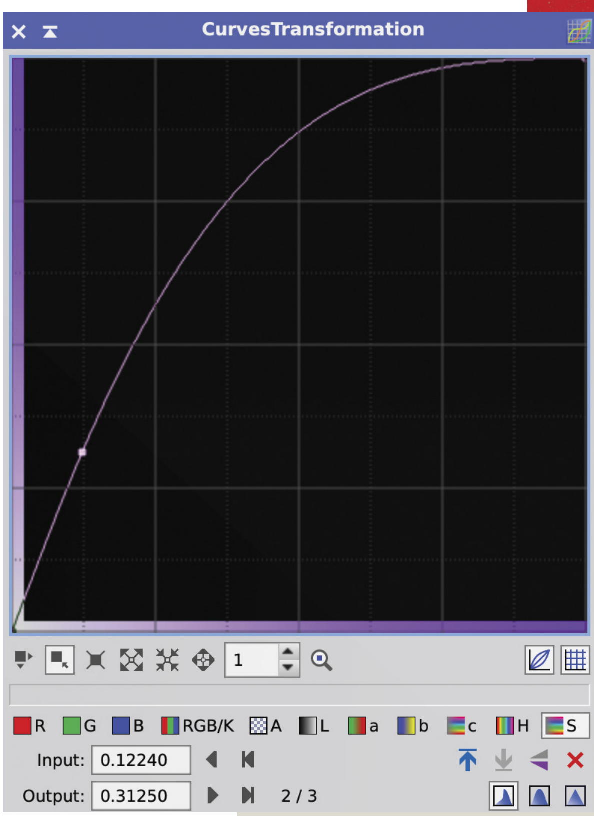
Third-Party Tools

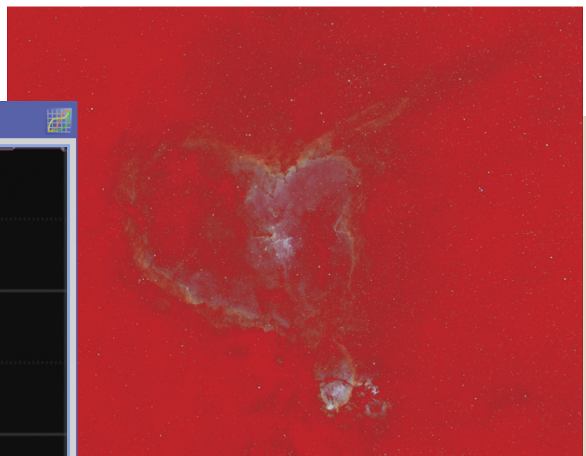
Some easier-to-use alternatives to these processes are available through *PixInsight*'s repository-based utility. These repositories let users install and automatically update built-in as well as third-party scripts and processess.

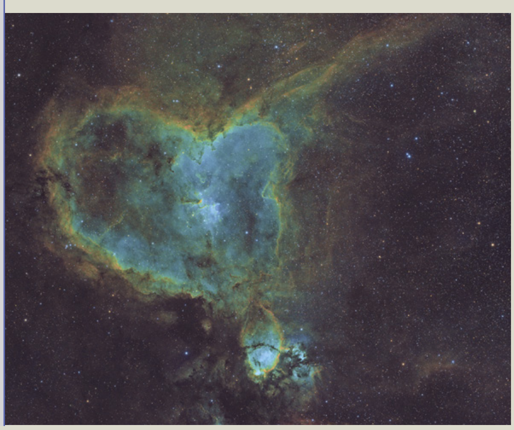
To install scripts and other processes in *PixInsight*, copy the repository link address listed below and select ***RESOURCES*** > ***Updates*** > ***Manage Repositories***. Next, click ***Add*** at lower left in the window and paste the repository link in the URL field. Click OK twice to save this change and exit back to the main screen. Now select ***RESOURCES*** > ***Updates*** > ***Check for Updates***. The program takes a moment to download the repository information. When it's completed, a list of updates appears. Click ***Select All***, followed by ***Apply***. Any available updates are then downloaded and queued for installation. When finished, quit out of the program and you'll see a dialog box confirming the installation (you may need to have administrator privileges). Note that these links will return an error if you try to open them in a web browser.

There are two excellent and easy-to-use alternatives to the ***StarMask*** process. The first is ***Starnet2***, a free plugin that requires adding these two repository locations: **https://pixinsight.starnetastro.com/** and **https://pixinsight.starnetastro.com/tensorflow/**. The other is ***StarXterminator*** ($59.95, available at **rc-astro.com** with the repository information delivered after purchase). These plugins extract the stars from the rest of your picture, splitting your photo into two separate views — one with only the stars in the field, the other with everything else (nebulae, galaxies, and the background sky). Both work well at default settings. The resulting view of just the stars is particularly useful as a star mask (though it needs to be stretched first). A star mask made from a color image remains in color, though it functions just like a grayscale mask.

Another useful plugin is Hartmut Bornemann's ***GAME***







▶ **SELECTIVE BOOST**
Top right: With the lightness channel applied as a mask, protected areas appear red in the target image. Applying a saturation boost with the ***CurvesTransformation*** process *(left)* affects only the unshielded regions *(bottom right)*.

script (**https://www.skypixels.at/HVB_Repository/**). This script allows you to select elliptical or polygonal shapes from a preview of your image and then generate one or more masks for the chosen areas, leaving the remainder of the mask black. Once installed, it's found in the ***SCRIPT*** > ***Utilities*** pulldown menu. My common workflow with the ***GAME*** script is to select the ***Ellipses*** tab and then check the ***Gradient Mask*** box in the ***Export Masks*** section. After clicking OK, an ellipse with four adjustment points appears in the center of the target photo; simply move it over your intended area to mask, then expand and rotate the ellipse to suit your need. Clicking ***+add*** inserts another ellipse, and you can add as many as you need. I recommend trying all the mask types the first few times you use the script to get a feel for how each appears and how it could be useful in your workflow. I often use this tool to define a circular region for color adjustment, such as the core of a galaxy.

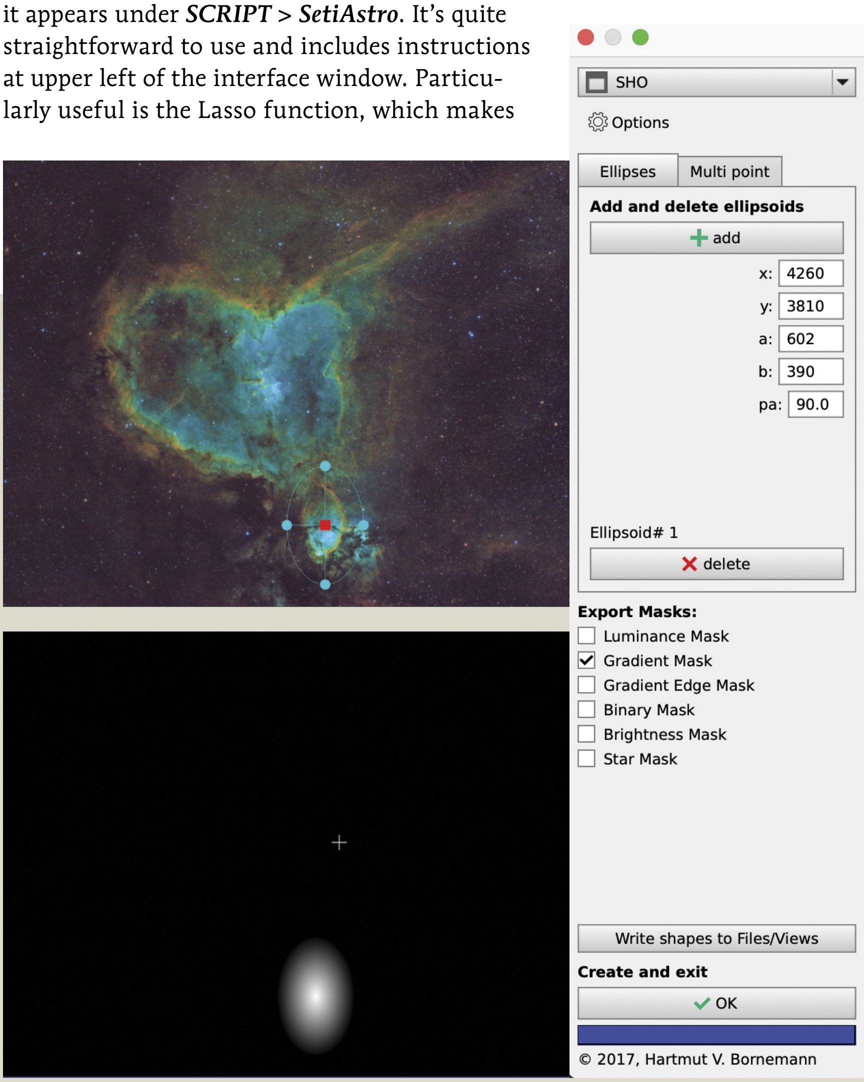
The ***FAME*** script (short for Freehand Adaptive Mask Editor) is located at **https://raw.githubusercontent.com/setiastro/pixinsight-updates/main/**) and provides nearly unlimited control over the creation of a mask. Once installed, it appears under ***SCRIPT*** > ***SetiAstro***. It's quite straightforward to use and includes instructions at upper left of the interface window. Particularly useful is the Lasso function, which makes selecting irregular features for enhancement easy. I use it with the ***Blur Amount*** set between 25 to 50 pixels.

While Jürgen Terpe's ***SelectiveColorCorrection*** (**https://www.ideviceapps.de/PixInsight/Utilities/**) is primarily used for selective color adjustment, it's also useful as a mask-making tool. Open the script by selecting ***SCRIPT*** > ***Toolbox*** > ***SelectiveColorCorrection*** and then select ***Target View***, the view from which you want to make the mask. Be sure to activate the ***Show mask*** checkbox, then select a mask type from the extensive dropdown list in the ***Mask*** section. Adjust the various sliders to modify the mask's appearance and ignore all the other settings. Don't be afraid to experiment with these mask-making controls; it's easy to reset the script and start over. Once you're satisfied, click ***Export Mask*** and close the script. The mask will then appear in a new view.

Editing Masks

Masks are modified with any *PixInsight* process or script that works on monochrome images, and they can be saved in any file format. You can modify one at any time to improve its effectiveness. Inverting a mask reverses its properties, so areas that were previously shielded will now allow processes to impact the target image underneath. You can quickly invert the mask image (or any selected view) with the keyboard shortcut Ctrl + I (Command + I on a Mac). A mask can also be inverted in-use by selecting the masked target image and using Shift + Ctrl + I (Shift + Command + I on a Mac). Another shortcut is Ctrl + K (Command + K), useful for quickly toggling the mask's visibility. The ***View Identifier Tab*** at upper left of the image window shows whether a mask is active or not. Its default color is gray and turns brown when a mask is in place and enabled.

PixInsight provides four ways to manipulate a mask relative to another view — select or remove a mask, invert it, toggle its masking function, or toggle the visibility of the mask. To access these options, left-click on the view that you want to mask (or unmask). Then open the menu from the top-level ***MASK*** tool bar and choose among the available options. Alternatively, right-click on the view you want to work on and use the Mask context menu to select the desired option. You can also include mask-control shortcut buttons on your tool bar by ensuring that the Mask toolbar is checked at ***View*** > ***Tool Bars*** > ***Mask***.



◀ **QUICK ELLIPSES** The ***Interactive Galaxy Mask Editor***, or ***GAME***, script is handy for selecting round and elliptical structures that require special attention. Despite its name, it works on any subject.

When a mask is applied to an image, the protected areas are shown in red. Users can change this color in the ***MASK*** menu or the Mask context menu by selecting a different color from the Rendering Mode dropdown menu. If the mask controls you want to use are grayed out, it might mean that the masked image is not the active view. To make it so, simply click on the masked view that you intended to work on and try again.

Just like any other view in *PixInsight*, you can modify a mask using any process or script. For example, I often use the ***Convolution*** process (found under ***PROCESS*** > ***Convolution***) to smooth out any sharp edges in a mask. I usually need to experiment with different ***StdDev*** settings and apply the process multiple times until I get the blur I want.

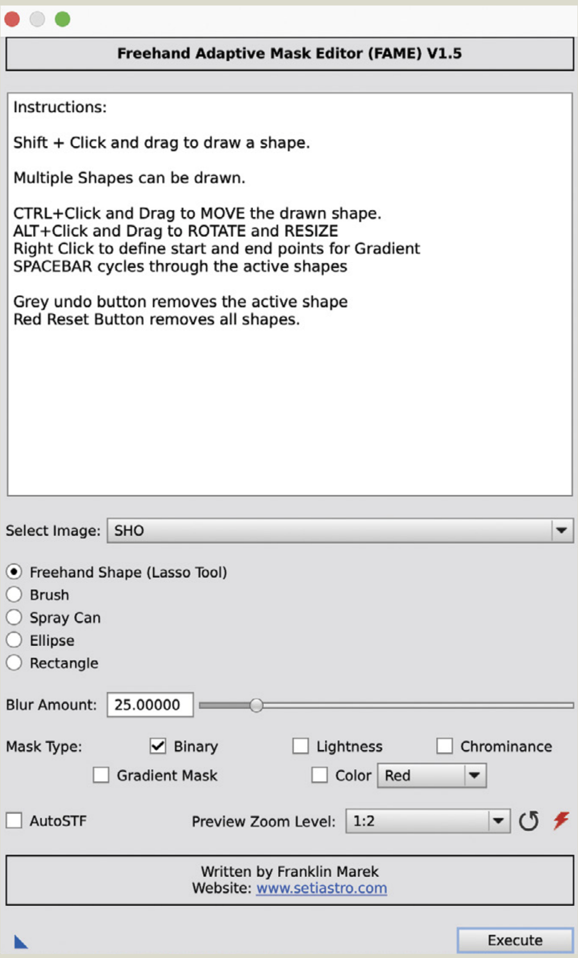
To combine different masks into a single view, I'll use the ***PixelMath*** process and combine them using addition or subtraction, depending on whether my mask is inverted or not. I sometimes combine multiple masks made with ***FAME*** or ***GAME*** scripts using the ***addition*** function.

I use the ***CloneStamp*** process (located at ***PROCESS*** > ***Painting*** > ***CloneStamp***) to quickly remove unwanted highlights in a mask. It's also useful for removing or dimming the brightest stars in a star mask. You can then brighten or add color to the remaining stars (through the modified mask) without damaging the brightest stars that received some protection from the mask.

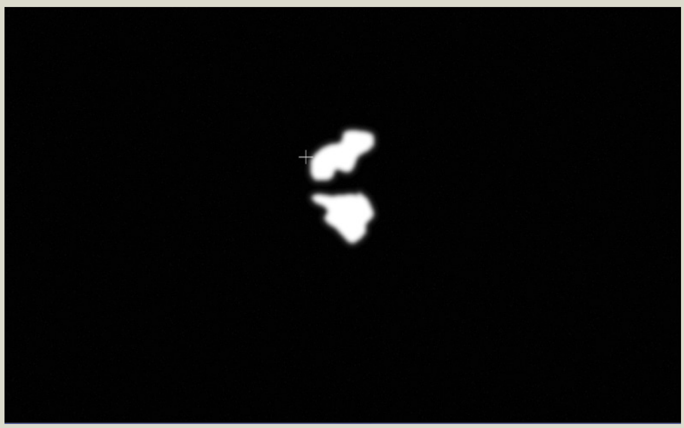
Surgical Precision

Learning to utilize masks can help you better control various elements in your astrophotos, like the light scatter around a bright star, or sharpening details in the spiral arms of galaxies, without modifying everything else in the picture. Practice using these tools and you'll gain much finer control over your image processing. Remember the mask mantras and repeat after me: White selects, black protects; white reveals while black conceals.

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

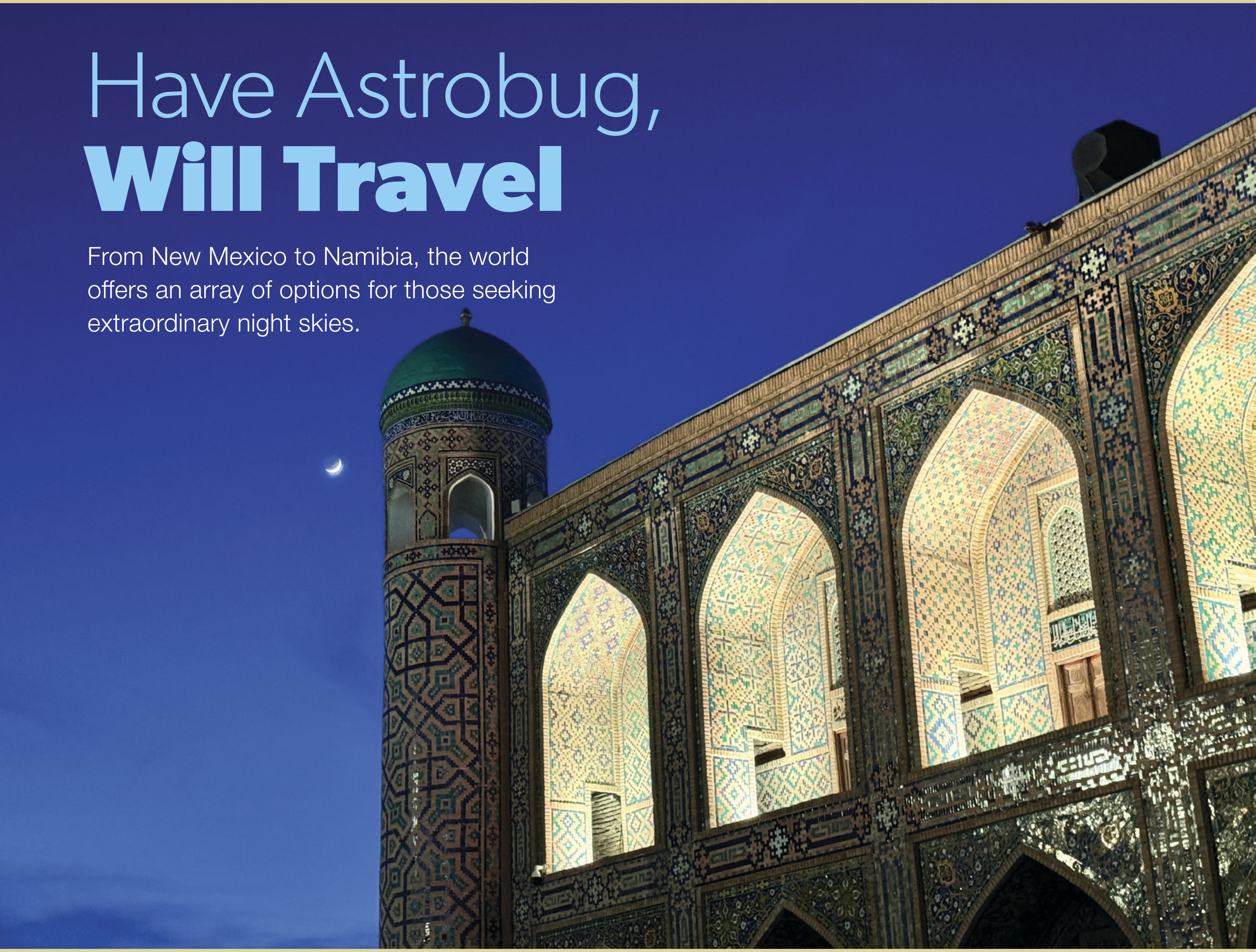


▲ **FREEHAND MASKING** The ***Freehand Mask Editor***, or ***FAME***, script is the author's tool of choice for selecting irregularly shaped features with its handy Lasso tool.



Have Astrobug, **Will Travel**

From New Mexico to Namibia, the world offers an array of options for those seeking extraordinary night skies.



On a cloudless night, I stood on the summit of Mount Maidanak and peered out into the dark. Before me spread the flat desert of Uzbekistan, and on the bare mountaintop nearby were several telescope domes and one giant, cylindrical building. Within it stood the 1.5-meter AZT-22 — the largest telescope in Central Asia. Overhead, the stars were coming out, and the day's dust was settling into the lowlands. It was completely dark.

Maidanak is the main scientific observatory in Central Asia, established by the Soviets in 1970; the AZT-22 saw first light in 1992. Inside, the main dome feels its age, with peeling wallpaper and rattling stairs. Nevertheless, Maidanak has quietly played a key role in global astronomy for decades, providing visible-light data for observatories and universities across Asia and beyond. The seeing conditions here are comparable to the world-class Paranal Observatory in Chile, home to the European Southern Observatory's Very Large Telescope.

Mount Maidanak is not normally open to visitors. I'd been given special access as a travel journalist, DarkSky International advocate, and author researching my forthcoming book on our relationship with darkness. Over the past several years, I've made it my mission to visit dark places throughout the world and to see the night sky through the eyes of people from different cultures. With light pollution growing at 10% every year, I wanted to unpack humanity's relationship with the night and understand why we are putting so much light into the world.

▲ **MOONLIT MOSAICS** The crescent Moon gleams above Registan, an old public square in the ancient city of Samarkand, Uzbekistan, along the Silk Road. The city's characteristic blue tiles decorate the three madrassahs (Islamic schools) that surround the central square.

THE AUTHOR

My work has taken me from that remote dome on Mount Maidanak to the jungles of northern Argentina, the glacial lakes of New Zealand's South Island, and the heights of the Himalayas. It has also brought me back to my home state, New Mexico, where I grew up learning to appreciate our starry skies thanks to my father, John, a night-sky lover and amateur astronomer who let me look through his Meade reflector as a child.

Through my job as the editor of DarkSky International's magazine, *Nightscape* (**darksky.org/nightscape**), I've had the good fortune to visit many certified Dark Sky Parks, Reserves, Sanctuaries, and Communities, where the skies are guaranteed to be protected from light pollution. I can't claim to have been to every dark-sky location — far from it. But I'm continually searching for the cosmic grandeur of a clear sky and the peaceful surroundings of a naturally dark night, with all of its beautiful nocturnal creatures.

Here, I've collected a few of the best dark-sky destinations for anyone wanting to plan a trip of their own. Some are close to home for those in the U.S., some require a manageable trip abroad, and some are bucket-list suggestions for memorable, far-flung adventures or luxury travel.

I've also included advice on travel documents for U.S. citizens; for those of other nationalities, check with your local embassy or consulate.

Across the U.S.

The Four Corners States

First-time dark-sky travelers should start in the Desert Southwest: Utah, Colorado, New Mexico, and Arizona. Lower population density, high elevations, a dry climate, and a plethora of DarkSky-certified parks and astronomical sites make this region a top choice for astrotourists.

Utah and Colorado are vying for the title of the state with the most certified dark-sky places. In Utah, you can go glamping at Under Canvas (**undercanvas.com**). Their Utah camp at Lake Powell-Grand Staircase became the world's first certified Dark Sky Lodging in 2023, thanks to a new dark-sky-friendly lighting scheme. (Subsequently, Under Canvas's other camps were also certified around the U.S.) The Lake Powell-Grand Staircase camp features luxury, safari-style tented rooms, some with sky windows above the beds, stargazing evenings, and a concrete platform for telescopes.

Arizona is full of accessible parks and certified communities, such as Saguaro National Park on the fringes of Tucson (also home to DarkSky International's offices); the town of Cottonwood, where you can take a starlit tour on the Verde Canyon heritage railway; and Flagstaff — the world's first certified Dark Sky Community (then known as a "Dark Sky City"). Flagstaff also boasts the world-class Lowell Observatory, which opened a huge new visitor center in 2024. Don't

SOUTHWEST STARS Canis Major and Orion shine over the snowy landscape of Cedar Breaks National Monument in Utah.

ALL PLANE AND PATH ICONS: HUNTER LEADER / SHUTTERSTOCK.COM; UTAH: ADAM CLARK / UTAH OFFICE OF TOURISM

GLAMPING Under Canvas's snazzy campground near Lake Powell perches on a canyon rim, offering outdoor splendor both day and night. The safari-style tents include bathrooms.

miss the 13-inch Lawrence Lowell Telescope, which Clyde Tombaugh used to discover Pluto in 1930.

Lesser-visited New Mexico has some truly dark skies and space sights, ranging from the New Mexico Museum of Space History in Alamogordo to the Sunspot Solar Observatory (**sunspot.nmsu.edu**), the Very Large Array radio telescope facility, and the Cosmic Campground International Dark Sky Sanctuary, which comes complete with observation pads for your telescope or camera.

Oregon Outback

The world's largest International Dark Sky Sanctuary is the Oregon Outback, an area in southeastern Oregon about half the size of New Jersey. Characterized by narrow mountain ridges separated by flat, arid valleys and salt basins, this is a dramatic, remote landscape populated by wildlife, including pronghorn and bighorn sheep. Travel Southern Oregon (**southernoregon.org**) has a handy map that shows dark-sky viewing locations.

This is a vast, backcountry landscape with few amenities, so you'll want to be prepared. Summer Lake Hot Springs (**summerlakehotsprings.com**) offers simple cabins, tent pitches, RV hookups, and a historic bathhouse with mineral hot springs. Run by Duane Graham, who was involved with the DarkSky certification, it's located on Highway 31 near the small town of Paisley. A variety of campsites elsewhere in the sanctuary offer the best chance at sleeping under the night sky, and you'll want a 4WD vehicle with good clearance to access the most remote locations. Before visiting Oregon, check out the Portland-based Rose City Astronomers (**rosecityastronomers.net**); they run star parties in various parts of the state during the summer.

Big Bend, Texas

Big Bend National Park was certified as an International Dark Sky Park in 2012 and now forms the core of the Greater Big Bend International Dark Sky Reserve — currently the largest Dark Sky Place in the world.

The town of Terlingua is the best base for astrotourism: Stay at The Summit at Big Bend (**summitbigbend.com**) in a geodesic dome with a stargazing window above the bed, and book a tour with Astro Mucho (**astromucho.com**), which provides private telescope tours with recliners and guides. The Big Bend Observatory Cabin (**bigbendvacations.com**) features a Seestar S50 telescope under a roll-off roof, a sky deck with tripods, and a mount for binoculars.

About 100 miles north near Fort Davis, McDonald Observatory (**mcdonaldobservatory.org**) offers guided star parties and telescope viewing through 8-inch to 22-inch scopes. A few times a year, they also run special evenings when you can observe through their two larger telescopes: a 36-inch retired research telescope and the 81-inch Otto Struve Telescope, one of the largest of its kind available for public observing. The site also includes the Frank N. Bash Visitors Center and a daytime solar-viewing program.

SANAM TAHAN / UNDER CANVAS

Michigan

Probably the best place to spot the northern lights in the Lower 48, Michigan's Upper Peninsula is home to Keweenaw Dark Sky Park (**keweenawdarksky.com**), centered at Keweenaw Mountain Lodge. There are a variety of dedicated observing spots (all mapped), and you can borrow a Celestron StarSense Explorer LT telescope or bring your own gear. The lodge also runs a program of night-sky events, including aurora and astrophotography workshops, moongazing, and the occasional "lights out" weekend, when the entire property goes completely dark.

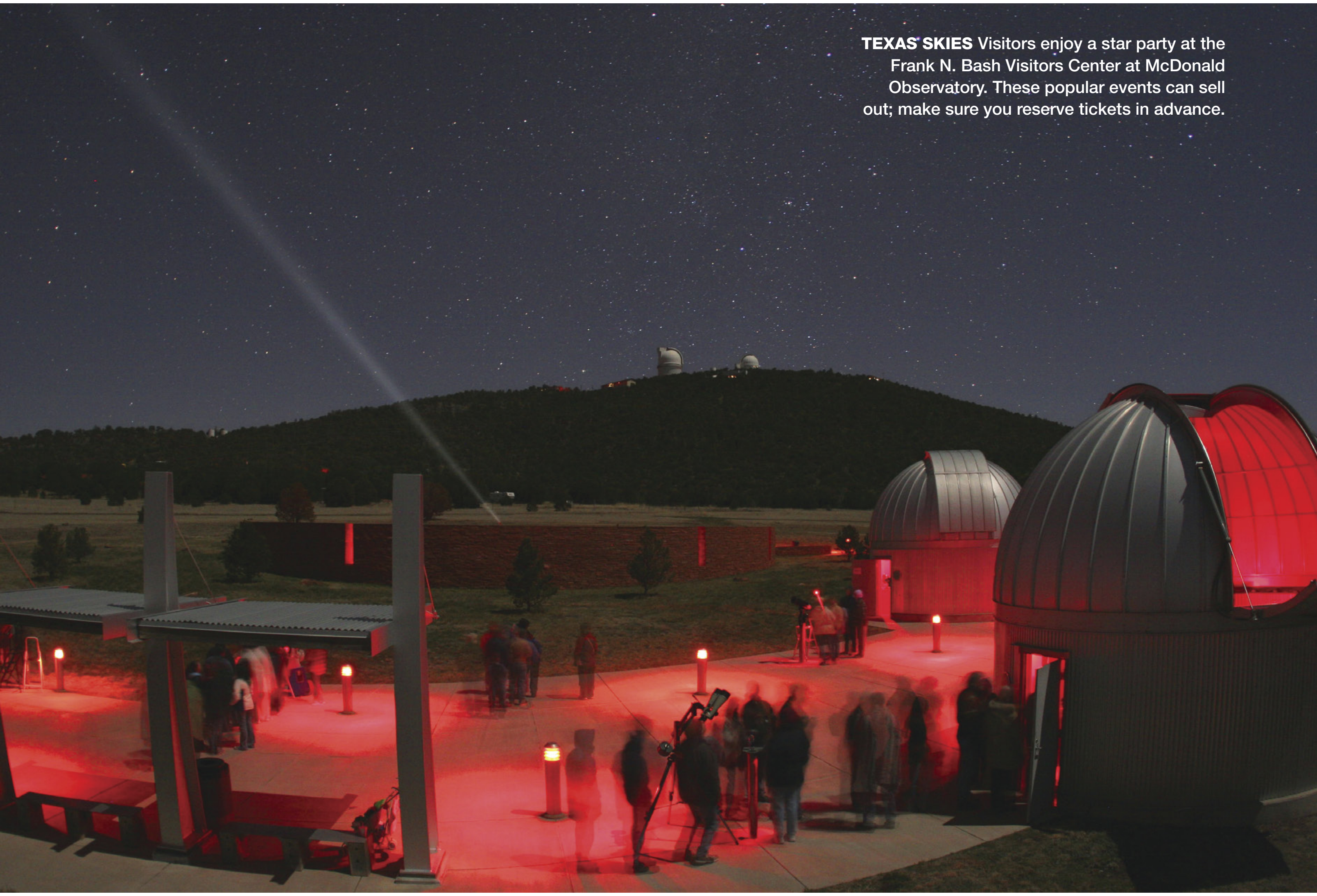
For a more remote experience, head to Beaver Island, in the middle of Lake Michigan. Accessible only by ferry from Charlevoix, it was certified as an International Dark Sky Sanctuary in 2024. You can glamp in a luxury safari tent at Beaver Island Retreat (**beaverislandretreat.com**), which also has "dark-sky lounges," and there are guided "skygawking" events with binoculars and 10-inch and 16-inch telescopes.

Middle Fork River Forest Preserve, Illinois

Located about two hours south of Chicago, Middle Fork River Forest Preserve is the first International Dark Sky Park in Illinois, designated in 2018 — a rare pocket of true darkness in the Midwest.

The preserve's mile-long Dark Sky Trail has dark-sky-friendly lighting, stargazing nodes with concrete telescope pads, and a solar-powered observatory where you can set up your own telescope. The North Waterfowl Management Area is open 24 hours for stargazers, and the park occasionally puts on guided night-sky programs. For a full overnight experience, the Harry L. Swartz Campground (**https://is.gd/swartzcamp**) has multiple dark-sky-friendly sites right in the preserve, making it easy to stay up until dawn.

FRANK CIANCIOLO / MCDONALD OBSERVATORY



TEXAS SKIES Visitors enjoy a star party at the Frank N. Bash Visitors Center at McDonald Observatory. These popular events can sell out; make sure you reserve tickets in advance.

AMC Maine Woods

Located in the North Maine Woods, this park was designated the first International Dark Sky Park in New England in 2021. Stay at one of the remote wilderness lodges managed by the Appalachian Mountain Club — Little Lyford and Gorman Chairback cabins are both tucked into the forest under Bortle Class 2 skies. On clear nights, join AMC's See the Dark program (**outdoors.org/see-the-dark**) for a mix of guided telescope sessions, night-photography tutorials, fireside storytelling, concerts, and outdoor activities like snowshoeing. There are few towns nearby, making this arguably the best option for serious dark-sky observing on the East Coast.

Canada, Europe, and Beyond

Mont-Mégantic, Quebec, Canada

Designated in 2007, this was the world's first International Dark Sky Reserve. It's easily reachable from the northern U.S. and offers darker skies, research-grade infrastructure, and high-altitude terrain.

The mountain at Mont-Mégantic National Park hosts two observatories. The first, Observatoire du Mont-Mégantic, is a 1.6-meter research telescope that's open for daytime tours and a few nights a year during the Popular Astronomy Festival. The second, Mont-Mégantic Popular Observatory, is regularly open to visitors at night. At the base of the mountain, the ASTROLab (**astrolab.qc.ca/en**) astronomy center hosts a public observatory, activity center, exhibits, and guided stargazing sessions.

In 2026, an expansion to the Popular Observatory at the summit will keep the existing 24-inch telescope and add two new public telescopes: a 200-mm refractor inside a new Astroshell observatory, and a 36-inch reflector that will be rolled out on rails. There will also be a new dome-shaped building with a multimedia theater, all of which will double the observatory's previous capacity. Note that all activities are conducted in French.

Crossing into Canada from the U.S. to visit Mont-Mégantic is relatively straightforward: U.S. passport holders do not need a visa for stays less than 180 days. Driving from Maine,

THE SKY AWAKES An auroral display dances over Keweenaw Mountain Lodge in Michigan on August 11, 2024.

CHRIS GUIBERT / KEWEENAW MOUNTAIN LODGE

it's about 30 minutes north of the border, or you can fly to Montreal, rent a car, and drive three hours to Mont-Mégantic. When bringing your own telescope, Canadian customs rules require you to declare any equipment upon arrival, including amateur-astronomy gear.

UK & Ireland

It may often be rainy, but the UK and Ireland together have an extraordinary number of protected dark places and, when the clouds part, it is a joy to stargaze here. Aim for sites like Mayo Dark Sky Park (**mayodarkskypark.ie**) in the west of Ireland, which hosts a popular dark-sky festival every fall, and the OM Dark Sky Park and Observatory (**omdarksky.com**) in Northern Ireland, which has a regular program of stargazing that integrates local myths, landscapes, and stone circles.

In Britain, sites certified by DarkSky include Eryri (Snowdonia) National Park in Wales, Exmoor National Park, and Northumberland National Park, with the popular Kielder Observatory (**kielderobservatory.org**), which houses a 16-inch TS Ritchey-Chrétien telescope and a Skywatcher 5-inch refractor. The combined reserves at the North York Moors and the Yorkshire Dales also host two popular dark-sky festivals annually. In Scotland, there's Moffat, a Dark Sky Community bordering Galloway International Dark Sky Park (the first in Europe), and it has its own dark sky–themed whisky distillery (**darkskyspirits.com**).

While you're in the UK, don't miss a visit to the Jodrell Bank radio observatory and the Royal Observatory Greenwich, where you can get up close with historic scopes like the 1893 Great Equatorial Telescope; the Airy Transit Circle used to define the Prime Meridian; and John Harrison's clocks, which helped solve the problem of longitude for navigation.

▲ **ARID LAND** Travelers will find a breathtaking landscape of volcanic rocks and high-altitude brush in Teide National Park, which sits at some 2,150 meters on Tenerife in the Canary Islands.

La Palma & Tenerife, Canary Islands

The Canary Islands are a Spanish archipelago off the northwest coast of Africa, about a three-hour flight from Madrid. They sit far out in the Atlantic and enjoy some of the clearest, darkest skies in the Northern Hemisphere. La Palma in particular is famous for the Roque de los Muchachos Observatory, home to one of the world's largest optical telescopes. The landmark 1988 "Law of the Sky" (Ley del Cielo) protects La Palma from atmospheric, light, and radio pollution.

On La Palma, you can take guided night tours or rent telescopes from Astro La Palma (**lapalmastars.com**). You can also follow the island's waymarked astro-hiking trail, which has stopping points and signage pointing to different celestial phenomena. Lodging options include ATHOS Star Campus

NEW ZEALAND Stargazers enjoy the Milky Way in the Aoraki/Mount Cook region of the South Island.

TENERIFE: CAMILLE M. CARLISLE / *S&T*; NEW ZEALAND: MT COOK LAKESIDE RETREAT (**athos.org**), which has observing platforms, telescopes for rent, and a semi-pro domed observatory; Casa Rosabel (**casa-rosabel.com**), which is located on a hillside and set up specifically for astronomers; and the stargazer-friendly Hotel Hacienda de Abajo (**hotelhaciendadeabajo.com**).

Nearby Tenerife, the largest island in the chain, is home to Teide Observatory and has a wider range of accommodations, beaches, and family activities, making it a good option if you're traveling with non-astronomers. Guided observing tours in Teide National Park are available through Volcano Teide (**volcanoteide.com**) and include large telescopes and pickup from a central location at or near your hotel.

On both islands, the Starlight Guide program trains guides to lead night-sky tours and astrophotography sessions in English and Spanish.

One highlight of a Canary Islands stargazing trip is the combination of Spanish food and wine with the night sky. Ad Astra La Palma (**adastralapalma.com**) offers a "Wine & Moon" evening that combines wine tasting with lunar viewing and telescopic observing, while on Tenerife, Teide by Night (**teidebynight.com**) offers a stargazing tour that includes an organic-farm dinner and wine as well as telescope time.

Flights from the U.S. typically connect through Madrid or Barcelona, and rental cars are recommended for reaching observatories and mountain sites. U.S. passport holders can visit Spain and the Canary Islands for up to 90 days without a visa. While Spanish is the main language, English is also commonly spoken in tourist areas.

Aoraki Mackenzie, New Zealand

The flight may be long, but New Zealand's cinematic landscapes and dark skies are worth the trip. New Zealand is aiming to have the largest amount of land area certified by DarkSky, with 10 International Dark Sky Places at the time of publication and more planned.

For such a big trip, you might want to rent a car and drive around both of New Zealand's islands, visiting dark-sky locations as you go. But if time is short, aim for the massive Aoraki Mackenzie International Dark Sky Reserve on the South Island. Stay in the town of Tekapo, where you can visit the Dark Sky Project (**darkskyproject.co.nz**), with its outdoor model of the solar system and 1894 Brashear Telescope, then join an observing evening at Mount John Observatory above the town. There are plenty of hotels and vacation rentals in Tekapo, or you can splurge for a stay at the Mt Cook Lakeside Retreat (**mtcookretreat.nz**), which has luxury villas and its own boutique observatory set in a wine cellar with a retractable roof and a 9-inch reflector.

U.S. citizens can visit New Zealand for up to 90 days without a visa, but before departure you must apply online for a New Zealand Electronic Travel Authority (NZETA) and pay a levy that funds tourism infrastructure and environmental conservation (see **nzeta.immigration.govt.nz**).

NAMIBIA The Moon rises over NamibRand International Dark Sky Reserve.

THE AUTHOR

Remote, Adventurous, and Unforgettable

South Africa & Namibia

If you're willing to travel far, the rewards grow exponentially. These dark-sky destinations in southern Africa pair celestial beauty with rare wildlife, rugged landscapes, and once-in-a-lifetime experiences under truly pristine skies.

Start at South Africa's Lapalala Wilderness, which in 2025 was certified as an International Dark Sky Park. A privately run reserve, it is a 3.5-hour drive from Johannesburg's international airport. The reserve is home to iconic African wildlife, including the Big Five — lion, leopard, rhinoceros, elephant, and African buffalo — as well as unique nocturnal species like the pangolin.

Lapalala sees a very limited number of visitors. Lepogo Lodges (**lepogolodges.com**) runs safaris and provides small telescopes for each room, as well as nighttime game drives around the reserve.

Heading to neighboring Namibia is an easy two-hour flight. This vast, sparsely populated country houses the continent's first certified International Dark Sky Reserve, laid across the Namib Desert and its famed red dunes at Sossusvlei. The best way to see Namibia is by car. Rent a 4WD vehicle from Advanced Car Hire (**advancedcarhire.com**) and plot your own route, taking in NamibRand International Dark Sky Reserve (**namibrand.com**) and Hakos Guest Farm (**hakos-astrofarm.com**), a hilltop hotel and observatory specifically for astronomers, with telescopes and observing sessions.

Dark-Sky Places

Most of the destinations highlighted in this article are certified by DarkSky International as locations that preserve and protect dark skies through responsible lighting policies and public education. There are various site categories. For more information, see **https://is.gd/dsi_places.**

If you have a strong interest in gamma-ray astronomy, you can contact the High Energy Stereoscopic System observatory (HESS; **hess-experiment.eu**), not far from Hakos, to arrange a private tour of this array.

U.S. citizens can visit South Africa without a visa for up to 90 days; for Namibia, you must apply online in advance for a "visa on arrival" (**eservices.mhaiss.gov.na/visaonarrival**). The political situation in both countries is safe and secure for visitors, and neither requires special immunizations for visitors arriving from the U.S.

Iriomote-Ishigaki, Japan

Probably the dreamiest place I have stayed in all of my dark-sky travels is the peaceful Hoshinoya Taketomi Island resort (**https://is.gd/hoshinoya**) on tropical Taketomi, a small island within Iriomote-Ishigaki International Dark Sky Park in Japan's Okinawa prefecture.

LUXURY LIVING Lepogo Lodges' Noka Camp overlooks the Palala River, just a few hours from Johannesburg in South Africa.

LEPOGO LODGES

▲ **SOLAR FURNACE** Towering 54 meters high, this solar oven in Uzbekistan can create temperatures on par with the surface temperatures of a red dwarf star. It's used for industrial smelting, metallurgy, and science experiments on things like fireproofing materials.

Located on a tiny island, this resort is less about hardcore observing and more about luxuriating under the night sky. In addition to the amenities of a tropical island, including a beach with star-shaped sand, it has a swimming pool designed to reflect the stars and offers well-being programs, such as night-sky pool floats and mindful stretching under the stars. You can also learn about the island's indigenous culture, its unique wildlife, and even take a nighttime excursion to neighboring Iriomote Island to try to spot its native wildcat.

Getting here is fairly straightforward and can form part of a larger trip to Japan — you can also stop off at Bisei Town in Okayama prefecture, home to the largest public observatory (**https://is.gd/biseiobs**) in the country.

To reach Taketomi, fly to Tokyo and then book a domestic flight to Ishigaki, a larger neighboring island that also forms part of the Dark Sky Park. In downtown Ishigaki, you catch a short ferry ride to Taketomi. The resort can help arrange local nighttime tours and wellness activities. U.S. citizens can visit Japan for up to 90 days without a visa.

Astrostays, Ladakh, India

For a true mountain adventure, Astrostays (**astrostays.com**) in northern India combines astronomy, indigenous culture, epic landscapes, and sessions with Buddhist monks. Located in the Ladakh region, part of the Himalaya Mountains, Astrostays is a network of astronomy homestays set up by dark-sky advocate Sonal Asgotraa. A trip here involves staying in beautiful homes run by locals who are also equipped with telescopes to take in the vastness of the sky. At this extreme elevation, the night is clearer and darker than many other places on Earth. You'll also spend an evening with Buddhist monks at the 500-year-old Phyang Monastery and learn about the Buddhist tradition's rich cosmology, as well as the local Ladakhi constellations.

U.S. citizens must obtain an e-visa before traveling to India; you can apply online at **indianvisaonline.gov.in** (and beware of fake websites). To get there, you can fly to a main hub like Delhi or Mumbai, then book a domestic flight to Leh, the capital city of Ladakh, via reliable airlines like IndiGo. The Astrostays team will handle your ground transportation, tour, and accommodations once you reach Leh. As a high mountain region, Ladakh's tourism season typically runs from April to October.

If you stop over in Delhi, you can visit the Jantar Mantar, one of five 18th-century astronomical observatories constructed in India by Maharaja Sawai Jai Singh II for measuring time and the Sun's declination and tracking celestial objects.

This trip is at high elevations and may not be suitable for those with certain health conditions; talk to your doctor before booking.

Uzbekistan

On this off-the-beaten-track, naked-eye stargazing trip, you will learn about Islamic contributions to astronomy and explore the extraordinary monuments of the Silk Road. Start in the capital city of Tashkent, where you can learn about the country's Soviet history — don't miss the Kosmonavtlar (Cosmonauts) metro station, with its space-themed decor, including ceramic medallions of Soviet cosmonauts like Yuri Gagarin and Valentina Tereshkova. About an hour east of Tashkent, you can also visit the Solar Furnace of Uzbekistan, a Soviet facility built in 1981, which uses thousands of mirrors to concentrate sunlight, reaching temperatures of up to 3000°C (5000°F).

From Tashkent, take Uzbekistan's shiny high-speed train to visit the ancient city of Bukhara, with its historic domed markets and Silk Road monuments, and then on to Samarkand, where emperor and astronomer Ulugh Beg built his famed observatory and school in the 15th century, which contributed significantly to astronomy. You can also add an evening under the stars at a yurt (round tent) camp in the desert of the Navoi region, with traditional Uzbek music by a campfire, camel rides, and stargazing under Bortle Class 1 skies near the shores of Aydarkul Lake.

U.S. citizens over the age of 55 can visit Uzbekistan for up to 30 days without a visa; travelers aged 17–55 must apply for an e-visa online before departure (**visa.mfa.uz**). Trusted local tour operators Veres Vert (**veres-vert.com**) or Caravan Travel (**caravantraveluz.com**) can arrange a bespoke astronomy tour including these sites.

■ Journalist and dark-sky advocate **MEGAN EAVES** travels around the world to better understand our deep connection to the dark. Her new book, *Nightfaring: In Search of the Disappearing Darkness* (March 2026, Grand Central Publishing), blends travel and nature writing with history and self-discovery to explore how the stars have helped her chart the course of her own life — just as they've guided humankind for as long as we've slept beneath them.

THE AUTHOR

SKY AT A GLANCE
April 2026

2 EVENING: The Moon, one day past full, rises above the east-southeastern horizon with Spica, Virgo's lucida, about 2° upper left. Follow the pair as it climbs higher during the night. See page 46 for more on this and other events listed here.

6 DAWN: Face south-southwest before sunrise to see the waning gibbous Moon with Antares, the heart of the celestial Scorpion, some 4½° upper left.

18 DUSK: The thinnest sliver of the Moon, just one day past new, and Venus adorn the west-northwestern horizon. Catch this sight before it sinks out of view.

19 DUSK: After sunset, turn toward the west-northwest and watch the Pleiades gradually appear in deepening twilight with the waxing crescent Moon about 4½° above and Venus around 6½° below.

22 MORNING: The Lyrid meteor shower is expected to peak. Viewers should continue looking for meteors during the night of April 22–23. The Moon, almost at first quarter, will not interfere with viewing (see page 48).

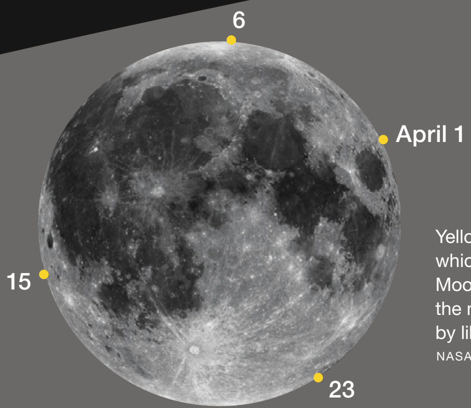
22 DUSK: Look high in the west to glimpse the waxing crescent Moon in Gemini forming a delightful tableau with Jupiter some 3° lower left and Pollux about 5½° above.

23 DUSK: Face west-northwest to see Venus around 3½° lower left of the Pleiades. Binoculars will enhance the view.

25 DUSK: The Moon, one day past first quarter, eclipses Leo's brightest star, Regulus, for many viewers in most of the Americas. For those who won't see the occultation, the sight of the star and the waxing gibbous will nevertheless be striking. Turn to page 49 for details.

29 EVENING: The waxing gibbous Moon gleams in the southeast with Spica a bit more than 2½° to its left.
—DIANA HANNIKAINEN

▲ The spring constellations — Ursa Major, Leo, Boötes, Virgo — line up from top to bottom. Keep an eye out on Regulus in Leo later this month when the Moon will eclipse it for many in the Americas.
ALAN DYER



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		

FULL MOON

April 2
02:12 UT

LAST QUARTER

April 10
04:52 UT

NEW MOON

April 17
11:52 UT

FIRST QUARTER

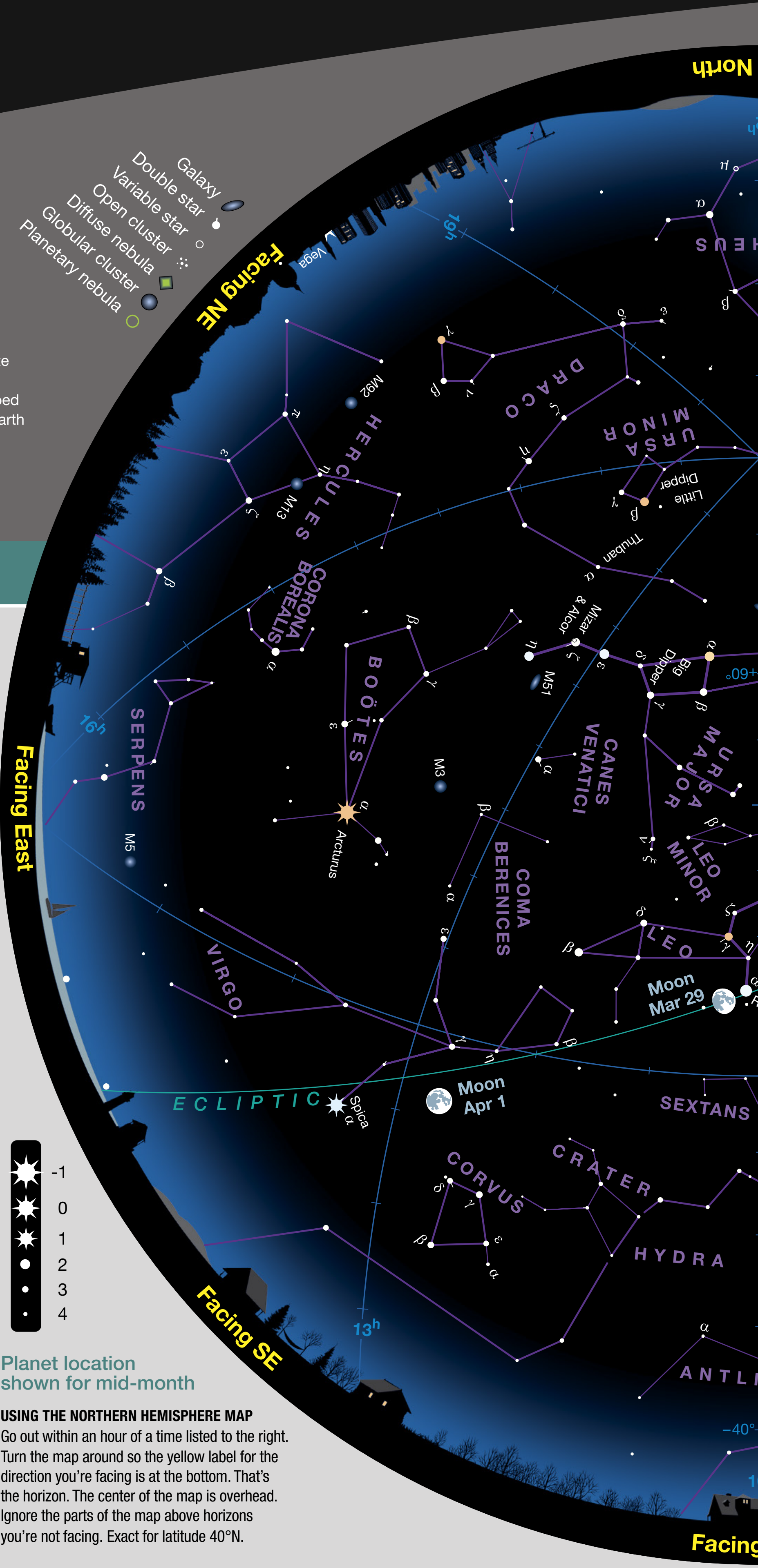
April 24
02:32 UT

DISTANCES

Apogee	April 7, 09h UT
404,970 km	Diameter 29′ 31″
Perigee	April 19, 07h UT
361,631 km	Diameter 33′ 02″

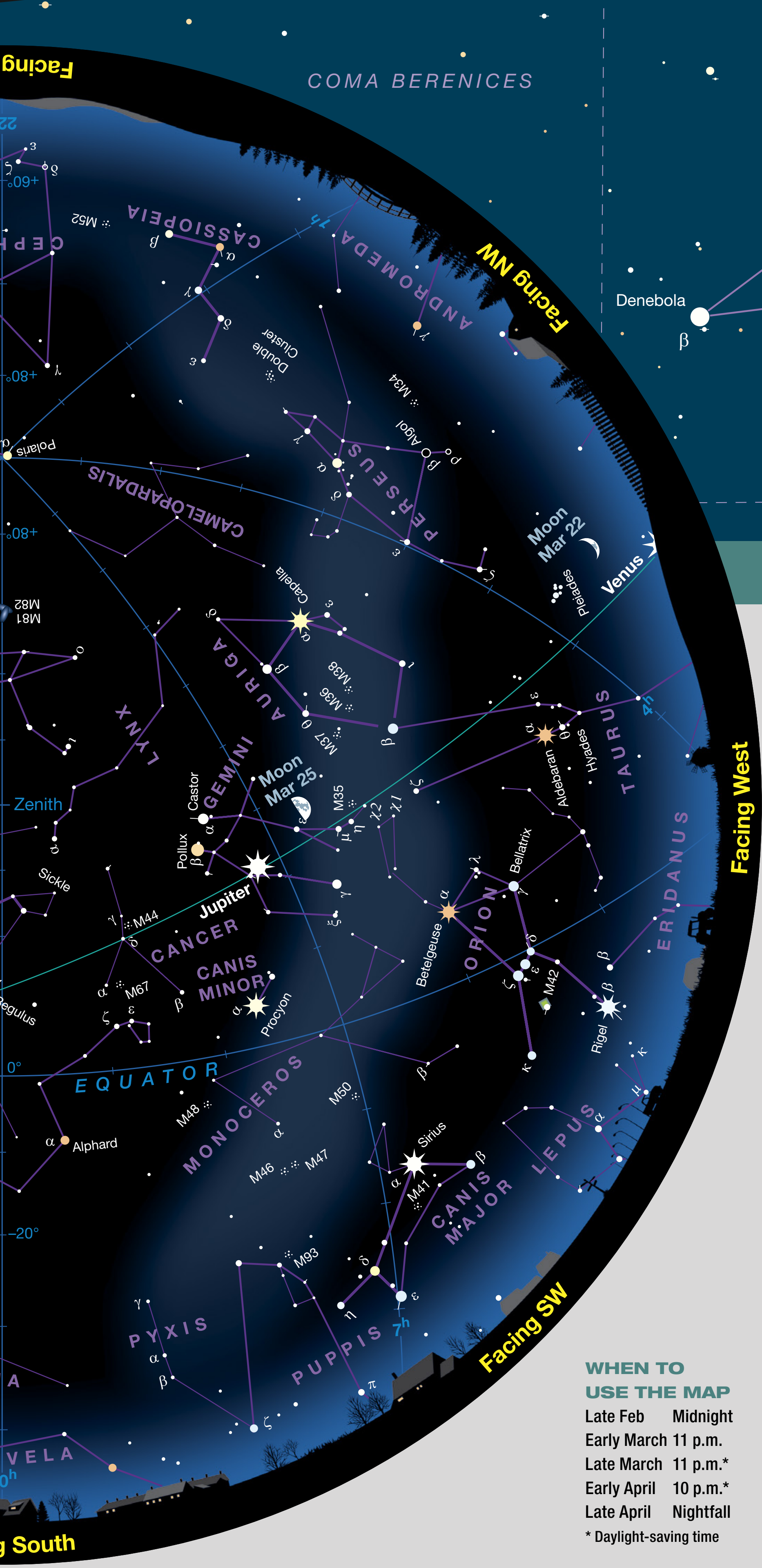
FAVORABLE LIBRATIONS

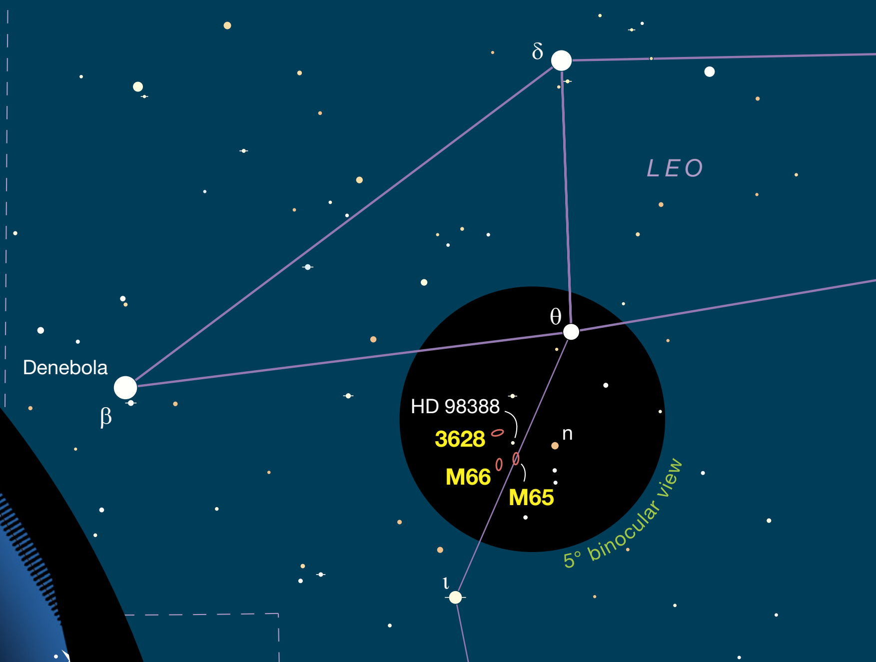
• Joliot Crater	April 1
• Byrd Crater	April 6
• Rimae Kopff	April 15
• Oken Crater	April 23



Planet location shown for mid-month

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





Binocular Highlight by Mathew Wedel

The Lion's Pride

Our target this month is the Leo Triplet, a justly famous group of spiral galaxies in the constellation Leo, the Lion. The trio of **M65**, **M66**, and **NGC 3628** are gravitationally bound to one another and show signs of interaction, which makes them fascinating targets for binocular observers.

To find the Leo Triplet, start with Theta (θ) Leonis and scan about 2.5° southeast. Many observing guides reference a chain of 6th- to 8th-magnitude stars trending south and east from 5th-magnitude n Leonis as an aid to getting on target. I used to struggle to see that asterism, until I mentally added 7th-magnitude HD 98388, which turns the shape into a pork chop. The galaxies bracket HD 98388 at the northeastern corner of the pork chop. Star-hopping is a personal activity; who cares if the pictures we visualize are silly if they help us find our way?

All three galaxies of the Triplet have been successfully detected with 7×35 binoculars, but not by me. I need 10×50s to spot them consistently, and I prefer the view in my 15×70s. The galaxies make a shape like a deconstructed Greek letter pi (π), with north-south-oriented M65 and M66 as the uprights, and east-west-oriented NGC 3628 as the horizontal bar. The members of the trio aren't equally bright. NGC 3628 is the dimmest, at magnitude 9.5. Most sources put M65 at 9.3 and M66 at 8.9, but that's total brightness. For me, M65 punches above its weight, thanks to its starlike core and more compact appearance compared to M66. On the other hand, I find NGC 3628 harder to spot than its integrated brightness suggests, thanks to a large dust lane which spreads out its light. Have a look and see what you think.

■ **MATT WEDEL** enjoys the incongruity of observing galaxies with handheld binoculars – sometimes mere hours after pointing them at birds (shudder).

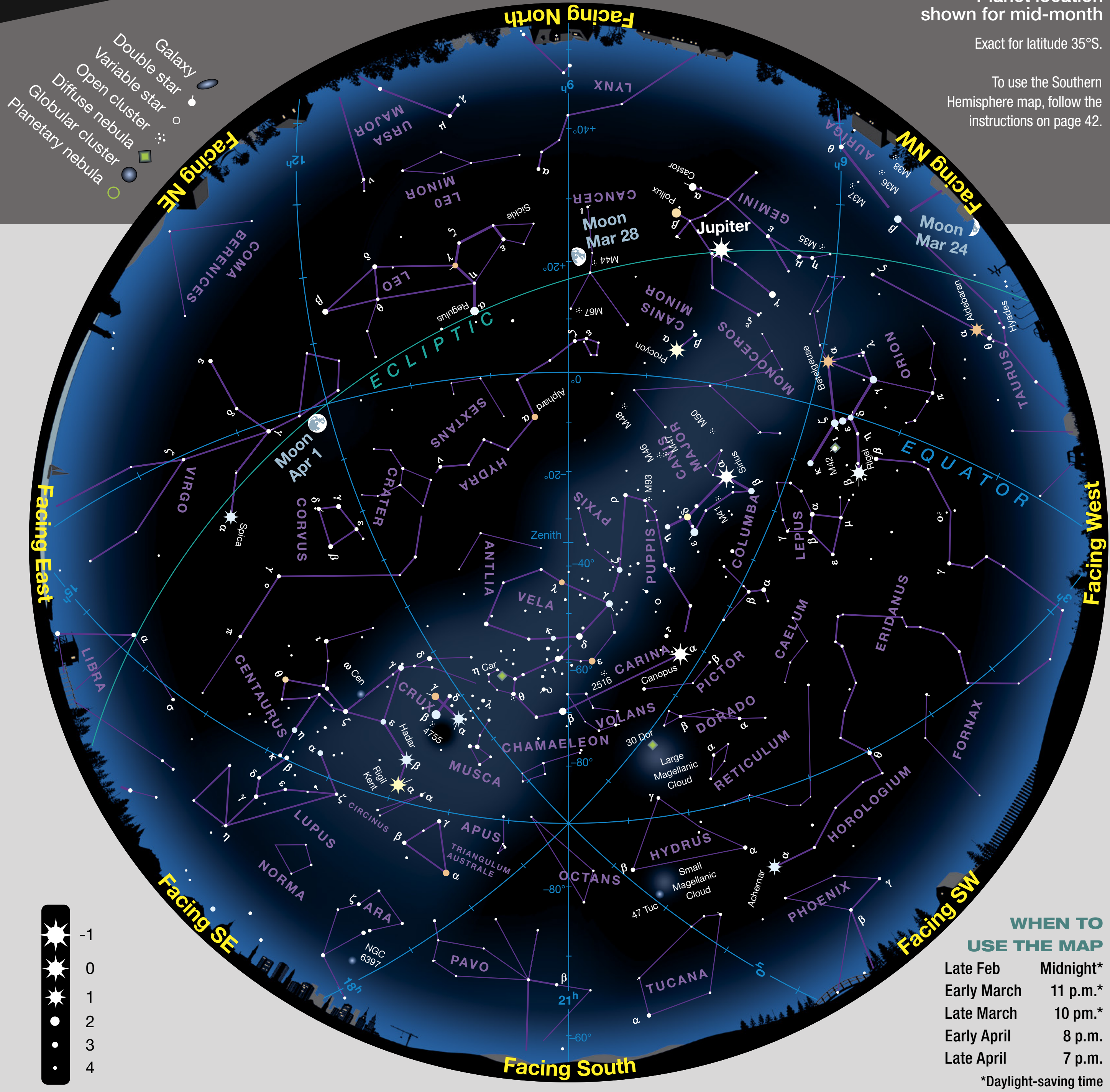
WHEN TO USE THE MAP

Late Feb	Midnight
Early March	11 p.m.
Late March	11 p.m.*
Early April	10 p.m.*
Late April	Nightfall

* Daylight-saving time

Southern Hemisphere Sky Chart

by Jonathan Nally



Planet location shown for mid-month

Exact for latitude 35°S.

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

WHEN TO USE THE MAP

Late Feb	Midnight*
Early March	11 p.m.*
Late March	10 pm.*
Early April	8 p.m.
Late April	7 p.m.

*Daylight-saving time

THE CONSTELLATION Puppis, the Stern, is a celestial oddity as it doesn't have Alpha to Epsilon designations for its five brightest stars. That's because it once belonged to a larger constellation, Argo Navis, which was eventually split into three — its Alpha to Epsilon labels were reallocated to stars in neighboring Vela and Carina. And so, Puppis's brightest orb ended up being the luminous, blue 2.2-magnitude Zeta (ζ) Puppis.

But what Zeta lacks in nomenclature, it makes up for in its nature. For a start, it is a fairly rare O-type star, more than 10,000 times brighter than our Sun. In fact, it's the nearest O star to Earth at about 1,000 light-years and is visible to the unaided eye. It's also a "runaway" object, zipping through space at high speed having probably been spun out from its original home when its companion went supernova. ■

M44 and the Tears of Ra

This bright star cluster in Cancer is absolutely buzzing.

▲ In this natural beehive, the insects are packed together like stars in a cluster. In ancient Egyptian mythology, each bee — or in our celestial sense, star — represents a teardrop from the Sun god Ra, as explained in the Salt papyri now housed in the British Museum in London.

As shown on the Northern Hemisphere Star Chart on pages 42–43, Cancer, the Crab — the only constellation whose brightest stars are fainter than a Messier object within its boundaries — is approaching its highest point in the south. The four brightest stars of Cancer shine between magnitudes 3.5 and 4.7, while M44, popularly known as the Beehive Cluster, shimmers at 3.1. But its light is spread across more than 1° of sky, making it a challenge to see unless you are under at least decent suburban skies.

From dark skies, the Beehive Cluster stands out to the unaided eye like the head of a tailless comet. Look midway along an imaginary line drawn between the 1st-magnitude stars Regulus in Leo, the Lion, and Pollux in Gemini, the Twins. It's also nested between, and a bit west of, 4th-magnitude Gamma (γ) Cancri (Asellus Borealis) and Delta (δ) Cancri (Asellus Australis).

Historically speaking, the "Beehive" moniker may be relatively new. The earliest mention of it I found was in English astronomer John Herschel's 1833 *A Treatise on Astronomy*: "In the constellation Cancer, there is . . . a luminous spot, called Praesepe, or the bee-hive." Note that Herschel first calls M44 *Praesepe* (Latin for *Manger* — representing the straw-filled crib of Jesus). That name has been used to describe this misty patch of light for thousands of years. So in a way, the idea of M44 also being a beehive does make sense, for prior to the mid-19th century, the traditional hive, called a *skep*, was made of straw or dried grass.

The true nature of this fuzzy, naked-eye cloud remained a mystery until 1609, when Italian astronomer Galileo Galilei turned his telescope on it and saw a "mass of more than 40 little stars." Today, under dark skies, a pair of binoculars may reveal just as many members. But what about the unaided-eye view? Does M44 look like a uniform patch of light to you?

If you take the time to truly study the glow, you may immediately notice it's not circular but elongated north-south — a fact demonstrated by Galileo. The Beehive contains about 15 stars between magnitudes 6.5 and 7.5, placing some of them within the limits of the naked eye for those trained in using keen averted vision — when you look at an object out of the corner of your eye, allowing light to fall on its night-sensitive retina (the layer of cells at the back of the eye). On several occasions, I have recorded a dozen members without optical aid while observing under dark Hawaiian skies at an altitude of 1,220 meters (4,000 feet). See if you can resolve at least six from lower altitudes.

If you succeed, use your imagination and try to see the resolved stars as the tears of Ra. In ancient Egyptian myths bees were sacred, linked directly to the divine, as they originated from the tears of the Sun god Ra. As the late Egyptologist Frank Filce Leek explains in a 1975 article in *Bee World,* titled "Some Evidence of Bees and Honey in Ancient Egypt," a Salt papyrus in the British Museum in London gives us an "eloquent and succinct expression of contemporary ideas on the origin of bees and their bountiful products: 'The god [Ra] wept and the tears from his eyes fell on the ground and turned into a bee. The bee made [his honeycomb] and busied himself with the flowers of every plant; and so wax was made and also honey out of the tears of the god [Ra].'"

Ancient Egyptians also believed that bees represented the connection between life and death. This latter point is interesting, as, at the time on the summer solstice, when life was most vibrant, the Sun would have been in Cancer at its highest point in the sky. After the solstice, the Sun starts its descent toward the celestial underworld, marking its celestial death.

■ Cosmic Mythographer **STEPHEN JAMES O'MEARA** has been studying the constellations and their lore for more than 50 years.

STEPHEN JAMES O'MEARA

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

Venus Drifts By the Pleiades

The Evening Star visits both the Moon and the Seven Sisters this month.

THURSDAY, APRIL 2

As darkness falls this evening, face east-southeast to watch the almost-full **Moon** rising with **Spica** to its upper left. Alpha (α) Virginis, as the star is also known, is one of only five 1st-magnitude luminaries strung out along the ecliptic. During tonight's meetup a bit more than 2° separates the Moon and the star — a gap that steadily grows as the night wears on. By the time they're at the meridian some five hours after they rise, the space between them has nearly doubled. Yes, the Moon moves that swiftly against the stellar background; it has a lot of ground to cover to complete a *sidereal month* and returns to the same patch of sky 27.3 days later. And because this evening's encounter happens so early in the month, on the 29th the Moon has a second encounter with Spica. That one isn't quite as close as tonight's, but it's worth checking out if only to observe the passage of an entire sidereal month. Your non-astronomy friends, however, will probably be more confused than impressed by your accomplishment.

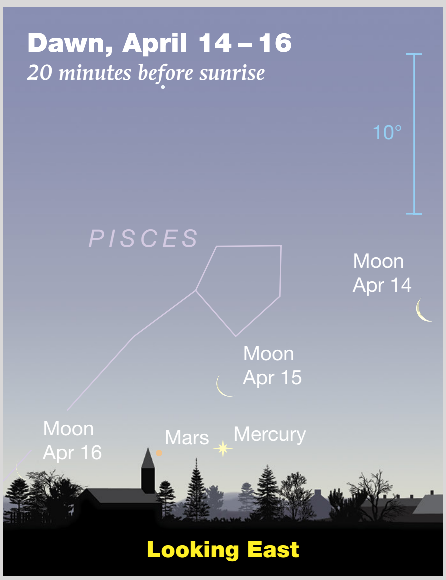
WEDNESDAY, APRIL 15

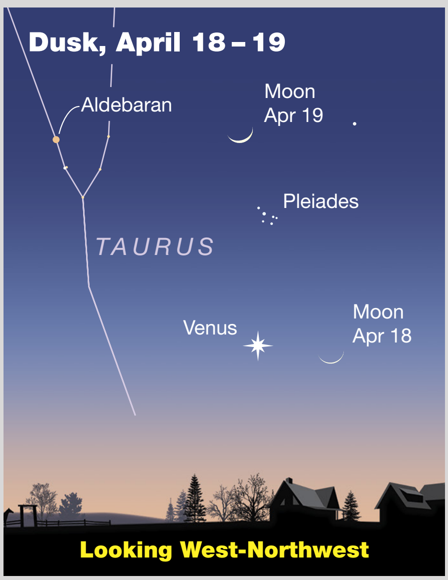
A remarkable quartet of planets is clumped together at dawn today. The grouping includes Mercury, Mars, Saturn, and Neptune, but only the first two are high enough and bright enough to be visible. If you have a completely unobstructed eastern horizon and you're eager for a challenge, try to catch the **Moon**, **Mercury**, and **Mars** in binoculars. The key to success is sighting the 5.5%-illuminated waning lunar crescent. Half an hour before sunrise, it hovers just 6° above the horizon — and it's the highest of the trio! Next, place the Moon at the top of your binocular field and Mercury should come in to view at the bottom. The innermost planet shines at magnitude –0.1 but is in the dying days of a rather poor dawn apparition that started last month. It sits a mere 2.2° above the horizon. If you have an exceptionally clear morning and are able to locate it without too much difficulty, you might as well try for Mars. This time, park Mercury at the right edge of your binocular field and look for the Red Planet near the left edge and at about the same height. The difficulty is Mars shines at magnitude 1.2, which means it's only one-third as bright as its planetary neighbor. Don't be disappointed, though, if the Moon is the only one of the three you catch.

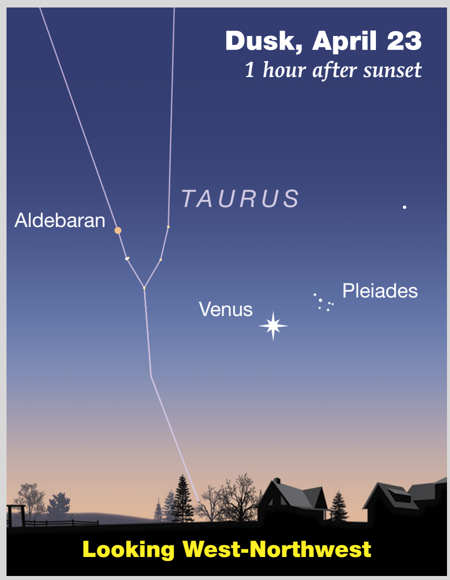
SATURDAY, APRIL 18

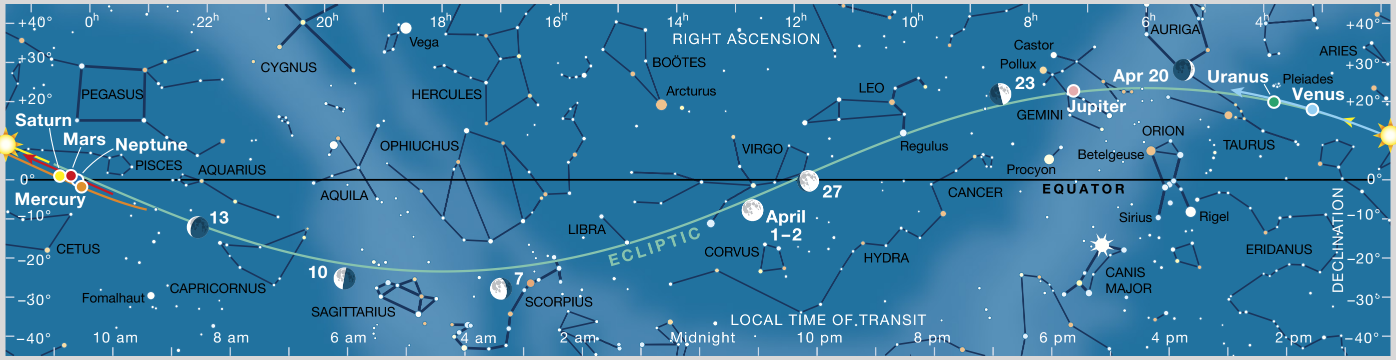
After the dawn challenge of the 15th, you're probably ready for something a

▼▶ 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.



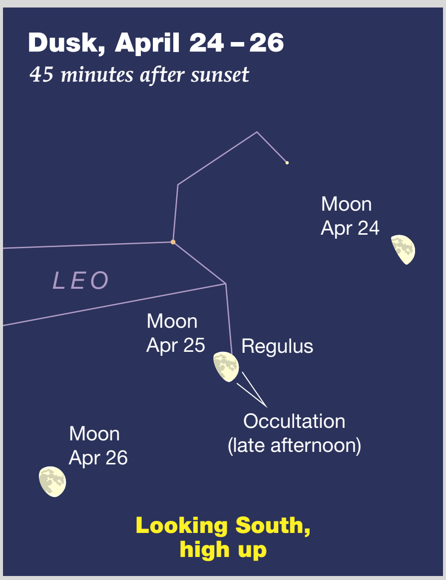






▲ The Sun and planets are positioned for mid-April; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

little less demanding. This evening, cast your gaze toward the west-northwest as the sky darkens to see the waxing crescent **Moon** sitting a bit less than 5½° lower right of brilliant **Venus**. The Moon is about 3.5%-illuminated tonight, which means it's very slightly narrower than it was during its dawn conjunction with Mercury and Mars. But thanks to the steep angle the ecliptic makes to the western horizon at this time of year, the Moon is much higher than it was in the morning sky. As for the reigning Evening Star, it gleams at magnitude –3.9 and should be readily visible shortly after sunset. Indeed, keen-eyed observers can sight Venus even in broad daylight — the trick is knowing exactly where to look. And this is where the Moon comes in handy once again. If you can find the slender crescent before sundown, look upper left of it to see if you can glimpse Venus too. You might be pleasantly surprised by how easy it is.



WEDNESDAY, APRIL 22

Having visited the brightest planet on the 18th, the **Moon** now greets the sky's second-brightest planet, **Jupiter**. High in the southwest during twilight the crescent Moon hangs 3° above Big Jove, which shines at magnitude –2.1. A couple of things make this scene particularly delightful. First, the presence of Gemini's bright stellar duo **Castor** and **Pollux** located above the Moon. Second, a bit more than 1° left of Jupiter is 3.5-magnitude Delta (δ) Geminorum, also known as **Wasat**. If you keep an eye on Jupiter over the coming days, you'll notice the planet slowly creeping closer and closer to the star until the 30th, when it's positioned upper right of the star. After that, the gap between the two starts to grow once again. The Moon may be able to circle the entire sky in one sideral month, but Jupiter won't buzz Wasat again until 2037.

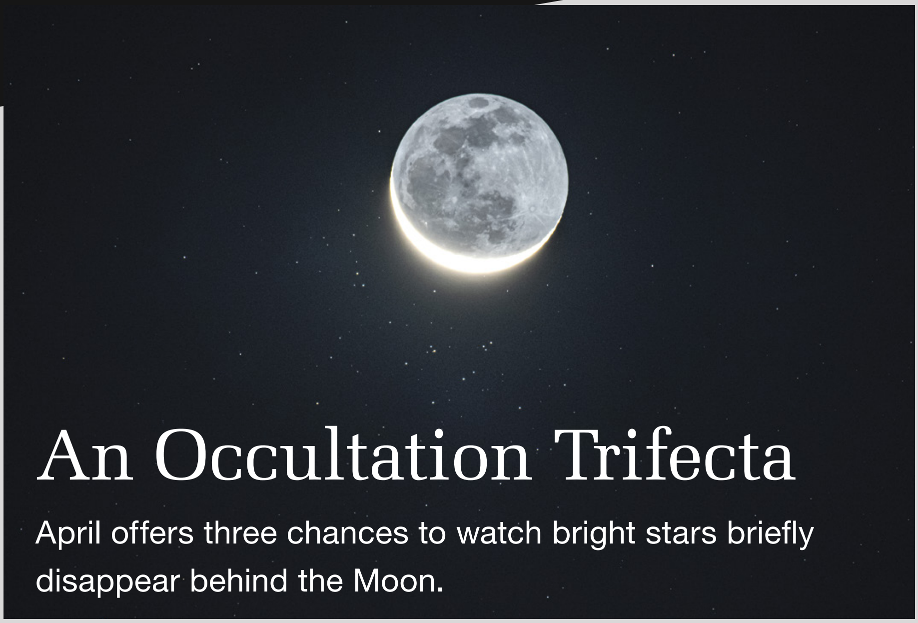
THURSDAY, APRIL 23

This evening, we can enjoy a pair of conjunctions involving **Venus**. The easier of the two is the Evening Star's close approach to the **Pleiades** in Taurus. The beacon-like planet is about 3½° from the cluster's center — a sight binoculars make even more appealing. And while you have the binos out, you can try for a second, more difficult conjunction between Venus and **Uranus**. Coincidentally, tonight Venus passes about ¾° upper right of that distant ice world. That's close enough that the two objects can even be viewed together in a telescope used at low magnification. However, there's a tremendous brightness difference between them. Poor Uranus is at the threshold of naked-eye visibility, glowing feebly at magnitude 5.8. Its neighbor is about 7,600 times brighter — little wonder when you consider that Uranus is about 14 times farther away.

SATURDAY, APRIL 25

The **Moon** doesn't play favorites — it just seems like it sometimes. And if it has a favorite dancing partner these days, it's **Regulus**, the Alpha star of Leo. The two paired up twice last month and do so once again today, producing an occultation for observers in most of the eastern U.S. and Central America, as well as the Caribbean and the northeastern part of South America. For the rest of the U.S. and most of Mexico, the occultation takes place in daylight hours. (Turn to page 49 for details.) However, those outside of the occultation zone still get to see a very close evening conjunction between the star and the 71%-illuminated waxing gibbous Moon. The two drift apart all night and by the time they set on the morning of the 26th, more than 2½° separate them.

■ Contributing Editor **GARY SERONIK** keeps tabs on the sky from his home in British Columbia's Okanagan Valley.



An Occultation Trifecta

April offers three chances to watch bright stars briefly disappear behind the Moon.

◀ An old crescent Moon aglow with earthshine passes in front of the Beehive Cluster (M44) in Cancer on August 25, 2019. Early on April 24th, the waxing first quarter Moon will again occult stars in M44 for West Coast observers.

ZOLT LEVAY

A David-vs.-Goliath story will play out three times this month when the modest, underdog Moon blocks two massive, bright stars and multiple suns in the Beehive Cluster from view.

The first to go will be 3rd-magnitude Pi (π) Scorpii, which the International Astronomical Union officially named Fang in 2017. It's the southernmost of the bright stellar trio that outlines the head of Scorpius. Early on April 6th, U.S. observers from the eastern Midwest to the Mid-Atlantic coast and southward to the Florida Keys will see the waning gibbous Moon occult this blue-tinged star. Due to the Moon's low altitude at the time, only those living in the southern part of the viewing zone can watch the star disappear behind the bright limb (along with observers in Central America and northern South America). In Savannah, Georgia, Fang blinks out at 12:06 a.m. EST and pops back into view at 1:05 a.m.

When the star reappears at the dark limb, the Moon has risen high enough for most viewers to witness its flashbulb-like return. A star's reappearance or disappearance at the dark limb is the more dramatic half of an occultation because of the stark contrast difference.

This is actually a triple-star system whose two primaries eclipse each other every 1.6 days. (The third, 11.9-magnitude companion is 50″ to their southeast.) Fang's eclipsing *B*-type stars appear only 0.0003″ apart — too close to be discerned visually. However, carefully timed lunar occultations do enable observers to split surprisingly close binary stars, as first one component then the other is covered or uncovered by the lunar limb.

To determine the times of Fang's disappearance and reappearance for your location, use a stargazing app like *Stellarium* (**stellarium.org**) or *SkySafari* (**skysafariastronomy.com**) to simulate the occultation and determine times for where you live. Or download the free occultation prediction program *Occult v4* at **lunar-occultations.com/iota/occult4.htm**. Click on the ***Lunar Predictions*** button, select your location, magnitude limit ("3" in this case), and event date, then click the ***Occultations*** button to get your customized result.

Luxuriate in Lyrids

IF YOU'VE YET to experience the Lyrid meteor shower in its humble glory, this is a fantastic year to address that deficit. The Lyrids are modest as showers go, with a maximum of 15 to 20 per hour visible from a dark, moonless site with the radiant positioned high in the sky. The International Meteor Organization (IMO) predicts a shower peak around 20^h Universal Time (4 p.m. Eastern Daylight Time) on April 22nd. Given the midday timing, North American observers should see maximum the morning of April 22nd followed by a second good opportunity to catch the show that night. The Moon, a waxing crescent, will have little effect on meteor rates.

The shower's streaming point, its *radiant,* lies in western Hercules about 8½° southwest of brilliant Vega. (Back in 1930, when the International Astronomical Union established the current constellation boundaries, this shower's radiant — long associated with Vega in Lyra — ended up in Hercules.)

Although this part of the sky culminates at the start of dawn, you can begin your Lyrid watch as early as 10:30 p.m. local time. After-midnight observation usually produces higher rates because when the radiant is high up, fewer meteors are hidden by the horizon. Also at that time, Earth's leading hemisphere is turned toward the direction of incoming meteors, which increases the particles' impact velocities and subsequently their number and brightness. My happy Lyrid time slot is 2 a.m. to 4 a.m.

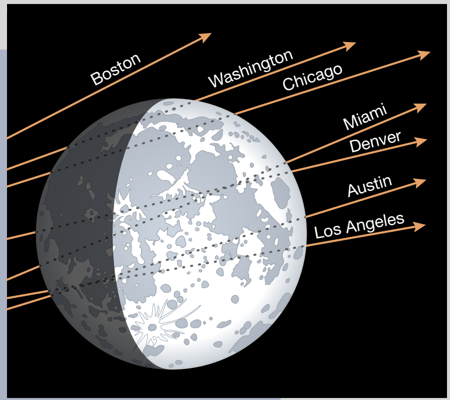
Dress warmly, and relax comfortably in an outdoor reclining chair. When I watch this shower, there are often gaps of five minutes or more between sightings, so you'll need a degree of patience that at times can feel like an eternity. Speaking of which, the parent body of the Lyrids, Comet Thatcher (C/1861 G1), has an orbital period of about 415 years and won't return until around 2283. Knowing that may help put you in the proper stoic frame of mind.

Every year during the last two weeks of April, Earth plows through the comet's path and the bits of dust and rock

Occultation of Regulus on April 25–26, 2026

City	Disappearance (UT)	Reappearance (UT)
Winnipeg	0:14.2	0:40.8
Edmonton	0:03.4	0:22.9
Vancouver	**23:39.0**	0:29.4
Washington, DC	0:41.8	1:23.0
Chicago	0:15.2	1:11.5
Miami	0:33.8	1:59.0
Atlanta	0:18.8	1:35.7
Austin	**23:56.6**	1:18.8
Kansas City	**23:58.9**	1:12.5
Denver	**23:43.2**	0:57.6
Phoenix	**23:34.9**	0:49.4
Los Angeles	**23:29.3**	0:39.7
San Francisco	**23:25.7**	0:35.6

Times on April 25th are shown in bold.



▲ The paths of Regulus behind the lunar disk for select cities during its occultation by the Moon on the night of April 25–26, 2025. The table at left provides times of the star's disappearance and reappearance for 13 cities.

Bees Hide on the Farside

On Friday morning, April 24th, the first-quarter Moon slides across part of the open cluster M44, better known as the Beehive. Most of the country will have to settle for seeing the Moon and cluster as a close binocular duo in the hours before dawn. But from the West Coast, observers using modest telescopes will see multiple "bees" disappear behind the dark lunar limb.

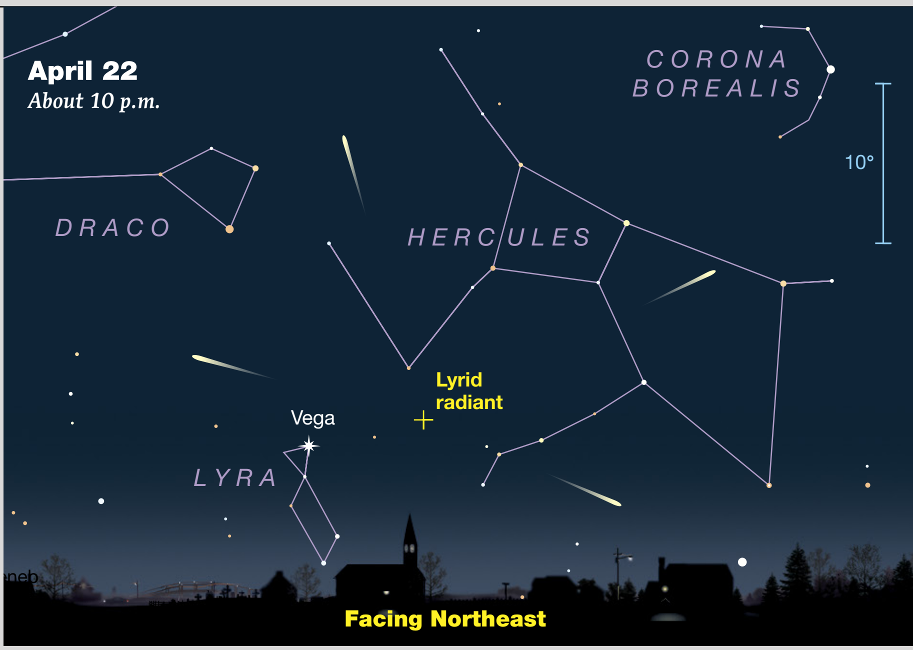
For example, those observing from Seattle will see the dark limb extinguish a half-dozen 6th- through 8th-magnitude stars as it slowly glides across the northern half of the cluster from about 1:50 a.m. to 3:00 a.m. local time. From San Francisco, the viewing window shrinks to about a half hour, 2:00 to 2:30 a.m. local time, before occulter and occultees are lost in the trees. Considerably farther west in Anchorage, Alaska, observers can watch the entire passage before moonset.

Grand Finale

Regulus gets its turn playing hide-and-seek on the evening of April 25th, when a thick wedge of the unilluminated lunar limb bears down on the star during evening twilight for viewers along the Eastern Seaboard. Observers there will see it snatched away in a deep-blue sky and re-emerge at the opposite limb in darkness. From Miami, Florida, Regulus disappears at about 8:34 p.m. local time and returns to view at the bright limb around 9:59 p.m.

From the Midwest the disappearance occurs with the Sun still above the horizon. While you hesitate to set up a scope for that, occultations of 1st-magnitude stars like Regulus can still be observed in daylight provided the Sun is low in the sky. It helps having the advantage of knowing exactly where to look for the target — right next to the Moon!

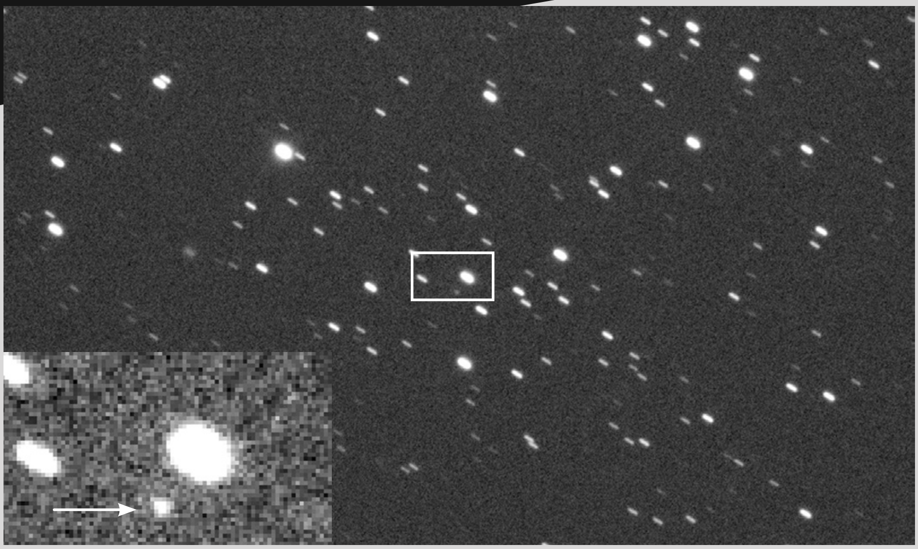
While it will be a challenge for sure, the star's reappearance at the bright lunar limb occurs around sunset and shouldn't pose a problem. For details about this event, the International Occultation Timing Association has provided predictions for 660 locations at **https://is.gd/RegulusApril2026**. Or use one of the software options described on the facing page.



pepper the atmosphere at 49 kilometers per second (108,000 mph). As a particle compresses and heats the air along its flight path, its temperature can reach more than 1,650°C (3,000°F), hot enough to vaporize into a superheated gas, which combines with oxygen to form metallic oxides or "meteoric smoke." These minute particles can act as condensation nuclei in the formation of blue-hued noctilucent clouds that appear in summer twilights.

Although unrelated, another noteworthy sky event occurs around the same time as the shower. On the evening of April 23rd, Venus passes just ¾° north of Uranus low in the northwestern sky at dusk just a few degrees south of the Pleiades (see page 47).

MOON: LEAH TISCIONE / *SKY & TELESCOPE* / SOURCE: EBERHARD REIDEL

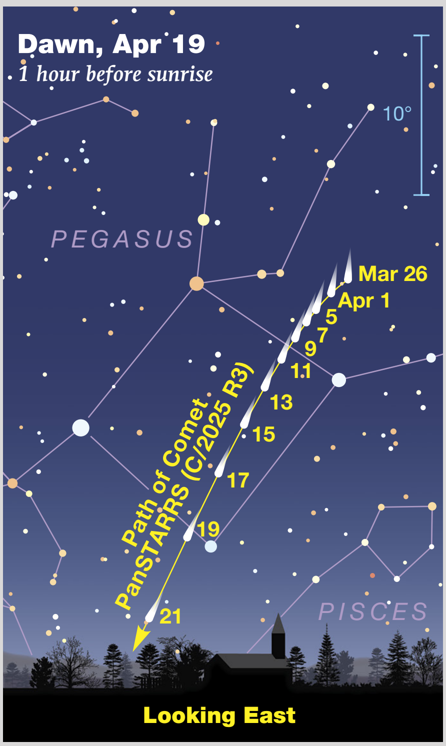


▲ On November 9, 2025, Comet PanSTARRS (C/2025 R3) was a 19th-magnitude blip in this image made remotely with a 0.51-m f/3.0 Cassegrain telescope.

Newest Comet PanSTARRS

A FAINT COMET discovered on September 8, 2025, by the Pan-STARRS2 telescope in Hawai'i may become an easy binocular object around the time of its April 19th perihelion, when it will pass 0.5 astronomical unit from the Sun.

Comet PanSTARRS (C/2025 R3) begins the month just west of the Great Square of Pegasus low in the eastern sky right before the start of dawn (the finder chart below shows stars to magnitude 6). Glowing at around magnitude 10, a 6-inch telescope should catch it from a dark-sky site.



Prospects quickly improve. Shortly before the comet disappears in twilight, about April 19th, it could reach 7th magnitude. Find a spot with an unobstructed view to the east and look 90 minutes before sunrise. Thereafter, the comet heads south, departing northern skies. But it should still be an easy 8th-magnitude evening object through early May for Southern Hemisphere observers.

C/2025 R3 may get a brightness boost from forward scattering of sunlight due to the comet's fortuitous location between the Sun and Earth — especially if it turns out to be a dusty comet.

Forward scattering is what makes the dust on your car's windshield become annoyingly bright when you're driving toward a low-altitude Sun. Sunlight scattered by a dusty comet behaves similarly and can greatly enhance its brightness. Comet Tsuchinshan-ATLAS (C/2023 A3), which peaked near magnitude −3 in October 2024, received a significant kick from this effect. Should C/2025 R3 experience the same boost, it could vault to magnitude 3 and possibly become a naked-eye object. Time will tell!

Action at Jupiter

THE JUPITER OBSERVING season is showing early signs of winding down as April begins. On the first of the month, the giant planet is already transiting the meridian as the Sun sets, though it remains well placed for telescopic viewing until around midnight local time. Jupiter shines prominently within Gemini at magnitude −2.2 and presents a disk spanning a generous 39″. By month's end the observing window narrows, and the planet is in prime position only until around 10:30 p.m. It also dims very slightly to magnitude −2.0 and shrinks to a diameter of 36″.

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

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

March 1: 3:33, 13:29, 23:25; **2**: 9:20, 19:16; **3**: 5:12, 15:07; **4**: 1:03, 10:59, 20:55; **5**: 6:50, 16:46; **6**: 2:42, 12:37, 22:33; **7**: 8:29, 18:25; **8**: 4:20, 14:16; **9**: 0:12, 10:07, 20:03; **10**: 5:59, 15:55; **11**: 1:50, 11:46, 21:42; **12**: 7:37, 17:33; **13**: 3:29, 13:25, 23:20; **14**: 9:16, 19:12; **15**: 5:08, 15:03; **16**: 0:59, 10:55, 20:51; **17**: 6:46, 16:42; **18**: 2:38, 12:34, 22:29; **19**: 8:25, 18:21; **20**: 4:17, 14:12; **21**: 0:08, 10:04, 20:00; **22**: 5:55, 15:51; **23**: 1:47, 11:43, 21:38; **24**: 7:34, 17:30; **25**: 3:26, 13:21, 23:17; **26**: 9:13, 19:09; **27**: 5:04, 15:00; **28**: 0:56, 10:52, 20:47; **29**: 6:43, 16:39; **30**: 2:35, 12:31, 22:26; **31**: 8:22, 18:18

STARS WITH COMET INSET: TARAS PRYSTAVSKI

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

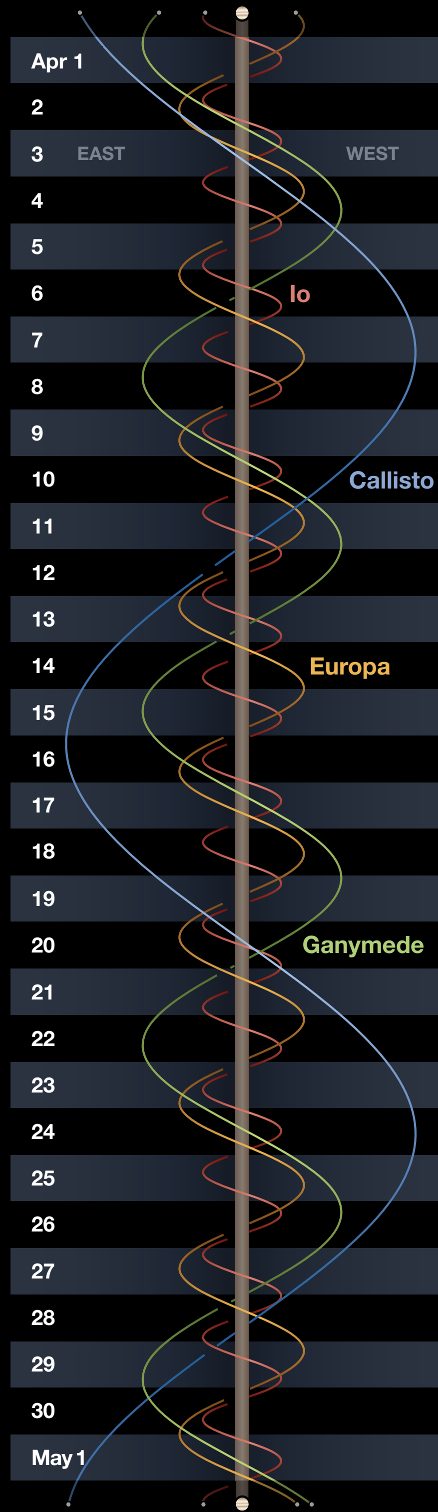
These times assume that the spot will be centered at System II longitude 90° on April 1st. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 90° and 1²/₃ minutes later for each degree more than 90°.

Phenomena of Jupiter's Moons, April 2026

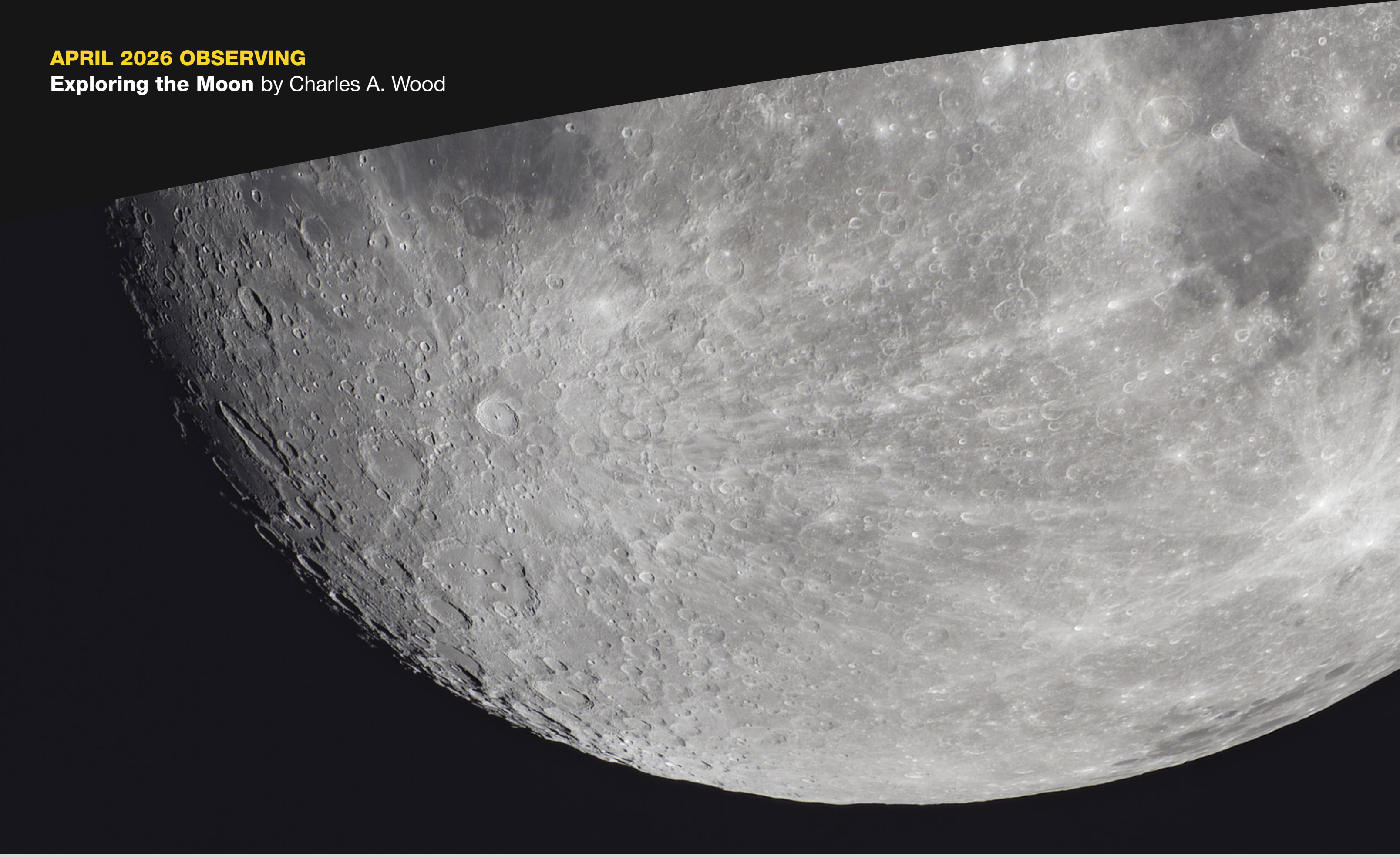
Date	Time	Event
Apr. 1	0:50	I.Sh.I
	1:49	I.Tr.E
	3:06	I.Sh.E
	14:11	II.Oc.D
	19:42	II.Ec.R
	20:52	I.Oc.D
Apr. 2	0:26	I.Ec.R
	18:02	I.Tr.I
	19:19	I.Sh.I
	20:18	I.Tr.E
	20:49	III.Tr.I
	21:35	I.Sh.E
Apr. 3	0:06	III.Tr.E
	1:58	III.Sh.I
	5:22	III.Sh.E
	9:17	II.Tr.I
	11:49	II.Sh.I
	12:05	II.Tr.E
	13:13	IV.Tr.I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

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

Jupiter's Moons



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



SEAN WALKER

▲The bright southern highlands best seen near full Moon are the remnants of the lunar magma ocean composed of low-density anorthosite crust material.

Revising the Timeline of the Early Moon

Newly acquired samples are changing our understanding of lunar history.

Samples returned from the Moon during the Apollo and Luna missions form much of the foundation of our current understanding of lunar history. Precise measurements of actual lunar rocks established new theories of when and how the Moon formed and its evolution over the next 4.5 billion years. Since then, new computational models of possible physical and chemical processes, as well as remote-sensing data from Earth-based telescopes and orbiting spacecraft, have broadened our understanding of lunar science. Now, nearly 60 years after Apollo 11, newly collected lunar rocks from previously unsampled terrains are generating an explosion of data that's forcing a rethinking of the history of the Moon. This new material comes from two Chinese sample-return missions: Chang'e 5, which landed in northern **Oceanus Procellarum** on the lunar nearside, and Chang'e 6, which landed in and studied the South Pole-Aitken basin on the farside.

Important outcomes from these latest data are significant revisions of the timing of fundamental lunar processes. Here are some of the new results.

According to early radiometric dating of the Apollo samples, the Moon formed between 4.35 to 4.47 billion years ago. Dozens of studies that followed extended this range slightly to 4.54 billion years. Since there are no samples from the actual event, all these ages are based on assumed models of the physical processes of how the Moon formed.

Recently, Mu-Han Yang (Chinese Academy of Sciences, Beijing) and colleagues determined a novel method to date the Moon's formation. Their model is rooted in the hypothesis that the most energetic event in early lunar history was the collision of primeval Earth with a large planetesimal whose impact debris formed the Moon. The immense temperature generated by this cataclysmic event started the clock for the radioactive decay of unstable isotopes into stable ones (known as *parent* and *daughter isotopes*, respectively). The high temperature also melted the young Moon and created the lunar magma ocean (LMO). Yang's team assumes that the LMO was molten and well-mixed so that it averaged out the various isotopic systems. Following complex geochemical analysis, Yang's group proposes that the Moon formed 4.516 billion years ago.

The heating and cooling of the LMO resulted in *differentiation*, or the separation of the ocean's mineral components by density. In particular, minerals made of heavy elements such as lead sank to the bottom of the ocean while minerals abundant in lighter elements rose to the top, creating the anorthosite-rich crust that dominates the lunar farside and the bright southern highlands of the nearside.

Yang and colleagues also determined that the cooling of the magma ocean would segregate more minerals, creating the source regions for the lunar magmas 4.38 billion years ago that later prolifically erupted as basaltic lava flows between about 4.0 and 3.2 billion years ago.

The 2,500-kilometer-wide South Pole-Aitken (SPA) Basin on the lunar farside is the largest and oldest impact basin on the Moon. Previously, scientists could only estimate the SPA's age by noting that it was older than Imbrium Basin, which has been dated to 3.85 billion years old. To do this, they used Imbrium as a calibration point and compared crater counts as well as other dated samples.

Then on June 1, 2024, Chang'e 6 became the first successful sample-return mission to the lunar farside. The craft touched down in the Apollo Basin on the floor of SPA (see image below) and provided samples of multiple rock types, which Chinese scientists categorized by their compositions. In particular, two groups of samples are different varieties of *norite*, a magnesium-rich igneous rock often considered to be from the lunar mantle. These norites are interpreted by Bin Su (also at the Chinese Academy of Sciences) and colleagues as mantle rocks crystallized in melt sheets created by the vast energy of a basin-forming impact.

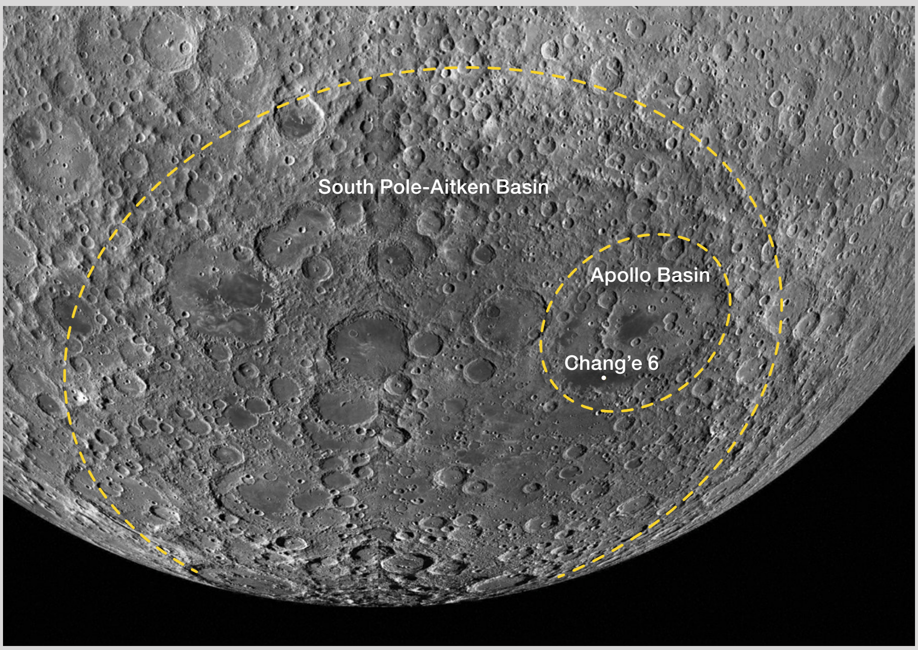
Researchers interpret the most magnesium-rich norites' age of 4.25 billion years to correspond to the formation age of the SPA. They dated other Chang'e norites with lower amounts of magnesium to 3.87 billion years, which they propose to be the age of the Apollo Basin, as implied by remote-sensing data. Interestingly, in 2018 Csilla Orgel (Free University of Berlin) and colleagues using the crater-counting method estimated the Apollo Basin's age to be 4.14 billion years. Which is correct?

Increasing the uncertainty, a 4.33-billion-year age for the SPA was recently proposed by two research groups. In 2024, Mélanie Barboni (Arizona State University, Tempe, Arizona) and colleagues noticed that 500 previously dated lunar zircons from multiple lunar locations frequently yielded ages near 4.3 billion years. Her team employed more precise measuring tools to reanalyze 13 zircon crystals from Apollo collections, finding ages between 4.334 and 4.338 billion years; This close clumping of ages argues that the zircons likely formed from a single, large event. The team proposed that the formation of SPA was the most likely major event that set zircon ages to one date and distributed them widely across the Moon.

In 2025, a research team led by Katherine Joy (University of Manchester, UK) published analyses of a lunar meteorite named Northwest Africa 2995. This meteorite is a *breccia*, a collection of different rock and mineral fragments. The compositions of those components are consistent with rock types found along the eastern limb and within the SPA Basin. Because Northwest Africa 2995 is dated at 4.33 billion years — older than any suspected age for the eastern side of the Moon — Joy and her colleagues propose that this dates the formation of the SPA Basin.

Radiometric measurements can be extremely precise, but often there remains uncertainty about what event a measurement is connected to. This is especially true for dated material that are *clasts* (fragments) of rocky material embedded within larger pieces of rock, and it's never certain where the clasts originate from. And as seen above, models or explanations are often proposed to suggest how physical processes could yield a measured age, but the models may not be correct.

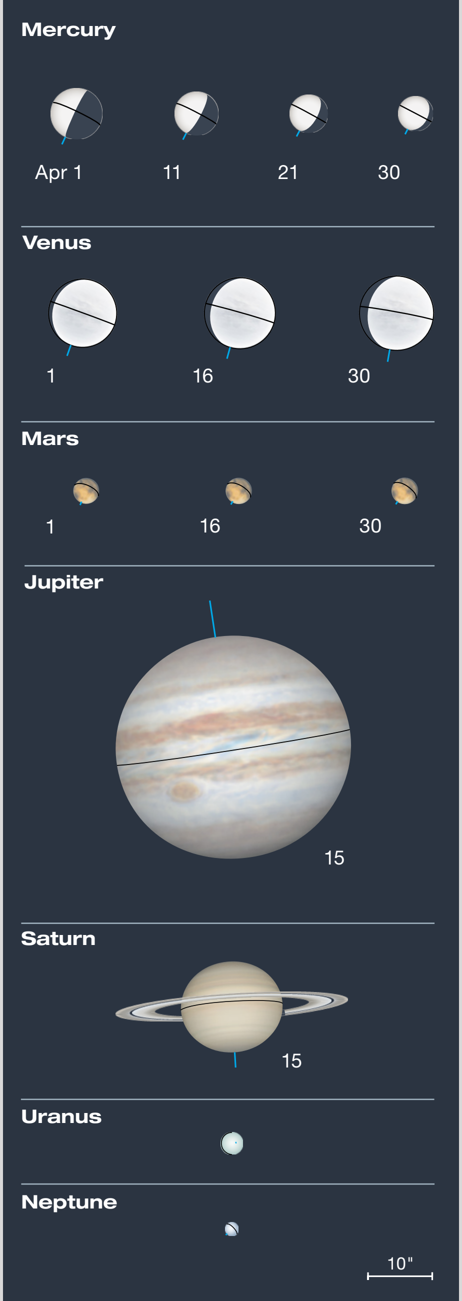
To gain more confidence in our interpretations of the most precise radiometric data, we'll need many more samples from known provenances. Hopefully, such samples will be collected during the next decade by both Chinese and American astronauts.



NASA / GSFC / ARIZONA STATE UNIVERSITY

Contributing Editor **CHUCK WOOD** is coauthor of *Extreme Illumination Atlas of the Moon*, available at **amazon.com**.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** lost in the Sun's glare all month • **Venus** visible at dusk • **Mars** remains out of view all month • **Jupiter** transits before sunset and sets in the predawn • **Saturn** visible low in the east at dawn starting on the 30th.



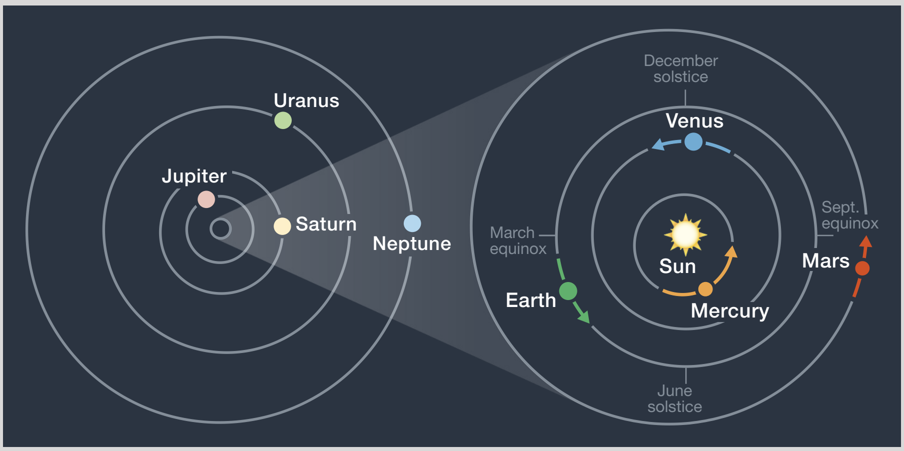
▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

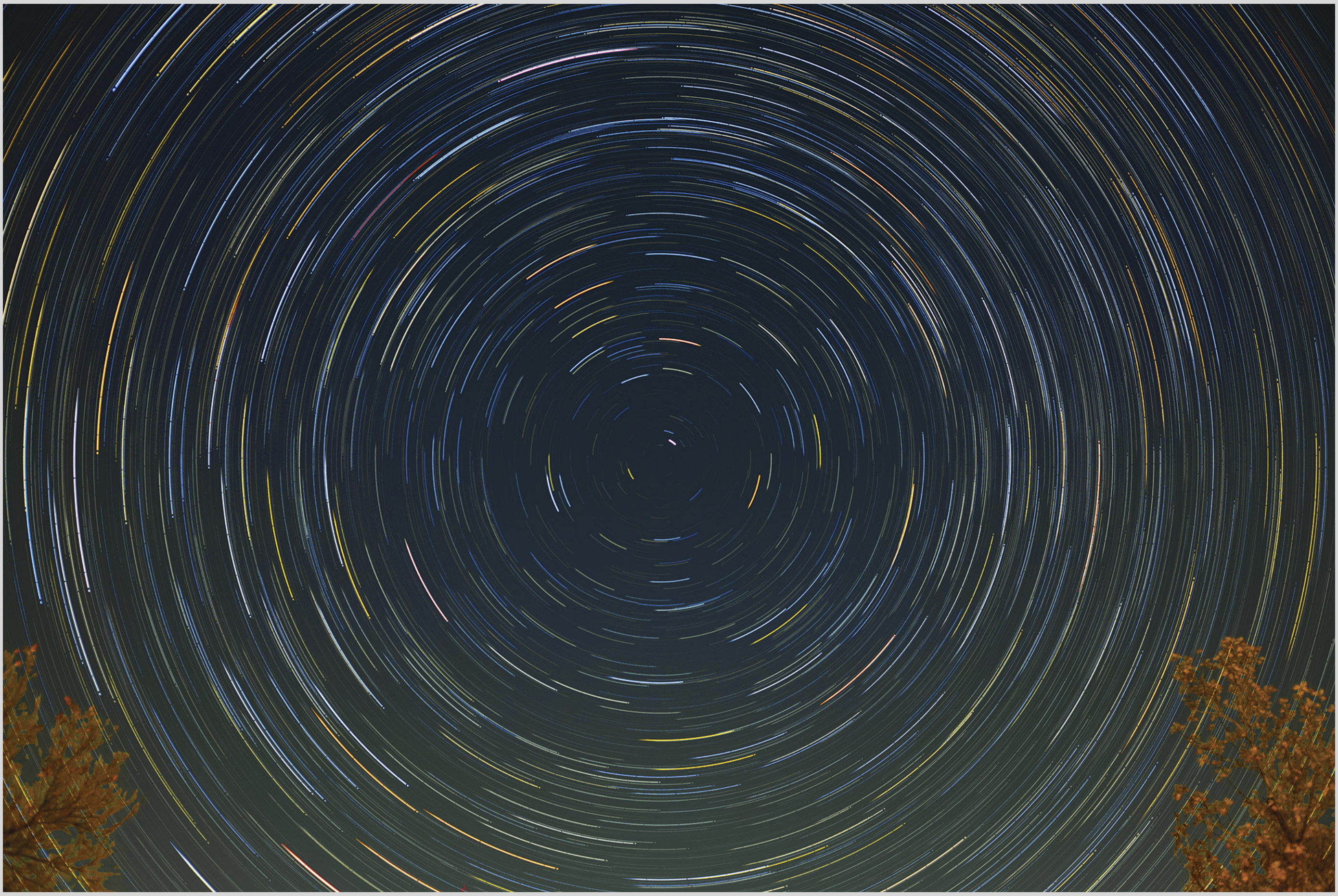
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during April. The outer planets don't change position enough in a month to notice at this scale.

April Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	0^h 40.1^m	+4° 19′	—	–26.8	32′ 01″	—	0.999
	30	2^h 27.7^m	+14° 36′	—	–26.8	31′ 46″	—	1.007
Mercury	1	23^h 00.6^m	–7° 45′	28° Mo	+0.3	8.0″	45%	0.842
	11	23^h 42.1^m	–4° 33′	27° Mo	0.0	6.8″	60%	0.987
	21	0^h 34.9^m	+0° 56′	22° Mo	–0.2	6.0″	73%	1.127
	30	1^h 31.0^m	+7° 20′	16° Mo	–0.7	5.4″	85%	1.239
Venus	1	1^h 57.2^m	+11° 30′	20° Ev	–3.9	10.6″	94%	1.569
	11	2^h 44.4^m	+15° 54′	23° Ev	–3.9	10.9″	92%	1.530
	21	3^h 33.3^m	+19° 38′	25° Ev	–3.9	11.2″	90%	1.487
	30	4^h 18.8^m	+22° 16′	27° Ev	–3.9	11.6″	88%	1.443
Mars	1	23^h 35.0^m	–3° 50′	18° Mo	+1.2	4.1″	99%	2.295
	16	0^h 17.9^m	+0° 52′	21° Mo	+1.2	4.1″	98%	2.271
	30	0^h 57.5^m	+5° 11′	24° Mo	+1.2	4.2″	98%	2.247
Jupiter	1	7^h 07.1^m	+22° 55′	95° Ev	–2.2	38.9″	99%	5.070
	30	7^h 20.0^m	+22° 33′	69° Ev	–2.0	35.7″	99%	5.529
Saturn	1	0^h 22.4^m	+0° 06′	6° Mo	+0.9	15.9″	100%	10.484
	30	0^h 35.3^m	+1° 27′	31° Mo	+0.9	16.1″	100%	10.334
Uranus	16	3^h 47.7^m	+19° 48′	33° Ev	+5.8	3.5″	100%	20.301
Neptune	16	0^h 10.9^m	–0° 15′	23° Mo	+7.9	2.2″	100%	30.801

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





Shooting Star Trails

Here's an easy way to capture Earth turning beneath our feet.

Most astrophotography is about holding the stars in place. We do this using a variety of techniques, from short exposures to star trackers and precisely aligned mounts to cancel out Earth's rotation. But star-trail imaging turns that idea on its head. Instead of resisting the sky's motion, star trails let it unfold, turning the passage of time itself into the subject of the final picture.

Over an hour or two, the stars draw their graceful paths across the camera frame. Where those paths go depends on where you aim your camera and where you're standing on Earth. The familiar arcs around Polaris by the north celestial pole is just one of many possible patterns. Some stars trace tight circles; others stretch long curves or nearly straight lines.

Best of all, these trails are surprisingly easy to capture. They don't even require dark skies — by taking a series of short exposures and then stacking and blending them with free, easy-to-use software, you can create a single image that records hours of stellar motion, even from a brightly lit backyard in the city. And part of the beauty is in how little you need to get started.

Your Basic Gear

Star-trail photography doesn't demand exotic, expensive equipment, but it does require consistency. Any DSLR or mirrorless camera with a wide-angle lens will work as long as it's mounted on a fixed, sturdy tripod and a ball head that truly locks down tight. You're committing to a long-exposure sequence, so even small shifts in your aim will show.

Automating your exposures is essential. Many cameras include an intervalometer (check your manual), but if not, shutter-release cables with a button lock are inexpensive. Either way, the goal is the same: set the camera to continuous-fire mode, lock down the shutter-release button, and let the camera fire on its own without being touched again.

Long star-trail sessions often fail due to battery power and storage. Cold

▲ **A CLASSIC SHOT** Centered on the north celestial pole, this iconic star-trail composition uses Polaris (short, bright streak above) to mark the apparent pivot point of Earth's rotation. The author captured the sequence from a residential neighborhood under Bortle 6 (bright suburban) skies and later combined into a single star-trail image.

▶ AUTOMATE YOUR EXPOSURE RUN
Use your camera's built-in intervalometer or an external handheld unit (shown at right) to program your exposure sequence. You can also use your camera's exposure settings combined with its continuous-shooting (burst) mode and a shutter-release cable to snap exposures for as long as you desire.

weather drains camera batteries fast, so start fresh and bring spares or use an external power supply. I prefer to use a high-capacity memory card with at least 32 gigabytes (or more).

Framing Your Shot

Star trails work with almost any lens you own, and this opens up creative opportunities. Wide-angle lenses (14- to 35-mm for a full-frame camera sensor, 10- to 24-mm for APS-C-size sensor) capture broad expanses of sky and make it easy to include interesting foreground elements like trees, mountains, buildings, or other landmarks in your field of view. The trade-off is patience. With so much sky to fill, expect an hour before the trails really take shape. Longer-focal-length lenses (50-mm-plus for full-frame, 35-mm-plus for APS-C) help when time is limited. You see less sky, but you're magnifying a smaller patch, so stars move across the frame faster.

Once you've chosen a field of view, the next decision is where to aim the camera. Both the direction you aim as well as your geographic latitude determines whether you record circles, arcs, or lines in the frame. Stars near the celestial pole draw tight, slow circles since the stars are closer to the point of rotation; stars near the celestial equator trace huge arcs that appear to move a greater distance in each exposure due to their distance from the poles. Your latitude dictates the angle of this rotation axis since the celestial pole sits above the horizon at the exact angle of your latitude.

From mid-northern latitudes, you have three distinct composition choices: Face north to capture concentric rings anchored by Polaris, the North Star, or turn south for broader, sweeping arcs. Aim east or west, and stars near the celestial equator draw nearly straight lines through the camera's mid-frame, while trails at opposite corners of the frame curve toward the poles. The Southern Hemisphere follows the same geometry, just flipped. The practical difference is the lack of a prominent "South Star," though it's easy to find by taking a single, 30-second exposure pointing roughly south. The short arcs in the photo will point the way.

Camera Settings

Focusing your camera on stars takes a little practice because autofocus doesn't work on stars, but manually focusing it is pretty simple. First, switch to manual focus (MF) and Live View, then aim at a bright star. Adjust the focus ring until the star image on the rear LCD screen appears as small as possible. If it's too dim to judge, decrease your shutter speed or boost the ISO setting temporarily.

Turn off image stabilization on your tripod-mounted camera since it can introduce small vibrations as the system hunts for nonexistent camera shake. And if your camera offers a long-exposure, noise-reduction setting, be sure to disable it as it's unnecessary and will add a larger gap between stars in your final composition.

For this workflow, you can shoot in JPEG format, which is smaller in file size, writes faster, and plays nicely with star-trail software without the need for file-format conversion. However, shooting in RAW format offers full, uncompressed image data and flexibility in post-processing. Many cameras can record both JPEG and RAW, but this takes up more memory space and requires converting or pre-processing the results before you can bring your images into your star-trail stacking software.

◀ BLENDED SEQUENCE COMPOSITE
This view, assembled from images taken from a dark site in Alberta, Canada, traces the geometry of the sky: long, arcing star trails to the north (upper left) and south (lower right) and the near-straight trails close to the celestial equator, which crosses the center of the field of view. All frames were exposed for 15 seconds at ISO 1600 with a 14-mm lens at f/4 on a full-frame DSLR camera.

Set the white balance to Custom or Daylight, as Auto White Balance isn't reliable in night photography, and you'll see it once you blend the frames together. Set the color temperature to anywhere between 3800 and 4200 kelvin, which works for many skies. Choose a warmer (lower) value if the background appears too blue, and cooler (higher) value if it skews orange. Then switch your camera to Bulb (B) mode to adjust for manual exposure settings and the intervalometer.

Exposure and Timing

With framing and focus set, it's time to dial in exposure. Only two things matter most for this workflow: sky brightness and how long you can expose before the background sky gets too bright. Start by opening the lens to its maximum aperture (lowest f-stop). Set the ISO to 1600 and take a 30-second exposure (the maximum most DSLRs can do in continuous-fire mode). When the exposure is complete, examine it on the rear LCD screen to determine if the sky background is acceptably dark, using the histogram in the camera function menu.

On the histogram, aim for the sky to peak about a quarter to a third of the way from left, such that star colors come through, but stars aren't oversaturated and appear white. Shooting with longer-focal-length lenses produces notable gaps in the final blend; bumping the ISO slightly smooths trails, and gap-filling software helps, too. If you're including the foreground, expose it in the same frames or shoot it separately and blend later. Then finish with a final focus check.

For trail density, two hours is a solid baseline. With 30-second exposures, you'll get around 240 frames for shot count and then let it run. Be sure to secure the shutter-release cable to the tripod so it doesn't dangle and get accidentally tugged mid-sequence.

Blending and Beyond

With your exposures in hand, you'll need to combine them into a final trailed result. Enter *StarStaX* (**https://is.gd/starstax**), a free, cross-platform tool designed for blending star-trail sequences. It reads JPEG, TIFF, and PNG. If you shot RAW, export them all using the same settings in your camera's RAW processing program, or *Adobe Lightroom* (**lightroom.adobe.com**) using the same white balance and settings across the run.

Before loading all your frames, do a quick cull. Move your test shots, frames with obvious bumps, heavy cloud smear, or bright satellite or aircraft streaks into a rejection folder. No need to delete them. You can bring one or two back if removing them creates too big a gap in the trails.

Load your accepted images into *StarStaX* and and click on the Preference icon at the right of the screen and click the ***Blending*** tab. I use most often the ***Gap Filling*** mode because it smooths small breaks from tossed frames. Both ***Gap Filling*** and ***Lighten*** blending modes use a lightening approach in which the brightest pixel wins and trails accumulate naturally, but ***Gap Filling*** lets you adjust for breaks afterward when you select the ***Tools*** icon located below ***Preferences***. Leave the other settings at default and hit the ***Start Processing*** icon at top-left of the screen. The preview builds frame by frame in real time. Once it finishes, adjust the ***Threshold*** and ***Amount*** sliders in the ***Gap Filling*** tools if needed, then save. If you plan to tweak curves or color later, save as TIFF and bring it into your preferred image editor.

Because you shot a sequence, you can also make a time-lapse video from the same frames (*S&T:* Feb. 2026, p. 55). Which route you choose is totally up to you. Good luck!

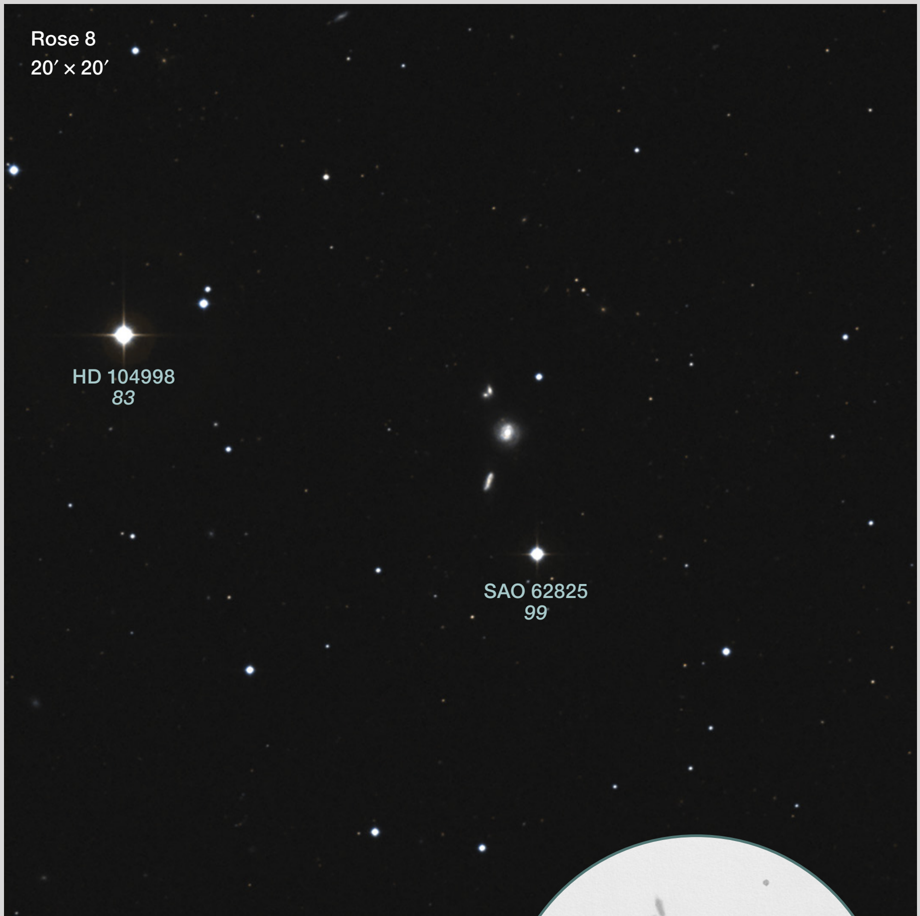
■ **SARAH MATHEWS** spends most clear nights outside with a camera, and the rest of her time convincing others to do the same through her YouTube channel (**youtube.com/@SarahMathsAstro**).

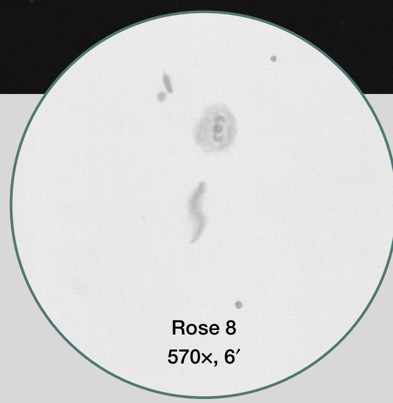
▶ **COMET STAR TRAILS** Star trails appear tapered in this composite, creating a comet-like, 3D effect as each bright star fades along its path. To achieve this illusion, the author used *StarStaX* with its ***Blending Mode*** set to ***Comet Mode***.

The Rose Galaxy Groups

Dip into this obscure catalog for a sample of challenging springtime targets.

Visual observers who've seen the popular Hickson galaxy groups (*S&T:* Apr. 2023, p. 57) may wonder if there are galaxies that huddle even more closely together. Yes, there are — but we'll have to peer a little more deeply into the universe to spot them. James A. Rose, who at the time was at Yale University Observatory, assembled a catalog of such extra-tight groups in 1977, which he published in *The Astrophysical Journal*. While Rose outlined precise criteria for selecting these groups, he also offered a rough definition of a compact group as an "aggregate of several galaxies whose projected separations are typically on the order of the diameters of the galaxies themselves." The area that he searched lies entirely in the springtime sky and yielded a total of 38 groups. Rose listed galaxies of magnitude 17.5 and brighter, which places them on the ragged edge of observability in amateur telescopes. Still, the careful observer will be rewarded with sights that could be considered breathtaking when taking into account what these huddled smudges represent. Better yet, under excellent observing conditions some of the member galaxies will show signs of structure. Let's take the opportunity to scan the springtime skies for a selection of Rose compact groups.





▲▶ **LITTLE-KNOWN GALAXY GROUPS**
Spend your spring nights hunting down these elusive targets.

In the Celestial Lions

I started my observing session with the first entry in the catalog, **Rose 1**, which lies in southern Leo Minor approximately midway between the 4.3-magnitude double 54 Leonis and 5.1-magnitude 41 Leo Minoris. For all the observations described here, I used my 20-inch Dobsonian sited at a remote Appalachian ridge. At 360×, a pair of 11th- and 15th-magnitude stars bracket the field in an approximately northeast-southwest direction. The members of this galaxy quartet are all around 17th magnitude and stretch across a little more than 1′. However, I could cleanly resolve the individual members. The easternmost and westernmost galaxies (PGC 1696640 and PGC 3760750, respectively) were immediately visible. The former appears compact, the latter extended in right ascension. The small galaxy PGC 1696639 next to the easternmost member is very faint, diffuse, and slightly extended north-south. The fourth galaxy, PGC 1696090, is the most difficult to see. It appears as a small compact dot that's only intermittently visible, like a slightly defocused star. When comparing the visual appearance of the group with photographs, I noted that the visible portion of the westernmost galaxy is only its central core; I couldn't detect its spiral arms even in the excellent transparency of the mountain skies.

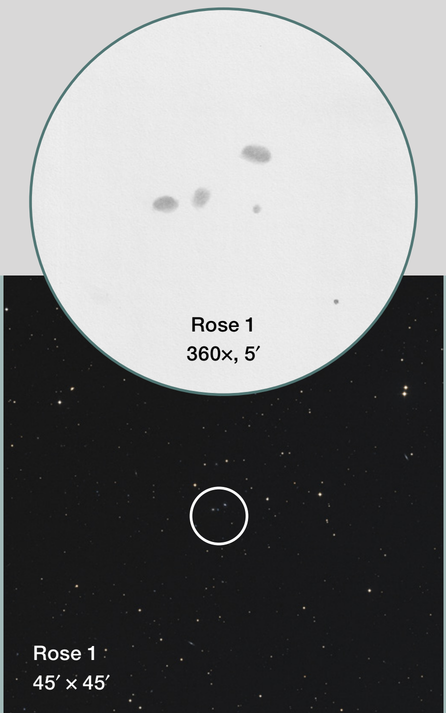
Moving on to **Rose 3** in Leo, you'll have to point your telescope about 14.5′ north of 8.2-magnitude HD 95620. I recommend using the comparatively bright edge-on galaxy UGC 6112 lying some 9′ south-southeast of this star — together they make a line that points the way to Rose 3. In the high-magnification field, the group is situated just southeast of a pair of stars that shine at magnitudes 12 and 15 and immediately south of a 16th-magnitude star.

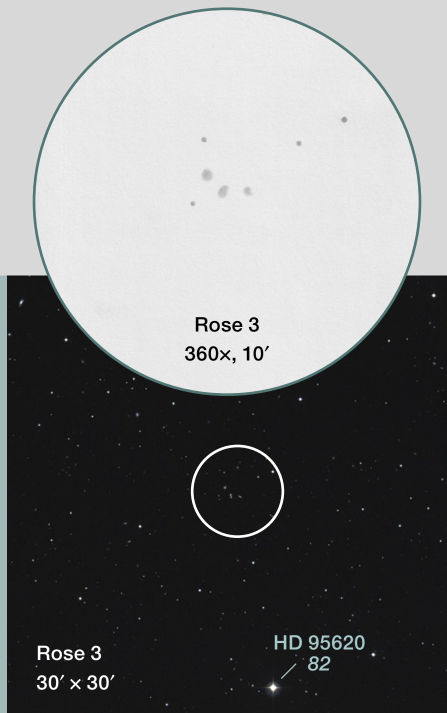
Each member of the galaxy cluster is magnitude 17.5, and together they extend approximately 1.2′, smaller than the entire size of UGC 6112. I instantly detected the easternmost component of the quartet, but it appeared round and small with no concentration. The two galaxies at the center of the group were visible intermittently as an unresolved glow. The fourth member was equally faint. In the poor seeing that usually accompanies the most transparent nights at my observing site, the best I could tease out was the round core of this edge-on galaxy lying on the western side of the group. I could just detect the brighter of two foreground stars on the eastern edge, shining at magnitude 17, which indicated the depth of the field.

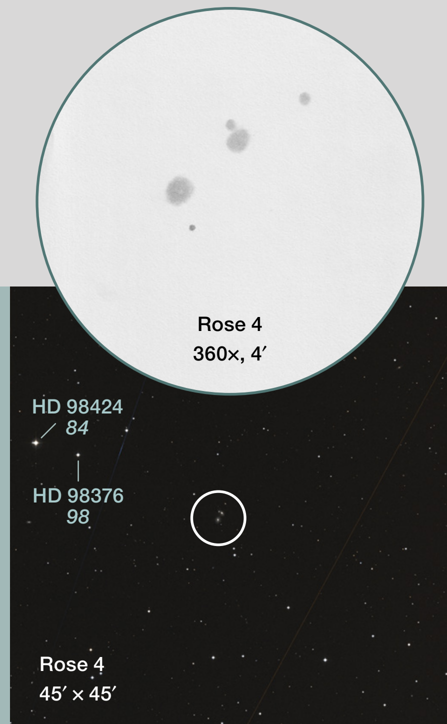
Visiting Ursa Major and Leo

To find **Rose 4** we need to visit Ursa Major, just south of the Big Bear's hind paws. Look for two stars a bit more than 1° south-southeast of 3.8-magnitude Xi (ξ) Ursae Majoris — HD 98424 and HD 98376 (magnitudes 8.4 and 9.8, respectively), which point to the galaxies some 15′ to the southwest. At 150×, I easily saw the group. Switching to 360×, the brightest member I noted wasn't the central galaxy (designated UGC 6314), but rather its neighbor to the southeast (PGC 34539). The UGC galaxy appears both fainter and smaller and has a small companion that touches its northeastern side. Farther to the northwest lies the fourth and faintest member at magnitude 17.0 and similar in size to the small companion. If in doubt, use the 16.8-magnitude star immediately southwest of the brightest galaxy to confirm whether you're achieving the necessary depth of field. The grand-design arms in UGC 6314 and the arm or plume stretching from its companion are appealing targets. While I couldn't detect any traces of them in the 4″ seeing we were experiencing, if you're lucky to observe Rose 4 on a night that's both transparent and stable, it's worth upping the magnification and expending some effort trying to spot these features.

Rose 5 is a highly detailed group east of the rear legs of the Great Bear. You can star-hop to it by starting at 6.5-magnitude HD 103500, skipping over to 11.6-magnitude NGC 3941 about ½° northwest, and then continuing another 1° northwest to land at 9.6-magnitude HD 102554. At 150×, Rose 5 was readily visible. Switching to 360×, the highest magnification I could use productively on this target, I initially detected two galaxies that lay almost parallel to a nearby pair of faint stars. With effort, I resolved the northeastern glow into







DIVING DEEP AND AT THE EYEPIECE Use these images as finders to guide you to the Rose groups of galaxies. The dimensions of the images are marked, and magnitudes are given without the decimal point. The author sketched the targets at the eyepiece of his 20-inch telescope from his observing site on an Appalachian ridge. The magnification that the author used are indicated as well as the size of the field of view.

Rose Galaxy Groups

Object	Mag	Size	RA	Dec
Rose 1	16.5, 16.5, 17.0, 17.5	1.3′ × 0.2′	$10^h\ 48.1^m$	+23° 58′
Rose 3	17.5, 17.5, 17.5, 17.5	1.2′ × 0.4′	$11^h\ 02.6^m$	+17° 06′
Rose 4	15.2, 15.5, 16.5, 17.0	1.8′ × 0.3′	$11^h\ 18.1^m$	+30° 25′
Rose 5	16.0, 16.5, 17.5, 17.5	0.9′ × 0.2′	$11^h\ 48.0^m$	+37° 26′
Rose 6	16.5, 17.0, 17.0, 17.0	0.5′ × 0.2′	$11^h\ 48.4^m$	+25° 45′
Rose 8	14.0, 15.2, 16.5, 16.5	1.9′ × 0.4′	$12^h\ 04.8^m$	+31° 10′

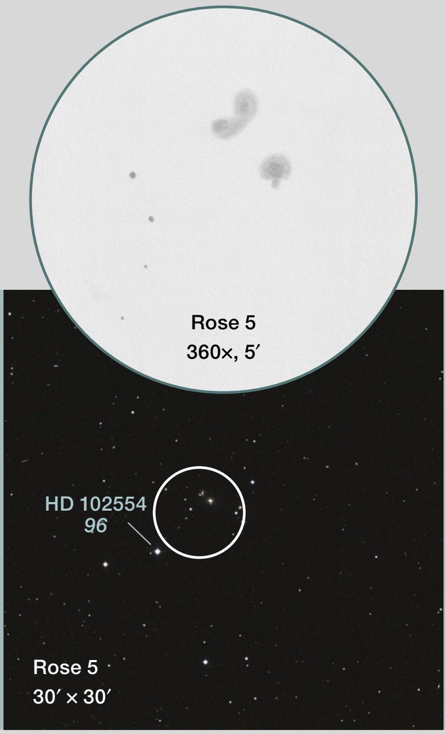
Angular sizes are from recent catalogs. Visually, an object's size is often smaller than the cataloged value. Right ascension and declination are for equinox 2000.0. Magnitudes are visual.

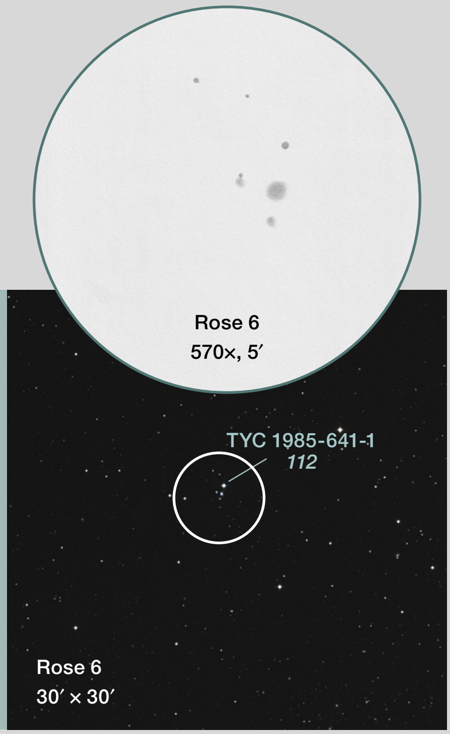
two objects that appeared compact and embedded in the common halo. The southwestern galaxy in the group is the brightest. I noted the faintest member only as an extension on the southern side of the southwestern galaxy. However, further scrutiny and patience began to yield finer detail. The large southwestern galaxy (PGC 2100898) showed a flattening on its southern edge, while its western edge appeared enhanced and separated. The galaxy pair on the northeastern side of the group consisting of PGC 4536310 and PGC 36838 is the most fascinating visually: two comma-shaped objects holding hands, like a miniature of the Antennae Galaxies, NGC 4038 and NGC 4039. The apparent curved connection in this case, however, proves to be an illusion. What we see here is one end of the edge-on galaxy overlapping with the bar inside the other galaxy's ring.

As the seeing had settled toward the end of my observing night, I increased the magnification to 570×. With this approach I succeeded in detecting the smallest members of our next target, **Rose 6**, in Leo. This group is some 9½° northeast of Delta (δ) Leonis, around 1° northeast of 6.0-magnitude HD 101980. (Alternatively, if you have a Go To scope, you can do what I did by finding NGC 3900, then dropping 1¼° south to land on the group.) In the high-magnification field, the 11.2-magnitude star TYC 1985-641-1 is just north of the galaxies. The eastern member PGC 4296837 masquerades as the brightest, but that's due to the added light of a faint star on the galaxy's edge. The largest component (PGC 36857) appears diffuse, and its spiral arms were low-contrast and remained invisible. I could only see the southern member (PGC 1748854) intermittently. In his catalog, Rose listed the latter as two galaxies, but they're difficult to separate.

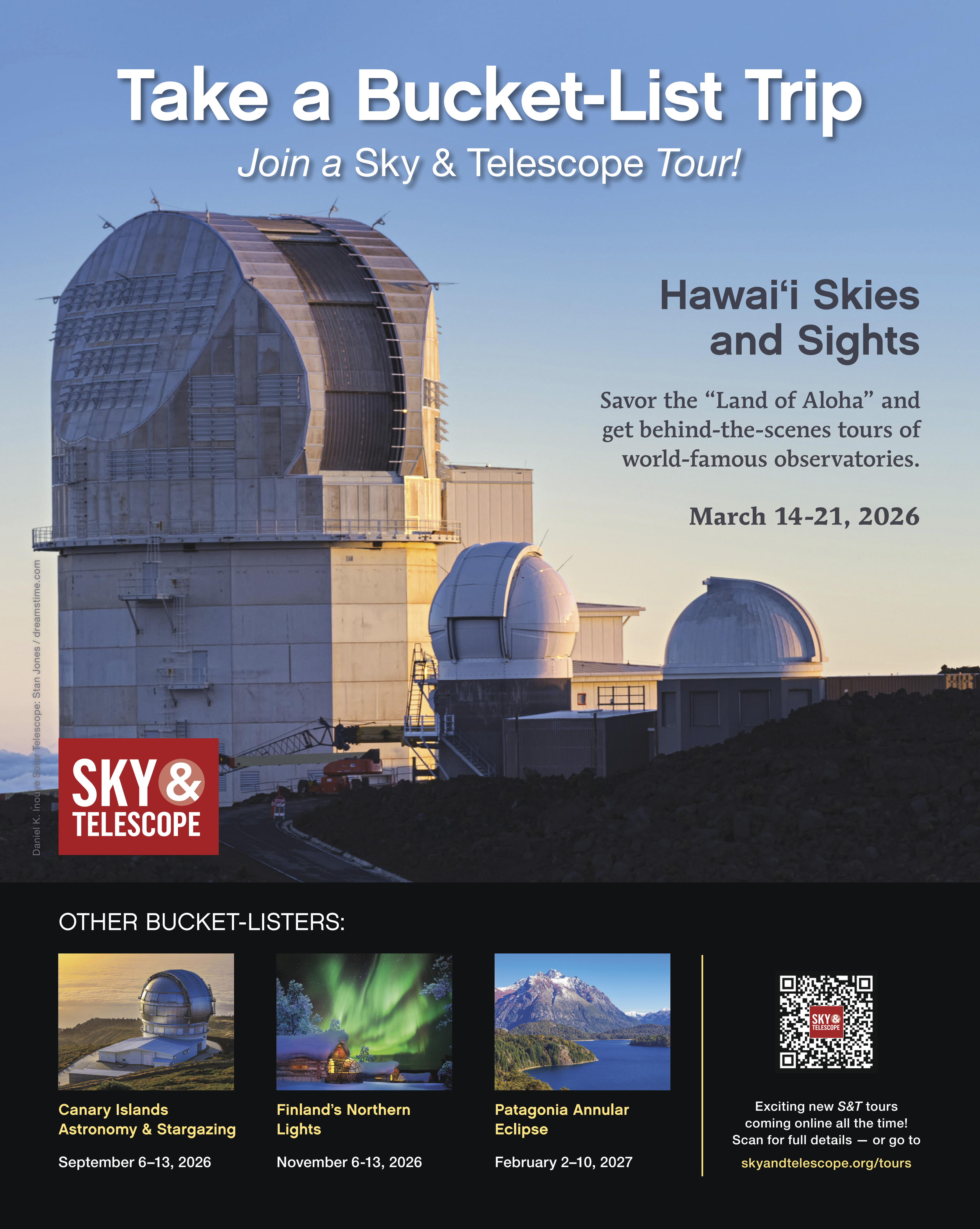
Rose 8 was the cream of the crop and showed tiny but dazzling detail in the seeing that continued to improve. Start at 11.1-magnitude NGC 4062 in southern Ursa Major, then move 45′ south-southeast to a conspicuous pair of 8th- and 10th-magnitude stars (HD 104998 and SAO 62825). The group is just north of the fainter star. At 150×, I spotted three galaxies. Switching to 570×, the northernmost member resolves into two components that touch each other. The western member PGC 38230 is elongated north-south, whereas PGC 4536774, the eastern one, is small and compact. The largest galaxy in the group, UGC 7064, displays a diffuse halo and a nonstellar core. Two extensions are visible north and south of the core and look like little arcs. Whereas images show these bright features to be part of the clockwise spiral structure, in my telescope they both appeared to be opening to the west. The southernmost galaxy stretches north-south and displays an S shape, with its northern end appearing brighter. Comparing my sketch (page 58) with images shows that the S is just the inner parts of the galaxy's far-flung spiral arms.

The Rose galaxy groups are a great project to pursue under dark skies in April. A dedicated observer blessed with good sky conditions may be able to attempt all the targets in Rose's catalog before the spring galaxy season is out. Hopefully the sampler laid out here whetted your appetite!





■ **IVAN MALY** is a biologist living in upstate New York. Visit his observing website at **www.deepskyblog.net**.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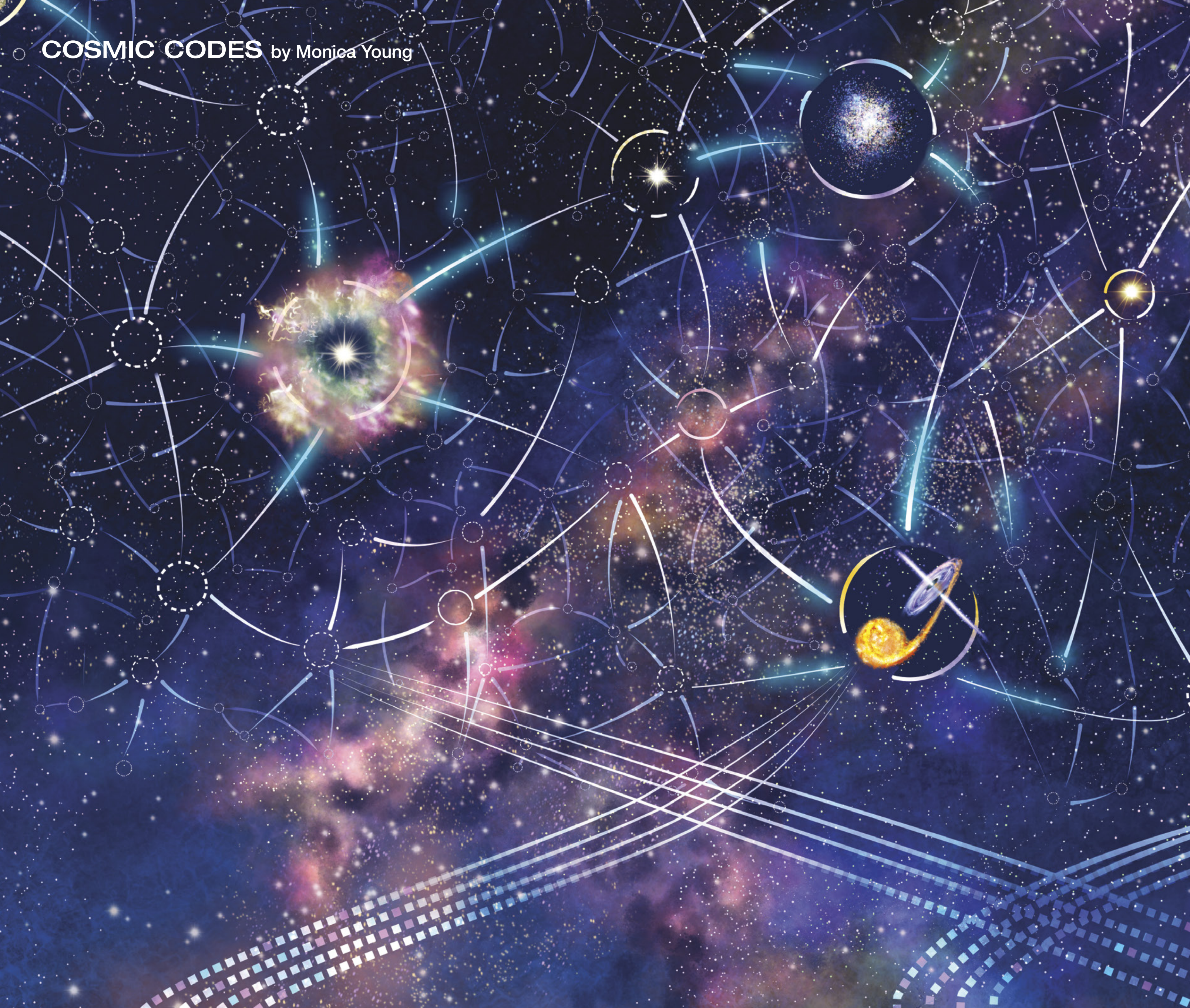


HOW AI IS RESHAP

Artificial intelligence is revolutionizing our world — and how we interpret the heavens above us.

Brains and black holes intrigue Cecilia Garraffo in equal measure.

Both entities caught Garraffo's attention back in 2010, when she traveled from Buenos Aires, Argentina, to work at Brandeis University. She was studying extreme gravitational fields, but she was curious about neuroscience, too. So she joined the school's computational neuroscience group.

There, she came upon the concept of *neural networks*. These aren't webs of cells in a human brain, though they are in some cases meant to mimic them. Neuroscientists can study the brain's complex inner workings using layers of mathematical functions called *neurons*. Similar to real neurons, these artificial neurons receive and send data (often to and from other neurons) as part of a larger network.

Such neural networks were already an integral part of the fast-growing field dubbed *artificial intelligence* (AI). Rather than write numerous lines of code to tell a computer exactly what to do in individual situations, a pro-

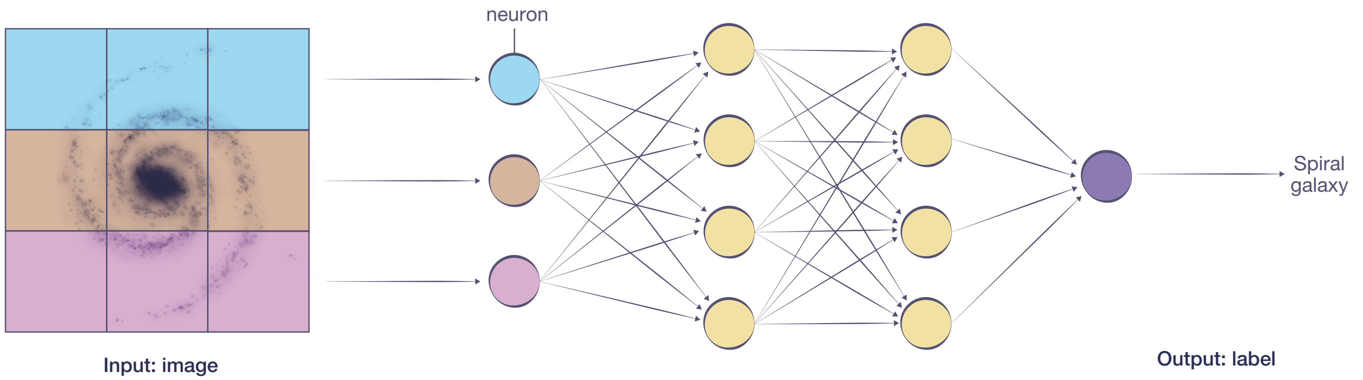
NICOLLE FULLER, SAYOSTUDIO

ING ASTRONOMY

grammer can, in a few carefully calibrated keystrokes, design a neural network that can handle a variety of scenarios without being told exactly what to do. Fine-tuning is required, which usually includes feeding the network a whole lot of training data from which it "learns." But once trained, a neural network becomes a tool that can analyze data on vast, even inhuman scales.

In astronomy, that capability isn't just nice to have, Garraffo argues — it's a must. The Vera C. Rubin Observatory in Chile, the Square Kilometre Array in Australia and South Africa, the global Event Horizon Telescope, and the Euclid space telescope are just some of the observatories that already are or soon will be producing more data than humans can handle.

"We're observing hundreds of supernovae a year now," says Garraffo (currently at Center for Astrophysics, Harvard & Smithsonian). But with Rubin, "we're going to observe 1 million a year." Following up on most of them isn't an option; astronomers must be particular. But choosing the most interesting ones requires looking at them all. "They have to have an algorithm that says, 'This is not only an explosion, it is an anomalous one,'" she adds.



▲ **NEURAL NETWORK** In this simplified diagram, an image is divided into pixels, which are fed into a network of nodes, or neurons, that's been previously trained on labeled images. Each neuron performs a calculation based on the input it receives. Its output then becomes the input to the next neuron. In this case, the result is a classification of the galaxy's type.

Garraffo continued to study theoretical physics, cosmology, and stellar astrophysics — not neuroscience. But she never lost her fascination with neural networks. In 2023, she founded AstroAI, a multidisciplinary group of computer scientists and astronomers, and the first institute dedicated to the development of AI for astrophysics.

It's unlikely that there are many readers of this magazine who don't regularly encounter AI in some form, whether in Google's AI search summaries, online shopping recommendations, or daily activities such as banking. But the technology's adoption in astronomy has been slow in comparison to its eager use in commercial applications.

Astronomer and data scientist Josh Bloom (University of California, Berkeley) champions AI but understands the need for caution. "We are going to have to put a tremendous amount of computational time and people time into this," he said at a colloquium focused on AI-human interactions. "Without a guaranteed result, it's dangerous."

But the rewards are worth those risks, Garraffo believes. "We're missing out on a lot of improvements, developments, and very powerful techniques that we're not using," she says. "Not having access to these methods is similar to not having had access to a computer when computers started."

What Is a Neural Network?

Although astronomers employ many forms of machine learning (*S&T:* Dec. 2017, p. 20), neural networks have recently experienced a real revolution.

To understand this complex model at its simplest, let's consider what's involved when you're deciding which book to read next. You've read many books, and you know what you like. So when evaluating new books, you might make some general distinctions, such as genre — perhaps you're partial to science fiction. You might also evaluate more specific properties, such as preferring a certain author. Some of those preferences might have a stronger weight than others: Even if you like the author Ursula K. Le Guin, for example, you might not mind branching out to other writers.

Supervised neural networks function in a similar way. Here, supervised refers to the learning process. The network learns how to weight preferences by testing against a large set of labeled-by-humans data (your reactions to previously read books) and refining the properties of the network as it goes. Each neuron of the network becomes sensitive to some property of the preferred books. By testing its guesses against the labeled data, the network adjusts how strongly each neuron responds. Now, faced with new data, the network can answer the question, "Should I read this book next?"

There's one key difference that makes this an imperfect analogy: In neural networks, no one assigns neurons to specific jobs. There's no preset "Le Guin" neuron, for example. Individual neurons in a network often have simple tasks, and it's not always clear how those tasks tie to the overall goal. It's only on a collective level that the network determines broader concepts, such as whether this is a book you'd like or whether a galaxy is a spiral. Both philosophically and scientifically, it's still debated whether a neural network can perceive these higher-level concepts the way a human does. Understanding why the network behaves the way it does, and in turn how machines learn what they learn, has been a challenge.

It's not an insurmountable one, though. To shed light on the "black box" problem, researchers are working to *interpret* neural networks, to better understand which choices they're making and why. They can even assess the certainty of any given decision — and that's key when applying AI to science.

Follow the Crowd

Large data sets aren't a new problem. Already at the turn of this century, professional astronomers realized there simply weren't enough of themselves to classify every galaxy in images pouring in from the Hubble Space Telescope's deep fields and the Sloan Digital Sky Survey. Fortunately, humans are pretty good at sorting galaxies by appearance, as long as enough of them participate.

Enter Galaxy Zoo and the crowdsourcing platform that hosts it, Zooniverse. Launched in 2007 (the same year the first iPhone came out), Zooniverse has by now hosted hundreds of projects, with people signing up by the millions to participate. Over almost two decades, those volunteers have classified almost 1 billion galaxies and other objects.

BEATRIZ INGLESSIS / *S&T*

But some data sets are beyond what even crowdsourcing can do. The Euclid space observatory, for example, is observing one-third of the infrared sky in Hubble-like resolution over the next six years, doubling back to image select fields even more deeply (*S&T:* Sept. 2025, p. 14). A decade before Euclid launched, astronomers knew the data volume would pose a challenge. In 2013, Galaxy Zoo lead Karen Masters (Haverford College) calculated that, based on past projects, citizen scientists would need some 70 years to classify just the well-resolved examples of the 1.5 billion galaxies that the space telescope was projected to find.

Nevertheless, citizen scientists contributed. Post-launch, the Euclid team created a short-lived project in which Zooniverse denizens helped classify the iffier-looking galaxies in preliminary data. Mike Walmsley (University of Toronto) used these labeled data to train a network named *ZooBot*.

For Euclid's first data release, *ZooBot* classified 380,000 galaxies "on the fly," as part of the pipeline that processes the telescope's images after they're downlinked to the ground. The AI model even notes whether a galaxy hosts a central bar or has tidal tails. Importantly, *ZooBot* includes a measure of each classification's uncertainty.

"It's a success story on how you develop and deploy AI into the workflow," said Walmsley's collaborator Marc Huertas-Company (Institute of Astrophysics of the Canary Islands, Spain) while speaking at an AstroAI conference in July 2025. "It's not that we took 70 years. It took zero months. . . . This would have been unbelievable 10 years ago."

But applying AI to citizen-labeled data sets won't always improve the results.

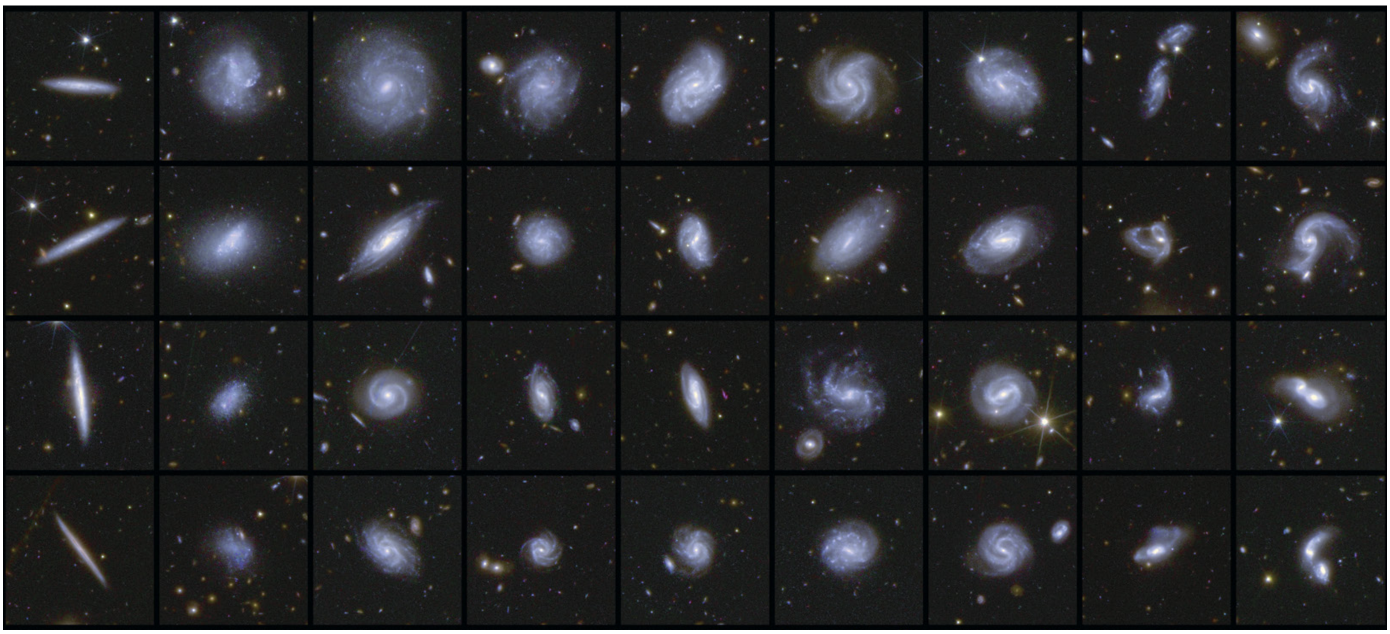
The Milky Way Project was another Galaxy Zoo initiative, launched in 2010, in which users tagged "bubbles" in infrared data. The winds and radiation from massive newborn stars heat and inflate bubbles in the gas that surrounds them. Back then, finding the myriad shapes these bubbles could take in 2D images was still beyond what computer algorithms could do. So in 2012, the Milky Way Project trained 35,000 volunteers to find more than 5,000 bubbles in data from the Spitzer Space Telescope.

Last year, a team led by Toshikazu Onishi (Osaka Metropolitan University, Japan) reported that they'd trained a neural network on the Milky Way Project's data. Testing their model on a small patch of sky, the team found that it identified 98% of the same bubbles as the citizen scientists. Then, when unleashed on a broader region of space, the AI model discovered twice as many bubbles as humans did. Only, most of those new objects aren't actually bubbles.

Matthew Povich (California State Polytechnic University, Pomona), who led the Milky Way Project a decade ago, glanced through a few of the 1,413 new objects. Many, he says, are instead small yellow circles that represent an intermediate stage of massive star formation. Citizen scientists found these features, too, and named them "yellowballs" (*S&T:* June 2015, p. 13). The AI also flagged what Povich calls "random fluff" and, in one memorable thumbnail image, the Pillars of Creation. (The pillars are a site of star formation, but they're not a bubble; they're inside one.)

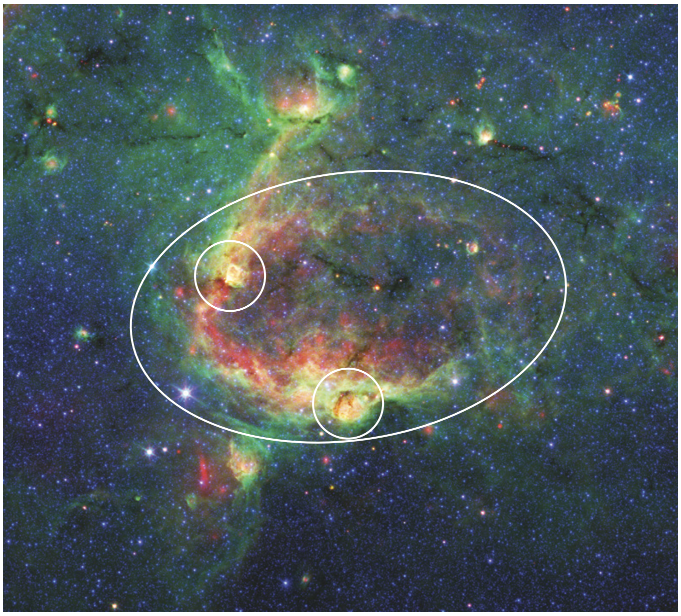
AI FOR AMATEURS

Professional astronomers aren't the only ones making use of AI. See the November 2025 issue, page 64, for a summary of the use of AI in amateur astrophotography.



ESA / EUCLID / EUCLID CONSORTIUM / NASA, IMAGE PROCESSING: M. WALMSLEY, M. HUERTAS-COMPANY, J.-C. CUILLANDRE

▲ **SHAPE SORTER** This image shows examples of galaxies of different shapes, released as part of Euclid's first data set. The release includes a detailed catalog of more than 380,000 galaxies, classified by *ZooBot* according to features such as spiral arms, central bars, and tidal tails that infer merging galaxies.



▲ **BUBBLES** Citizen scientists with the Milky Way Project cataloged bubbles blown by massive newborn stars, such as the ones in this infrared image (marked by white ovals) from the Spitzer Space Telescope.

There are good reasons that finding new bubbles is a difficult task. Even for humans, bubbles are more difficult to identify than spiral galaxies. Spirals look like spirals whether images are fuzzy or sharp, but bubbles may change appearance depending on image resolution.

Or, it could simply be that there are no new bubbles to find: Earlier attempts using a different type of machine learning — a bubble-finding algorithm named *Brut* — found that the Milky Way Project's scouring of the infrared data was mostly complete.

Interpretability: What Does It All Mean?

Even as humans still outcompete AI in select cases, it's appealing to take humans out of the labeling loop. Labeling data is time-consuming and limiting. A workaround is to let the data points label themselves in *unsupervised learning*.

One way to do this is by using a particular neural network called an *auto-encoder*. In this kind of network, data pass through multiple layers of neurons collectively known as an *encoder*. Each layer typically contains fewer neurons than the last, boiling down the data to the most fundamental features. Then, the process runs in reverse: A multi-layered *decoder* expands on those features to reproduce the original data. If the model found the right fundamental properties to describe the data, then the input and output should look the same.

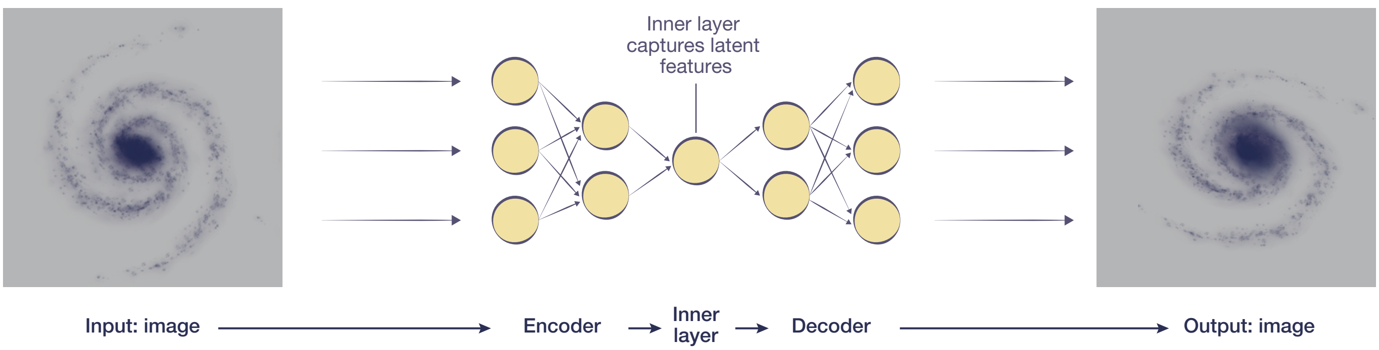
Humans do something similar on a regular basis. Predicting what comes next in "2, 4, 6, 8, 10, 12, . . . " is easy because we recognize the latent pattern: even numbers. Scientists do it, too: If all we know about a star is its temperature, then we can apply a single physics equation (Planck's law) to describe the general shape of that star's spectrum.

Auto-encoders excel at finding latent patterns. The data points themselves tell the neural network what parameters are important — even though the AI isn't trained on labeled data. Such models can learn what cats look like in an unsupervised way — that is, without being told which images show cats — and then go on to generate images of cats on demand.

In commercial settings, that's good enough. But that kind of reconstruction isn't sufficient for science.

"For us, that's not what we want," Garraffo says. "We don't want to merely reproduce the universe. We want to understand it." If the parameters the network deems important don't have an obvious meaning — and they all too often don't — then astronomers must interpret those parameters to understand how they tie to real physics.

As a proof of concept, graduate student Ethan Tregidga (then at Center for Astrophysics, Harvard & Smithsonian) and members of the AstroAI collaboration applied auto-encoders to stars orbiting black holes. In these *X-ray binaries*, the black hole siphons off the star's outer layers. That gas heats up as it spirals in toward the black hole, releasing high-energy radiation as it goes. The processes involved leave fingerprints in the X-ray spectrum that astronomers capture.



▲ **AUTO-ENCODER** In this diagram of an auto-encoder, an image passes through simpler and simpler layers of neurons, which encode the data into a few parameters. Then the decoder reconstructs the data. Comparing the input and output ensures that the network has captured the data's fundamental features.

GALAXIES: NASA / JPL-CALTECH / UNIVERSITY OF WISCONSIN; AUTO-ENCODER: BEATRIZ INGLESSIS / *S&T*

To make sense of the spectra, and to do so in an expedient way, Tregidga employed an auto-encoder. He started backwards, working first with the decoder. Using real, physical quantities, he trained it to create a set of X-ray spectra for various parameters. Then Tregidga froze the decoder, disabling further changes, before hooking it up to the encoder. The network compared the parameters that the encoder was finding against the parameters that the decoder had learned, essentially calibrating itself.

Finally, Tregidga turned the whole thing loose on real data. With a processing speed 2,700 times faster than traditional software, Tregidga's AI model can now derive physical meaning from thousands of X-ray spectra at a time.

There are countless examples of one-off methods like this one, in which researchers have successfully applied a novel AI method to a unique scientific problem. But some astronomers are dreaming bigger.

One Model to Rule Them All

In recent years, revolutionary advances in AI have enabled the development of *large language models*, such as OpenAI's ChatGPT. These train on large fractions of the internet and then offer users answers for just about any question. AI chatbots are capable of taking on everyday, mundane tasks or even quite creative ones. (Note: ChatGPT did not write a single sentence of this article.)

ChatGPT is possible because of a type of neural network introduced in 2017 called a *transformer*. Given enormous quantities of data to train on, transformers learn to give more attention to relevant aspects in the data. As a result of this advance, we now have generalized *foundation models* — of which ChatGPT is only one — that can just as quickly answer "What's the weather today?" as "What is Planck's law?"

Astronomers are employing similar techniques using the languages of physics and math. One example is the "proto-foundation model" for stars that Henry Leung and Jo Bovy (then both at University of Toronto) created.

"WE DON'T WANT TO MERELY REPRODUCE THE UNIVERSE. WE WANT TO UNDERSTAND IT."

"Me and Henry, we got very excited about the kinds of technologies behind large language models," Bovy says. "But they didn't have any way of taking into account scientific data directly, the way we do when we analyze astronomical data."

So they set about doing just that. Using a transformer-based structure, Leung and Bovy built a neural network that can take on a variety of tasks that it wasn't specifically designed to do. The model trained on data from the European Space Agency's Gaia space telescope, which measured brightnesses, spectra, and motions of more than 1 billion stars in the Milky Way.

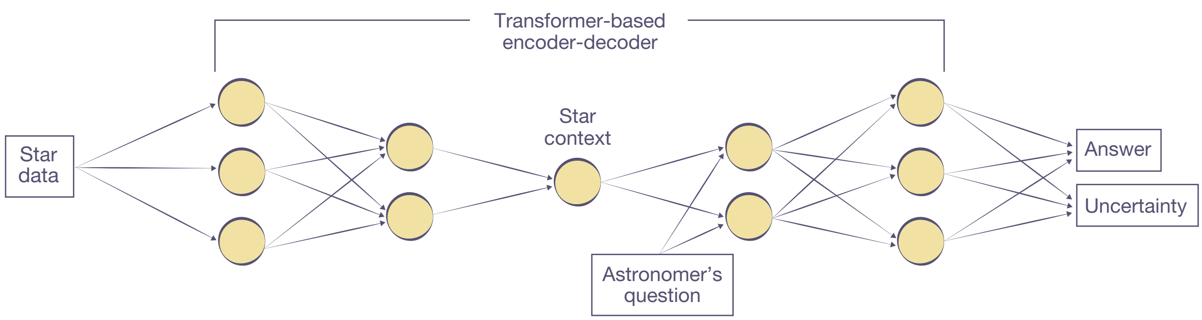
"[We] put in as little physics as we could," Bovy adds, "because we wanted to keep it very broad and see what it could just learn from the data."

The duo also added extra layers of neurons to evaluate the distribution of possible results, enabling the model to measure the certainty of its answers. This capability proves useful when researchers ask the AI a physically impossible question.

When one asks a large language model a question it doesn't know the answer to, it may *hallucinate* an answer that has no basis in reality. For example, when asked "how many a's are in strawberry," a past version of ChatGPT answered: "The word 'strawberry' has 2 letters 'a'." Its answer is wrong because large language models recognize patterns better than they execute calculations. (When queried about why its answer was incorrect, the chatbot offered a reanalysis, a correct answer, and an apology.)

However, Leung and Bovy's proto-foundation model was designed to answer questions not with confidence but with qualifications. "Our take has been that [hallucination] isn't

▼ **FOUNDATIONS** The proto-foundation model that Bovy and Leung created passes data from the Gaia mission through a neural network that's structured as a transformer-based encoder-decoder.

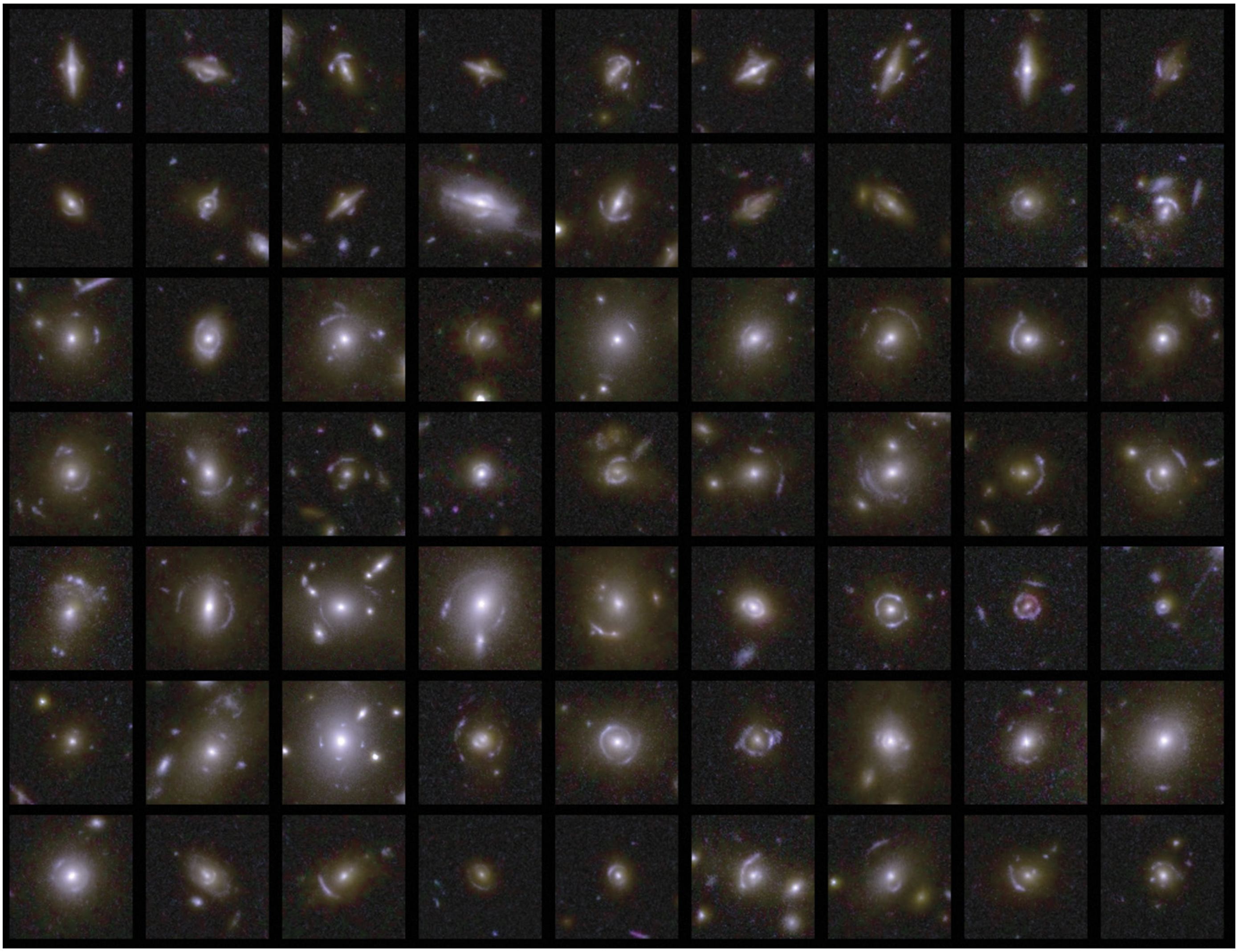


INPUTS: Any number of data points from the Gaia mission (up to a limit, for this model) are fed into the network.

NETWORK: Unlike the auto-encoder that reproduced X-ray binary spectra based on their physical parameters, this encoder-decoder transforms the data. It extracts fundamental physical quantities and observational properties ("star context") and figures out which of those data points are relevant to an astronomer's question.

OUTPUTS: The result is both a single value — the answer — as well as a range of possible values that represents the answer's uncertainty.

BEATRIZ INGLESSIS / S&T



▲ **THROUGH A LENS** Astronomers detected 500 new gravitational lenses in Euclid data using the ZooBot model to do a first pass through the data, followed by citizen-science inspection and expert vetting and modeling. Euclid is expected to capture 100,000 such lenses by the end of its mission.

ESA / EUCLID / EUCLID CONSORTIUM / NASA, IMAGE PROCESSING: M. WALMSLEY, M. HUERTAS-COMPANY, J.-C. CUILLANDRE

such a problem in scientific data," Bovy explains, "as long as we also predict the uncertainty."

For example, he and Leung asked their model to generate a spectrum for a star with a combination of temperature and surface gravity that doesn't exist in nature. "Our model will give you the spectrum of this star," Bovy says. "But it will also say, 'This is extremely uncertain, because I don't really know what I'm doing.'" The model indicates its low confidence in the answer by providing very large error bars.

"HUMANS ARE WAY, WAY BEYOND ANY MACHINE."

Leung and Bovy's model is far from the first attempt to build a foundation-type model — multiple teams of astronomers have released more than a dozen of them over the last two years. In fact, Walmsley's *ZooBot* is a foundation model that can transfer previous learning to new tasks with minimal retraining. Using a tiny sample of just 200 ring galaxies that citizen scientists had identified, *ZooBot* found 10,000 more in data from the Dark Energy Camera Legacy Survey.

Such successes don't mean citizen science is going away — far from it. "We can now use the new labels Galaxy Zoo volunteers are creating to quickly build specialized models," Walmsley wrote in his blog. "Every label is now more valuable, not less."

As powerful as foundation models may be, they are not necessarily the best tools for a given problem. It's also worth noting that their use remains controversial. The broad training they receive makes it easy for scientists to adapt them to different tasks, but adapted models inherit defects in the "parent" model. And of course, with ease of use comes the potential for misuse.

The Many Faces of AI

At last year's AstroAI conference, participants voiced excitement about AI's potential to revolutionize the way astronomy is done. Besides analyzing data, AI tools help astronomers on a daily basis, whether in writing code or scientific papers.

But the true excitement lies in the unknown. AI technology may enable new approaches or interpretations of astronomical data that simply weren't possible before. "There are things that can only be discovered when someone looks at enough scales simultaneously, and that might be more scales than a human can comprehend," says astronomer and machine-learning researcher Philipp Frank (Stanford).

But even as AI accelerates the processes that fuel astronomy, it's generating concern, too. Scientists at the conference pointed out that astronomers risk losing touch with their data if they don't examine celestial objects individually and instead focus solely on ensembles. It's not always easy to see when populations don't represent reality.

"Things can be intrinsically rare in your data set because they're intrinsically rare in the universe — or they can be rare because they're hard to find," one AstroAI participant pointed out. "And then, when you train on that data set, you end up with an algorithm that has learned that bias." Ferreting out biases can be difficult, all the more so when we don't know they are there.

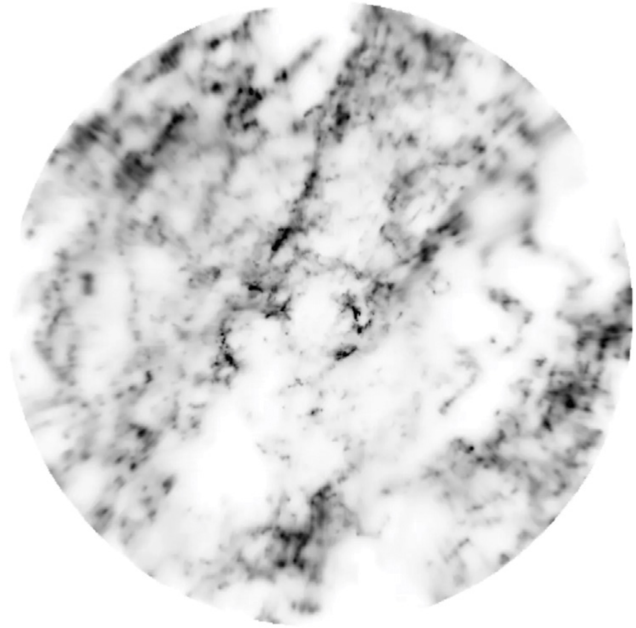
Some concerns are even more philosophical: Do we want AI to be the ones making discoveries? "I wouldn't want to have in my living room something that was painted by AI," points out astronomer-turned-data scientist Viviana Acquaviva (New York City College of Technology). "I assign a value to human creativity." Part of that value is the struggle, she says. Making mistakes is how humans learn. AI helps us find answers faster, but that increased speed may come at the cost of human experience.

Multiple participants at the conference — even those deeply involved in using AI for their research — worry that the technology will ultimately take the joy out of their work. If AI can analyze data, interpret it, and write papers, then perhaps AI can take over astronomers' work completely. "What do we want our job to be in 10 years?" asks Acquaviva. "Do we want to know as much as humanly possible? Or do we want to preserve some of the things that we enjoy?

"You wanted AI to do your dishes, so you can write and study," she adds, "and all that's left for you is the dishes."

Not everyone shares those concerns to the same degree. "There are certain caveats and things for us to maneuver around," says Frank, "but I do think [AI] is transformative in virtually every task."

Frank is part of a team that used AI to map dust in the Milky Way. Dust tends to scatter more blue light than red light, so a star that appears redder than it ought to likely has dust in front of it. By training a neural network on a few million stars observed by the Gaia mission that remain unreddened by dust, researchers generated artificial spectra that are high-resolution, dust-free, and accurate for a star's given spectral type. Then, by comparing Gaia data against generated spectra for millions of stars at a time, Frank and collaborators obtained a measure of how much dust is out



▲ **BETWEEN THE STARS** Astronomers created this dust map around the solar neighborhood using AI. Darker regions are denser with dust. The Sun is at center and the galactic center toward the right; the map is 8,000 light-years wide.

MPA

there. The result? A dust map that extends 4,000 light-years out from the Sun.

"I would say it's AI-assisted, human-in-the-loop work, in the sense that the humans decided what to look at and why, but a lot of the modeling is then machine-driven," says Frank. "We tried to keep the fun — but then, no human is able to process a million stars."

Frank sees this combination of human guidance and AI assistance as key to the future. AI, after all, can understand data in several different forms, scales, and dimensions, and it can process massive amounts of data to learn something new. But it's humans who excel at grasping new ideas using only a few examples.

"Humans are incredible at getting these extremely minimalistic, extremely expressive models," Frank says. "Humans are . . . way, way beyond any machine."

The use of AI continues to expand, and the roles it plays in our everyday lives are still evolving. But from Garraffo's perspective, the developments in astronomy have been overwhelmingly positive. "We are doing it for something that is good," she says.

These tools will free up astronomers' time to do astronomy, she argues — and there will be plenty to do. The wave of cosmic data is still coming, she says. "I'm freaking out, we should all be freaking out! We're not ready." With AI, she adds, "we're going to make so many more discoveries."

■ As news editor of *Sky & Telescope*, **MONICA YOUNG** enjoys experimenting with new technology (and learning about its pitfalls) with regard to strawberries.

Sky-Watcher's HAC125DX Minigraph

This little astrograph packs lightning-fast photographic speed into a compact tube.

HAC125DX Minigraph

U.S. Price: $995.00*
skywatcherusa.com

What We Like

Fast, affordable astrograph

Cabling accommodation in dew shield

What We Don't Like

Small corrected field

Hard to align camera

**Prices subject to change*

MOST EVERYTHING HAVING to do with astrophotography is undergoing a downsizing trend — from the computers controlling our equipment to the cameras recording amazing details virtually unknown to the imaging community a generation ago. Even the telescopes we shoot with are getting smaller or, more accurately, shorter — the focal ratios of astrographs are decreasing, which means photographic speed gets faster, and that's good for astrophotographers (see *S&T:* Aug. 2022, p. 54).

When I started astrophotography decades ago, a telescope with an f/7 focal ratio was considered fast compared to the ubiquitous f/10 Schmidt-Cassegrain telescope that was popular at the time. Fast forward to the mid-2000s when astrophotographers began showing up on the observing field with fast, exotic optical systems sporting f/3 focal ratios — it was like pulling up in a red-hot sports car.

Compact Tube

Today, encountering an imager using a super-fast astrograph is fairly common. The current "speed" bar seems to be f/2, with Celestron's Rowe-Ackermann Schmidt Astrographs currently holding pole position in the race (*S&T:* Jan. 2025, p. 66). Now Sky-Watcher enters the competition with its new Honders Advanced Catadioptric 125DX (HAC125DX) Minigraph. This small imaging telescope, or astrograph, sports a 125-mm (4.9-inch) aperture with a 250-mm focal length, adding up to a blazing-fast f/2 focal ratio costing less than $1,000. Sky-Watcher sent us one so we could determine if this little speed demon was as impressive under the stars as it appears on paper.

The HAC125DX weighs 3.8 kg (8.4 lbs) and is a little less than 40 centimeters (15.7 inches) long when fully assembled. It comes with a pair of hinged-aluminum tube rings on a short, V-style (Vixen) dovetail mounting plate and a pair of universal finderscope brackets that can also hold a small guidescope and ride-along mini-computer if desired.

Given the scope's relatively tiny 16-mm corrected image circle, the HAC125DX with a camera, guidescope, autoguider, and minicomputer would tip the scales at only about 4.5 kg. This is easily accommodated by a small equatorial mount, such as Sky-Watcher's Star Adventurer GTi that I reviewed in the May 2023 issue to make for a complete portable imaging rig that's airline compatible.

The minigraph's Honders Advanced Catadioptric optical design uses a sophisticated combination of a Mangin primary mirror in addition to a full-aperture corrector plate and a final corrective optic in front of the camera to eliminate spherical aberration and field curvature across a 16-mm image circle.

▼ Sky-Watcher's HAC125DX Minigraph is a fast astrograph designed for use with small cameras having tiny pixels.

ALL PHOTOS ARE COURTESY OF THE AUTHOR.

▲ *Left:* Looking down the tube reveals the primary mirror as well as the final corrector where the camera is mounted. A thumbscrew at lower left secures the camera when connected to one of the three included adapters. *Right:* The rear of the Minigraph features a large focusing knob surrounded by two trios of collimation screws; the black ones move the primary mirror while the silver screws lock the mirror's position. Two vents in the upper and lower sections help the optics reach ambient temperature quickly. The pair of black screws at right are used to mount third-party focus motors.

The primary mirror uses Sky-Watcher's signature Radiant Aluminum Quartz coatings, though what sets a Mangin mirror apart from a conventional primary is that the reflective coating is on the back surface of the mirror — its glass serves as an intentional refractive component of the optical design.

The Minigraph is focused by moving the primary mirror with a helical focuser sporting a large, knurled knob in the center of the back of the tube. The mirror is on rails with this approach so there isn't noticeable image shift as the scope moves about the sky. The focuser is smooth with enough precision to operate by hand despite its fast focal ratio, wherein very small adjustments can make a large difference in image quality. This makes motorizing more challenging as most third-party motor kits aren't designed for this rear-knob approach. Starizona (**starizona.com**) offers a $49 adapter to use with a ZWO EAF focus motor on the scope.

Surrounding the focuser knob are three sets of push-pull collimation screws, allowing users to adjust the tilt of the primary mirror. With the scope's fast f/2 focal ratio, you'll likely be using them, as even a tiny misalignment of the optics will show as odd-shaped stars on the outer areas of exposures.

Much like Celestron's Rowe-Ackermann Schmidt Astrograph (RASA) design, there's no secondary mirror in the HAC125DX, and cameras are connected to the front of the telescope in the middle of the corrector plate. The unit comes with three camera adapters. The first accepts standard 1¼-inch nosepieces. The other two are threaded to connect cameras with an M42, or T-thread, interface. The 12.5-mm spacer is for cameras with its detector set close to the outer flange of the body, while the 6.5-mm adapter is for cameras with a detector set deeper in its housing.

I noticed an oddity about the camera adapters I should mention. The shorter one is threaded on the outside and screwed perfectly into my Player One cameras. The longer adapter (for cameras requiring 6.5-mm spacing) is threaded on the inside as if intended for specific camera models such as I've seen on some ZWO cameras. The back focus requirement of the Minigraph is extremely limited, and there's no way to use a camera requiring 17.5 mm or more. The two camera adapters are also internally threaded on the scope side to accept 1¼-inch filters such as an UV/IR blocker or light-pollution filter.

A small dew shield is secured via three thumbscrews and includes a hole for running a camera cable through for better cord management. As with other fast Honders-designed astrographs, the dew shield is an integral component in the optical system and is designed to reduce off-axis light from entering the tube. Stray light is a big concern with fast optics, so the shield is required whenever using the scope.

The optical design of the HAC125DX limits the choice of cameras that are a good match for the scope. Having the camera mounted where it obstructs the

▲ The HAC125DX comes with three camera adapters —two are threaded to connect cameras using M42 threads, also known as T threads. A third adapter comes installed on the scope and accepts cameras with a 1¼-inch nosepiece. Also included are a pair of hinged tube rings, a V-style (Vixen) dovetail bar, a hex wrench for collimation, and a dew shield secured with thumb screws that includes a convenient opening for running cables from the camera.

◀ Both of the threaded camera adapters accept 1¼-inch filters in a recessed aperture that won't increase the spacing between the connected camera and the corrective optics.

optical path requires a model that won't block much (or any) additional light. The corrected image circle produced by this instrument measures 16 mm — perfect for small, low-noise planetary cameras suitable for live-stacking work, and a particularly good match for cameras using the Sony IMX533 CMOS sensor currently popular for deep-sky imaging. As you'll be installing a camera directly within the light path of the scope, you'll need one having a narrow, symmetrical housing to prevent blocking much more light. The central obstruction of the scope is 53 mm, so a camera with a larger diameter could block a significant amount of light.

For this review, I used three different cameras: an 8-megapixel QHY5III585C, which has a barrel size smaller than the Minigraph's 53-mm central obstruction, as well as both Neptune-C and Uranus-C units from Player One Astronomy (the latter also using the IMX585 sensor). The Player One cameras measuring 76 mm have a slightly larger body than the central obstruction. Calculating the aperture by this additional obstruction works out to an effective focal ratio of f/2.35. This may seem significant but the advertised focal ratio of the HAC125DX doesn't take into consideration the light loss produced by the Minigraph's native central obstruction. Taking that into account, the focal ratio actually comes out to f/2.2 — not a true f/2 performer. Because of this, the larger obstruction when using the Player One cameras works out to a 10% increase.

In the Field

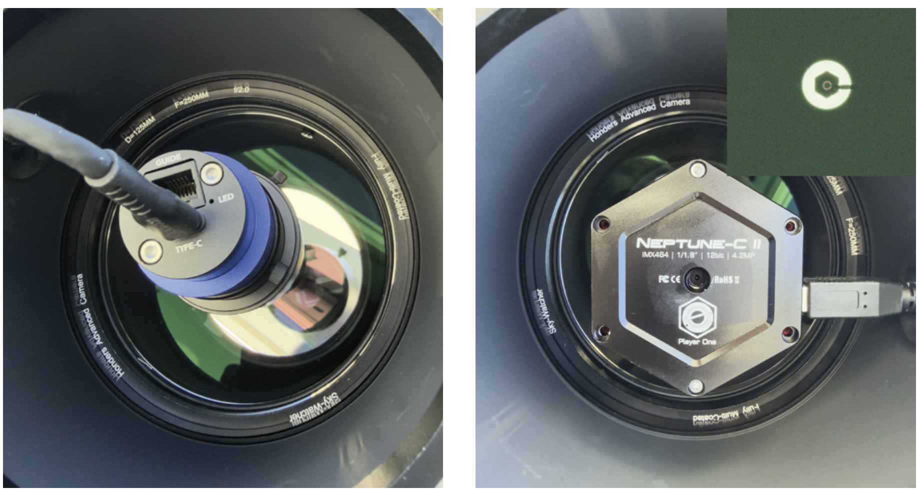
This scope was fun to work with and produced some great images that have the feel of using a much larger instrument. Its fast focal ratio meant that even very short exposures resulted in recognizable images of most targets right away. The focuser was fine enough to manually turn to nail focus without a great deal of hassle, and there was very little backlash when I reversed direction. The focuser travel is about 9 mm, which should accommodate any camera that can come to focus even with a filter placed inline.

Although the primary mirror is on a rail system that minimizes lateral movement, it isn't entirely free of it. There's a small but visible shift in the position of stars on the sensor when moving back and forth through focus, but it's negligible and likely won't throw off any autofocus software.

The Minigraph's fast focal ratio is particularly sensitive to collimation error, and if your camera sensor isn't perfectly aligned to the light path, stars can look pretty bad very quickly. I found that using the 1¼-inch camera adapter was the worst offender in this regard. It secured the camera with a brass compression ring and a single thumbscrew, but even tightening down and adjusting the mirror collimation, the camera wiggles slightly in the holder, preventing me from reaching perfect collimation. With the QHY camera slipped into this adapter, I could see the stars progressively worsen toward one side of the frame. Connecting the Player One cameras using the threaded adapters was much better, and I could adjust it's tilt correction screws to ensure the detector was properly aligned with the focal plane. Users would be wise to pair this scope with a camera having its own tip/tilt adjustments.

Photographing through a fast scope such as this Minigraph floods your sensor with light, which helps overcome a lot of noise issues associated with using an uncooled camera. I did find in some cases, however, that the background was a bit mottled and challenging to process out, particularly on warm nights. A camera with regulated cooling will really sing on this scope, but currently there aren't any models available today with symmetrical housing that won't greatly increase the obstruction of the aperture and cost you more of the system's precious photographic speed. (Sky-Watcher is rumored to be working on a cooled camera just for this scope.)

When using the Minigraph, cable management also becomes a cosmetic concern, as the data and power line



▲ The 53-mm obstruction by the camera mount can affect your image results. One with a slender body, such as the planetary cameras manufactured by QHYCCD, fits entirely within the central obstruction *(left)*. Bigger cameras, like this Player One Astronomy model *(right)* will still work with the Minigraph, though will block more light from reaching the detector and decrease the effective photographic speed of the system. Using this combination, the effective focal ratio becomes f/2.35. Also note that the camera's hexagonal shape add diffraction effects to photos taken with the scope. An out-of-focus image of a star at upper right recorded with the Player One camera clearly shows the camera's profile as well as its USB cable.

coming from your camera passes directly across the light path and produces two diffraction spikes similar to a Newtonian reflector with a single-stalk secondary mount. Users can minimize this effect by making the cable curve around towards the cable opening in the dew shield. Due to the position of the camera, the HAC125DX produces mirror-reversed images.

If you like diffraction spikes, your camera choice can add them to your images. I was particularly delighted when I first swapped in a Player One Astronomy camera. Its hexagonal body produced six strong diffraction spikes that, together with a pair of spikes from the data cable, gave my images the combination "James Webb" diffraction effects.

One consideration I encountered when using extremely fast astrographs like the HAC125DX is its compatibility with special filters. The scope should work fine with cameras having an integrated UV/IR filter. But if you intend to use an additional filter inline, particularly ones that isolate emission wavelengths, be sure to check that it's rated for operation with fast focal ratios of f/2. Many of the dual-, tri-, and quad-band filters becoming popular with color-camera users these days aren't designed for such a steep light cone, which results in the filter passband shifting off its desired wavelength at the edges of the field. The light-pollution filter I used produced large reflections in the system, so I replaced it with a Chroma LoGlow 1.25-inch filter after confirming it would work well at f/2. Its performance was perfect for the Minigraph.

The HAC125DX is a fun, little astrograph that makes for a great travel scope for deep-sky imagers, or a primary imaging rig for budget-minded astrophotographers. It pairs well with the current crop of small, multi-megapixel cameras and produces excellent deep-sky astrophotos in less time than required with slower instruments.

■ Contributing Editor **RICHARD S. WRIGHT, JR.**, is celebrating his new neighbors' decision to remove all the trees that were blocking much of his sky.

This two-hour stack of M31, the Andromeda Galaxy, was captured using 90-second subexposures with a QHY5LIII585C camera.

The HAC125DX delivers excellent signal in a short time, serving up rich, colorful images of faint objects such as IC 434, the diffuse nebulosity surrounding the Horsehead Nebula. This image consists of 2.8 hours of stacked 90-second exposures using a Player One Astronomy Uranus-C color camera. The diffraction spikes are due to the hexagonal shape of the camera body and its data cable.

Omega Centauri

This celestial dandelion puff is the globular cluster Omega Centauri. Omega Cen is a big ball of stars visible in the southern sky. It's the largest and brightest globular cluster in our galaxy, with some 10 million members. At a measly 17,000 light-years away (give or take), it's bright enough to be visible to the naked eye in dark skies.

When it comes to the level of heavy elements they contain, the cluster's stars have a wide variety of compositions. The variety makes Omega Cen abnormal among globulars — but similar to the central star clusters of galaxies. In fact, astronomers suspect that Omega Cen is the stripped nucleus of a long-gone dwarf galaxy, which the Milky Way unraveled and ate like a cinnamon bun.

This cluster may be a lovely sight, but it's what we *don't* see with our eyes that makes it truly appealing: One or more black holes might lurk in its core.

Astronomers have debated for years whether there's a reasonably beefy black hole at the heart of Omega Cen. If the cluster really is the remnant of a dwarf galaxy, then we might expect it to contain a black hole that — if its growth hadn't been stunted — once had the potential to reach supermassive size. But confirmation has proven elusive.

Scientists have studied the cluster's stars to see if they can spot signs of an unseen mass influencing the stars' motions. But Omega Cen, despite its wowzer appearance, has a fairly low central density. And due to projection effects, only a tiny fraction of the stars that appear to be in the center actually lie there. It's thus immensely challenging to find and track stars that are caught in the putative black hole's gravitational net.

The black hole doesn't reveal itself directly, either. Occasional snacks on gas — provided by winds from aging stars — would make the black hole light up dimly. But observations have turned up nothing, leading astrophysicist Jay Strader (Michigan State University) to call Omega Cen's central object "the quietest black hole in the universe."

In 2024, an analysis of seven stars' motions suggested there indeed might be a black hole hidden in the cluster's heart, with a mass of at least 8,200 Suns . . . or, as a separate team soon countered, a batch of thousands of stellar-mass black holes that have sunk to Omega Cen's center (*S&T:* Jan. 2025, p. 11). It'll take observations of the stars' movements over longer spans of time to untangle the mystery.
—CAMILLE M. CARLISLE


Photograph by
Scotty W. Bishop

Night-Vision Monocular and 3D Prints

Here's my DIY solution to a very specific set of problems.

WHEN I FIRST STARTED using a night-vision device, or NVD, for stargazing, it was as amazing as it was awful. Let me explain — my skies just north of Houston are so bright that I don't even need a red flashlight to read labels on my observing gear. With an NVD coupled to the eyepiece, however, I'm able to cut through the light pollution to snag the spiral arms of M51, and by adding a narrowband filter I can see the Horsehead Nebula. But whatever futzing with filters and adapters ordinary visual astronomy brings, I was dealing with it tenfold when using the device. Removing the device from the eyepiece, swapping the filter from hydrogen alpha (Hα) to infrared (or vice versa), and putting the device back on the eyepiece was an ordeal, and each swap exposed all surfaces to dew. I was burning a huge amount of eyepiece time and needed the specific kind of fix that only DIY could bring.

▲ The author's 3D-printed, fully assembled apparatus is shown here with the PVS-14 Gen 3 Night Vision Monocular mounted securely to the filter wheel adapter system.

This was a tall order. Companies like Tele Vue (**televue.com**) and RafCamera (**rafcamera.com**) sell a slew of adapters explicitly for joining an NVD to a filter and eyepiece, but this would still mean unscrewing things and squinting at labels out in the cold, damp field.

I didn't know what I was going to make, but the doodad would need to do several jobs. It has to hold my device, a 1×-power PVS-14 Gen 3 Night Vision Monocular, to a large Plössl eyepiece. But it should also allow speedy switches between telescopic and handheld viewing. I wanted seamless swapping with the Hα filter as well as the IR longpass filter, which transmits only wavelengths longer than 685 nanometers. Finally, it needs to keep that Houston humidity out.

I drew up plans for a complicated doohickey with a skeletal filter wheel, magnetic joints, and some ball bearings. I wasn't sure if it would work in practice — would it cause vignetting? Could a 3D print even hold such a tall stack? I couldn't gamble that many hours in CAD (computer-aided design) software on a maybe. But 3D printing is wonderful for prototyping, and what can't be understated is how easy the matured ecosystem of free files available online

▲ *Left:* The PVS-14 is a relatively common night-vision device (NVD). However, good ones can cost up to $5,000 and may be subject to export restrictions. The author notes that these devices vary wildly, taking some research to identify an ideal unit for astronomy — even among the same "model." *Middle:* The wheel's 1¼-inch slots shown are for clear (blank), 685- and 642-nanometer infrared filters (the second for adding a bit of hydrogen-alpha signal), and 12-nm and 6-nm Hα filters. "I came to prefer solely the 6-nm Hα and 642-nm IR filters for observing," the author says. *Right:* The author modified his 65-mm Plössl eyepiece with a twist-lock adapter to easily remove and attach the filter wheel.

ALL PHOTOS COURTESY OF THE AUTHOR

▲ *Left:* M16, the Eagle Nebula in Serpens, seen through a friend's 25-inch Dobsonian and the PVS-14 fitted with an Hα filter. NVDs use an image intensifier that greatly amplifies available light, even at very low levels (see the August 2025 issue, page 28). *Right:* The Milky Way's central region as seen with the PVS-14 from a Bortle 2 location. According to the author, it really pays to be able to swap quickly from telescopic to handheld viewing. Here, he added a UV-IR-cut filter as the skyglow in infrared was brighter than the ambient light pollution.

makes this kind of thing possible.

I didn't have to do much real CAD — just carve up meshes (3D model files) with planar and cylindrical cuts. I found a press-fit adapter for attaching 1¼-inch filters to the front of the device. There were also files available online for creating a complete filter wheel and twist-lock adapters for securing the eyepiece, and some thread-generating software tools. I ultimately had to design very little: I carved up these preexisting files in the slicing software (used to prepare meshes for printing) and merged them. I digitally swapped the filter adapter's 1¼-inch thread for a T2 thread to match the filter wheel. The twist-lock bundle came with "parameterized" CAD files, which allow me to specify things like the inner diameter, and the 3D model auto-adjusts, so scaling it to fit was a breeze. I just needed to make an adapter to join it to my Plössl.

The filter wheel took some assembly — notably, all the M3 screws, springs, and ball bearings I had on hand. Bits like these are affectionately called "vitamins" in the 3D-printing community. Much like our body needs but cannot make vitamins, desktop printing projects need but cannot (yet) make fasteners, springs, and such. While I could have designed this whole apparatus in a more monolithic manner, print orientation is of concern since it significantly impacts the unit's load strength and overall quality. (Parts are strongest when printed along the bed's horizontal, or X–Y, axes rather than in the vertical, or Z, axis.)

Superglue bonds to the printer's PLA (polylactic acid) filament extremely well, so I glued the twist-lock adapter on one side of the filter wheel and the NVD adapter on the other. I have a "3D-printer pen" sitting around, and this was a great chance to try it in a different capacity: I went around the edges, extruding molten plastic into and over the gaps. With these bits now welded on, the unit felt sturdy, in spite of its jury-rigged construction. (I had to remind myself that PVS-14s, originally made for the military, are drop-tested for ruggedness.)

My first real trial of the apparatus was a doozy: my astronomy club's Messier Marathon. And boy, did it work! Wasted time at the eyepiece all but evaporated, and I was cranking through target after target when there wasn't a line at my scope. The planetary nebula in M46 responded beautifully to blinking through different filters; I could very easily switch from looking at M13 in infrared to panning the device handheld across Cygnus in Hα, which lit up with nebulae like a Christmas tree.

It's pretty special being able to pop the PVS-14 off at the filter wheel, look through my Telrad using the device, see my target at 1×, aim, and then snap it all back into place. This was actually how I aimed at my favorite target: NGC 5139, Omega Centauri. During that pause around midnight in the Messier Marathon, after I'd finished off the galaxies but was still waiting for the globulars to rise, I was far enough south that Omega Centauri had crept above the horizon. My fellow observers and I compared views and found that with "glass" the object was mush, with just a few resolved stars. But viewed in infrared, it was dazzling. What a sight!

■ You can find Contributing Editor **JONATHAN KISSNER** in his backyard, eyeing up Barnard's Loop between glances at faint galaxies.

SHARE YOUR INNOVATION
Enthused tinkerers interested in having their work featured here can share their projects at **workbench.kissner@gmail.com.**

The Hunter and the Bull

Jorge Restrepo

This expansive mosaic encompasses the entirety of Orion and Taurus, revealing the faint dust and gas that permeates the region. Barnard's Loop encircles the Orion Nebula (M42) at far left while Sharpless 2-264 surrounds the head of the Hunter. The bluish reflection nebula at right contains the Pleiades star cluster (M45).

DETAILS: *ZWO ASI2600MC camera with Rokinon 135-mm f/2 lens. Mosaic of 48 panels each exposed for 2 hours.*

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The Last Zambuto

The author is presented with a very special opportunity.

WHAT IF ENZO FERRARI offered to build you one last engine?

Opportunity crackled over the phone. I hesitated. "Well, that sounds great but . . . I've never made a truss Dob."

"Oh, fiddlesticks man, there's books. You'll figure it out. Have you heard the Rush song 'Caravan'?" The chorus goes, "I can't stop thinking big."

Writing is a dangerous thing. Now, famed optician Carl Zambuto — a magician's name — was on the line because of something I'd written. It started one June night long ago.

New to the club, I was a teenager on a budget. Jim showed up, an avuncular stargazer who lived the park-ranger ethos. He piloted a Portaball, a boutique scope with a 12.5-inch Zambuto mirror.

"Come take a look at this." Jim's voice floated out of the darkness, a quiet note of *fish on*. I looked up from my beginner scope and ambled over.

A strange thing happened. There was no need to squint through smudges, no optic to wrestle. The Portaball vanished, leaving only pure starlight. There, misty on blue velvet, almost alive: the Whirlpool Galaxy. The years passed. We fished a lot with that scope.

Jim is a generous man. After decades of mentorship and friendship, he's passed the Portaball on to me. I share views with flocks of tourists and friends, some starlight evangelist, powered by Zambuto. *"Knock knock, have you looked up tonight?"* But the years always go faster than we realize.

In August of 2025, Carl Zambuto and Chuck Smith announced they were closing their mirror shop, ". . . the applicable fact is, large-aperture visual astronomy is waning and is being replaced by technology."

I had to write a thank you for everything their mirror brought: the little boy struck nearly wordless by Saturn, the crowds in the national park jostling for a view, how the gossamer light of the Andromeda Galaxy graced my soul many a night.

Carl wrote back. "You get it, man." Then we talked. He put me on speakerphone with Chuck, and they told stories about telescopes and sidewalk astronomy and John Dobson for an hour.

"By the way, if you guys have any extra mirrors for sale . . ." I ventured.

"What are you looking for? I've got an 11-inch that might do." If Antonio Stradivari wants to build you *anything,* you say yes.

He kept thinking. "You need a large mirror — to see spiral structure in galaxies, to see far, and to share views with people." A few days later, he called back. "Josh, I've got it. My friend Steve Swayze died before he could finish a 22-inch. What if we completed that?"

The plan is Dobsonian in design — a 22-inch f/4.2 truss — and Dobson in spirit: *We build telescopes for soft, warm eyes.* We're calling it *The Encore.*

It'll honor Steve Swayze and the mirror he started. It'll honor Carl and Chuck, and their wizardry of glass. It'll honor Jim's sharing of the sky. Most of all, we hope it will remind people to look up.

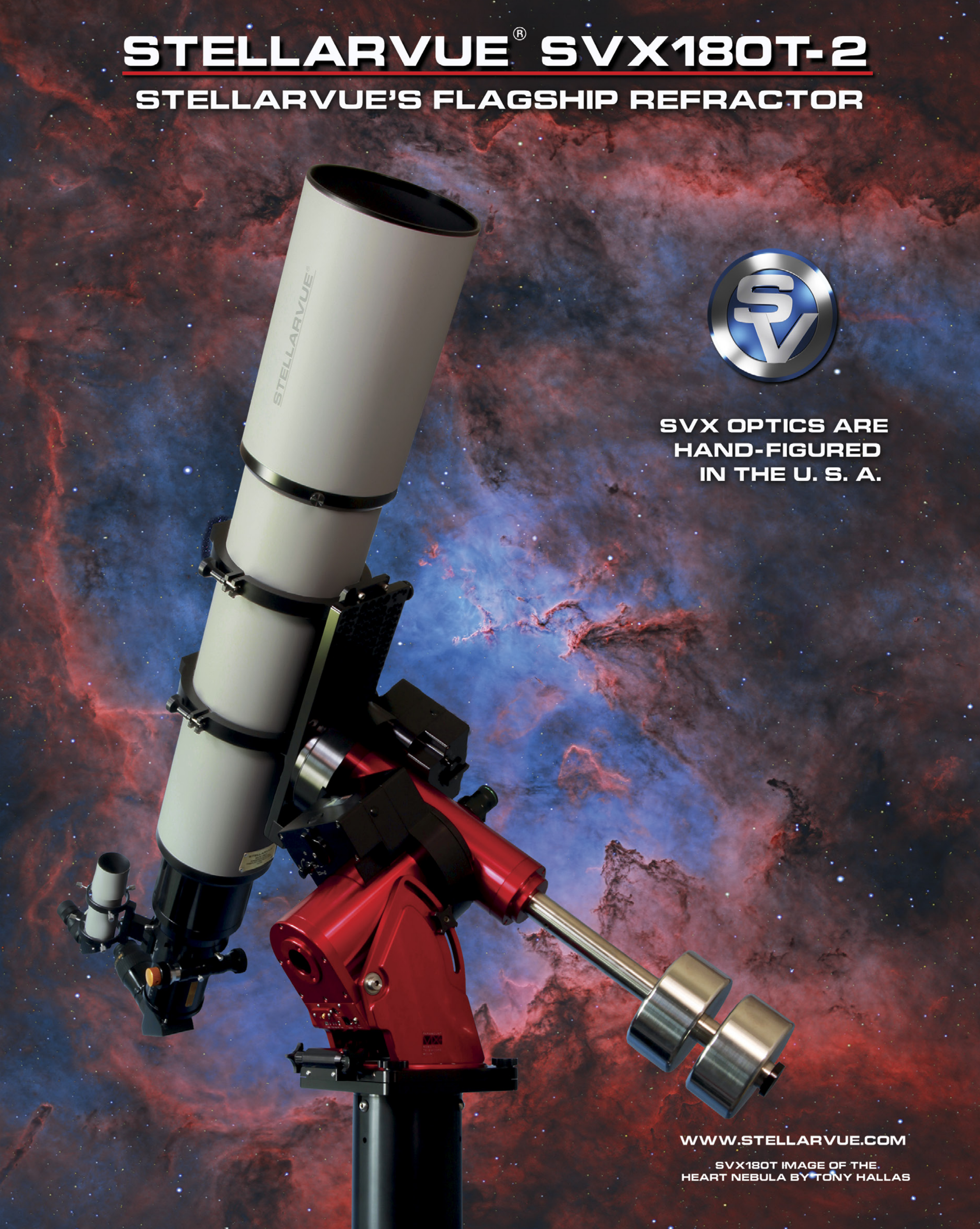
Maybe AI and electronic telescopes will beep away the night, everyone squinting down into bright screens. But we'll have live photons on tap, forged in those great churning furnaces: that delicate, subtle, shimmering starlight, traveling unimaginable distances to the human eye, the universe looking back at itself.

Come visit, and see for yourself. First, I have to build it, so advice is welcome, too.

Keep thinking big. Keep looking up.

■ **JOSH URBAN** watches the skies of Lynchburg, Virginia. He writes stories on rainy nights.

JOSH URBAN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