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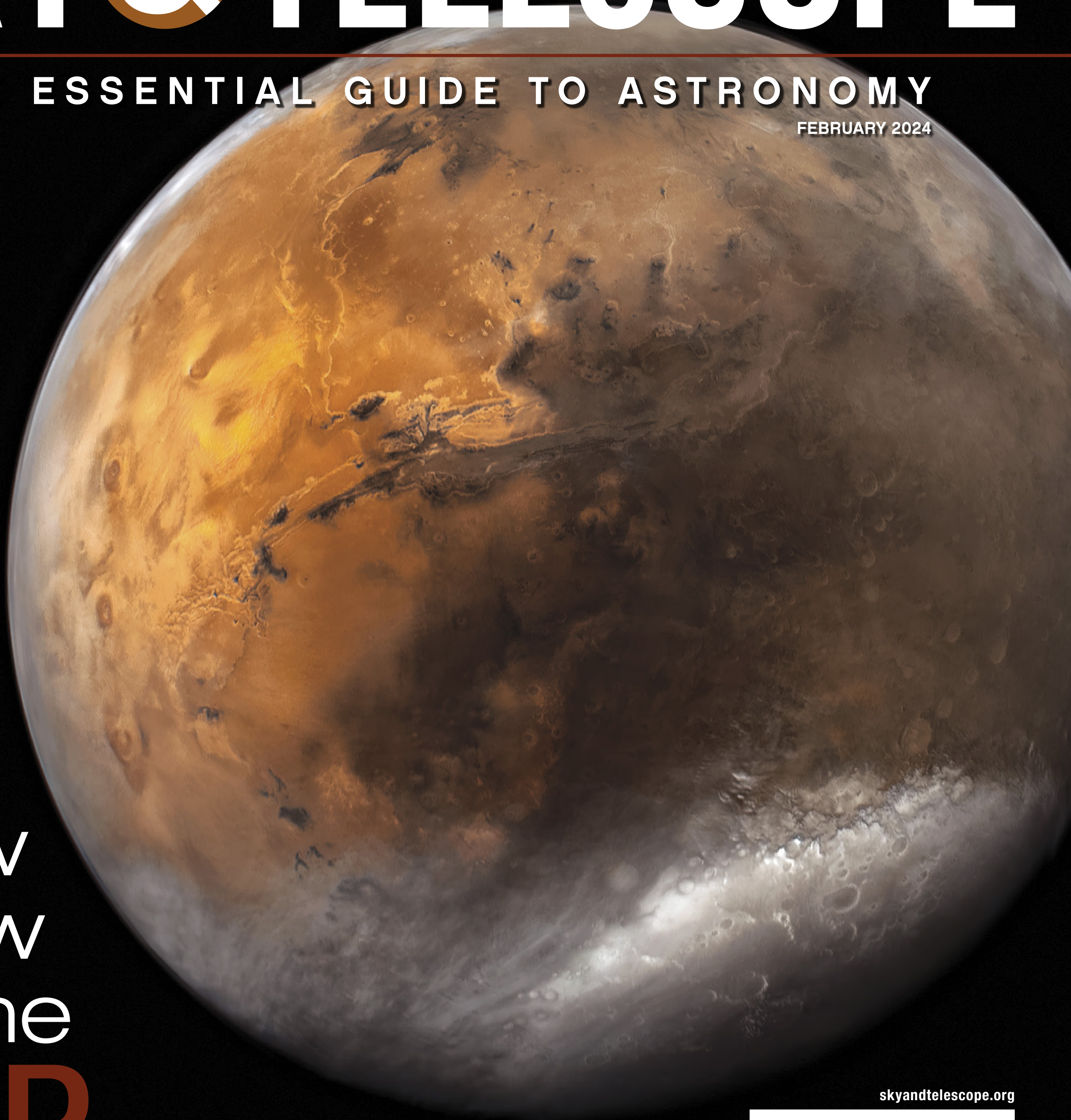
SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY
FEBRUARY 2024



New View of the RED PLANET

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Background Image: IC 1396
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PROMO PALOOZA!

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At Sky-Watcher we're gearing up for all of the holidays** by putting our gear on sale to make your life a little easier for the season. And just so it won't be too overwhelming, we're easing out our sales over November, starting with:

November 6 - Sky-Watcher Optical Tubes
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Promopalooza kicks off on November 6th, so don't wait to check out our website to see everything that's going to be on sale or how much you can save. Just visit **skywatcherusa.com** or your favorite authorized dealer.

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DAVID KIRKBY / DESI COLLABORATION

ON THE COVER

Natural-color composite image from Hope's EXI camera
PHOTO: EMM / JASON P. MAJOR

ONLINE

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Follow Contributing Editor Bob King as he takes readers on an adventure through the night sky.
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Aptitude Creep

MUCH OF WHAT we present in *Sky & Telescope* is aspirational: It's meant to entice you to expand your horizons. Wherever you are in our shared avocation — beginner, mid-level hobbyist, or advanced practitioner — we'll give you the means to push the envelope.

We craft our content with this goal in mind. For those new to *S&T*, or even for long-time readers who might question the method to our madness, let's take a brief tour of this issue to show how we structured it.

If you're new to stargazing — or want to light the spark in a friend or family member — start by learning your way around the night sky with our monthly charts (pp. 42–44). Also see Sky at a Glance (p. 41), Stories in the Stars (p. 45), and Beginner's Space (p. 74). Appearing each month, all these pages require no equipment or prior experience — just eyes to look up and a brain to wonder.

Want to go beyond naked-eye stargazing using binoculars or telescopes? See Binocular Highlight (p. 43); Sun, Moon & Planets (p. 46); and Exploring the Solar System (p. 52). For ephemeral events like comets or meteor showers, consult Celestial Calendar (p. 48).

▲ Expanding horizons: Abell 21, the Medusa Nebula (see p. 39)

STEFAN BINNEWIES / CAPELLA OBSERVATORY

For a greater observing challenge, try Don Ferguson's sampler of planetary nebulae viewable this season even from light-polluted areas (p. 36). Don lives in blazingly bright Houston, Texas, yet he enjoys sights of these wispy celestial balloons in his 3.5-inch and 7-inch scopes. Or have a go at observing the most southerly treasures visible from the U.S. (p. 30). For this winter-sky tour, Mario Motta recommends telescopes with apertures ranging from 3 or 4 inches up to 16 inches or larger.

To be truly ambitious, turn to our bimonthly Going Deep column (p. 58). For his sky outing, Al Lamperti primarily wielded a 22-inch scope to observe the ring galaxies that his coauthor Frank Colosimo imaged.

We don't stop at observing, naturally. Want to break into astrophotography? See Tony Puerzer's bimonthly First Exposure (p. 55). For those more adept, hear from Ron Brecher on deep-sky mosaicking (p. 62). Keen on DIY tinkering? Jerry Oltion's monthly Astronomer's Workbench (p. 72) is for you.

We also cover the science of astronomy, of course, from the latest planetary missions (p. 12) to cosmological mysteries like dark energy (pp. 20 and 26). Those features are also aspirational — broaden your understanding!

In short, no matter where you find yourself in your astronomical journey, there's something for you in every issue of *S&T*. You may have heard of aperture creep, that hard-to-resist urge among passionate observers to acquire ever-larger light buckets. Well, we like to encourage *aptitude* creep. Expand away.

Editor in Chief

Editorial Correspondence (including permissions, partnerships, and content licensing): *Sky & Telescope*, 1374 Massachusetts Ave., 4th Floor, Cambridge, MA 02138, USA. Phone: 617-500-6793. E-mail: editors@skyandtelescope.org. Website: skyandtelescope.org. Unsolicited proposals, manuscripts, photographs, and electronic images are welcome, but a stamped, self-addressed envelope must be provided to guarantee their return; see our guidelines for contributors at skyandtelescope.org.

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Vesto Slipher and Edwin Hubble

In “Vesto Slipher’s Fast Stars and Hotrod Galaxies” (*S&T:* Sep. 2023, p. 20), Douglas MacDougal rightly characterizes Slipher’s discovery of the redshifts of spiral nebulae as “one of the most fundamental discoveries in the history of science,” and the first evidence of the expanding universe. Slipher’s achievement, however, has never been commemorated.

This is owed partly to Edwin Hubble. In his landmark 1929 paper in *Proceedings of the National Academy of Sciences* (Vol. 15, p. 168), establishing the linear relationship between Slipher’s radial velocities and Hubble’s distances, Hubble failed to cite Slipher’s 1913–1925 publications or even mention his name! Perhaps realizing this ethical breach, he did credit Slipher in ensuing years, but it was still dubbed solely “Hubble’s law.”

At the General Assembly in 2018, the International Astronomical Union adopted a resolution renaming it the “Hubble-Lemaître law,” to honor Georges Lemaître, who in 1927 had predicted the expansion of the universe through Einstein’s general theory of relativity. They rejected any Slipher eponym on the rationale that a “law” should be based on theory.

As a workaround, we propose that the IAU consider renaming the separate “Hubble constant” — the observed velocity-distance proportionality — the “Hubble-Slipher constant.” Hubble himself provided the rationale: While writing to Slipher in 1953, he praised Slipher’s “first steps as by far the most important of all” in “the combination of your velocities and my distances . . .” Slipher worked alone gathering these critical early radial velocities. He deserves this honor.

Joseph N. Marcus
Lowell Observatory Advisory Board
St. Louis, Missouri

Marcia Bartusiak
Professor of the Practice Emeritus
Massachusetts Institute of Technology
Cambridge, Massachusetts

Douglas MacDougal responds: *The extent of Hubble’s reliance on Slipher’s work is shown in a letter to Slipher dated July 8, 1940, in Lowell Observatory’s archives. There Hubble asks Slipher to confirm details of “your now famous list of velocities” for a catalog Hubble was creating. The list, in Hubble’s hand, is headed “Slipher’s Velocities” and contains the “list of your [Slipher’s] velocities as we know them.” Even the casual researcher can’t fail to notice the mirror-like match-up of the Slipher’s Velocities to those in Hubble’s 1929 paper. In fact, 40 of the 44 galaxies cited by Hubble came from Slipher.*

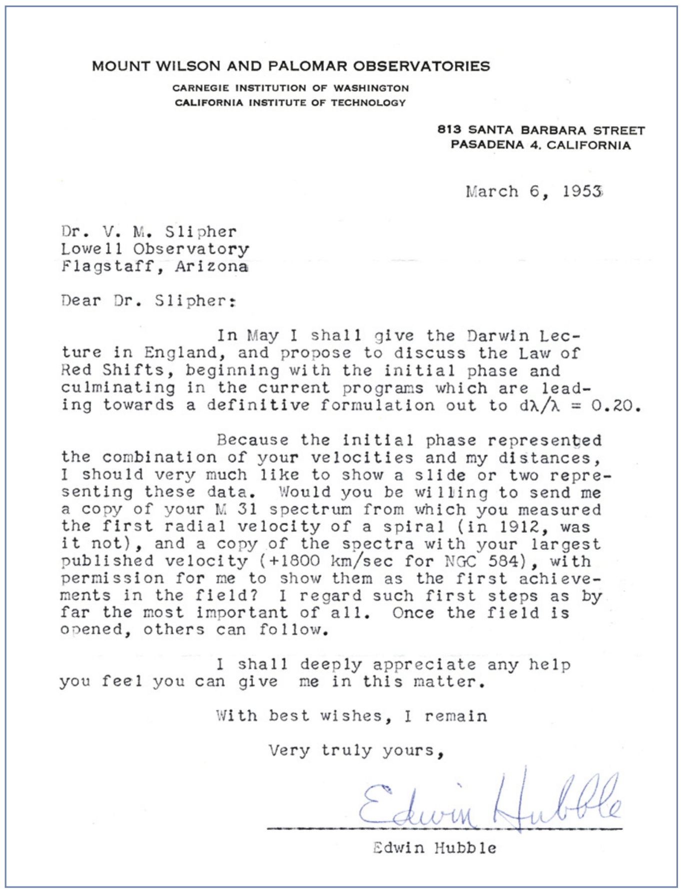
The historic velocity-distance graph in Hubble’s 1929 paper, and the “Hubble constant” derived from its slope, was thus apparently built in halves: The vertical axis (of velocities) properly belongs to Slipher, and the horizontal axis (of distances) belongs to Hubble.

Arguably more important even than the quantifiable extent of Hubble’s reliance upon Slipher’s data, though, was Slipher’s paradigm-smashing idea that there could be such a universe of receding galaxies. This completely new and revolutionary aspect of our cosmos was entirely due to Slipher. Marcus and Bartusiak’s proposal is a welcome recognition of these facts.

I am an avid reader of *Sky & Telescope.* My husband and I keep a close watch on sky activity, as we live in a dark-sky area of rural Texas. Our visitors are constantly amazed to see the Milky Way in its full glory! I don’t own a telescope, so I often breeze over the telescope articles in the magazine, but I love the articles on the science of new discoveries and theories. However, my favorite articles are the historical ones. In the September 2023 issue, you had two great articles, “Vesto Slipher’s Fast Stars and Hotrod Galaxies” by Douglas MacDougal on page 20 and “Hubble’s Eureka Moment” by Dave Tosteson on page 26! Learning the history of how we got to where we are in our knowledge base is fascinating. I am especially enthralled when you have articles about ancient sky observers.

Keep up your great work on covering articles for everyone’s interests!

Barbara Barnes
Junction, Texas



MOUNT WILSON AND PALOMAR OBSERVATORIES
CARNEGIE INSTITUTION OF WASHINGTON
CALIFORNIA INSTITUTE OF TECHNOLOGY

813 SANTA BARBARA STREET
PASADENA 4, CALIFORNIA

March 6, 1953

Dr. V. M. Slipher
Lowell Observatory
Flagstaff, Arizona

Dear Dr. Slipher:

In May I shall give the Darwin Lecture in England, and propose to discuss the Law of Red Shifts, beginning with the initial phase and culminating in the current programs which are leading towards a definitive formulation out to dλ/λ = 0.20.

Because the initial phase represented the combination of your velocities and my distances, I should very much like to show a slide or two representing these data. Would you be willing to send me a copy of your M 31 spectrum from which you measured the first radial velocity of a spiral (in 1912, was it not), and a copy of the spectra with your largest published velocity (+1800 km/sec for NGC 584), with permission for me to show them as the first achievements in the field? I regard such first steps as by far the most important of all. Once the field is opened, others can follow.

I shall deeply appreciate any help you feel you can give me in this matter.

With best wishes, I remain

Very truly yours,

Edwin Hubble

Edwin Hubble

▲ Edwin Hubble wrote this letter to V. M. Slipher asking for copies of the spectra Slipher took that best represented the redshift of galaxies for his lecture. Hubble built his famous theory on Slipher’s studies of redshift.

LOWELL OBSERVATORY ARCHIVES

Smoking Scope

I read Arwen Rimmer's "The Sun: Now in High-Def" (*S&T:* Nov. 2023, p. 14) with interest, including the admonition regarding the danger of concentrated sunlight to both observer and scope.

On a recent Sunday, I rolled my 13-inch Dobsonian off the back lawn to run the sprinklers. I parked it in a safe spot, poured myself a coffee, and sat on the patio to enjoy the morning. A few minutes later, I glanced over at my scope, and it was smoking! I rushed over and quickly reangled the scope. Concentrated light had passed through the 5-inch off-axis mask and started to burn the ABS mask material. I covered the burn with black camera tape, and it's good as new.

I consider myself very lucky. If the mask had not been on, the full force of the mirror would have drifted onto the flat-black plywood of the secondary cage.

Lesson learned.

Bob Gitzen
Concord, California

Living-Room Observing

The "Astronomy for Retirees" letters (*S&T:* Oct. 2023, p. 6) from Edward Daugherty and Benton Kesler in response to "An Observatory for Seniors" (*S&T:* July 2023, p. 84) prompted me to write about my own reasons for building a remote-controlled observatory at my home. My wife has Alzheimer's and can't be left alone. This negated the pursuit of many of my hobbies — but not astronomy. I purchased a NexDome observatory, which I installed next to my home (after months of discussion with county zoning officials). I can now remotely control my observatory from within my home and view images on my big-screen television. I can spend time with my wife and still do astronomy. Life can be good even with dementia.

The observatory has also prompted a great deal of public interest within my community. People frequently stop by to see it. I had several reflector telescopes, which I gave to neighborhood youth. The observatory has become quite a conversation piece.

William Johnson
Manassas, Virginia

Cosmic Relief on Hold

David Grinspoon's Cosmic Relief is one of my favorite columns, and I was sad to read in "Seeing Through the Smoke" (*S&T:* Nov. 2023, p. 11) that he will not be writing the column for a while. I read his book *Chasing New Horizons* [co-written with Alan Stern]. It was riveting throughout. I'm grateful that David Grinspoon became a columnist with *S&T*. Thanks, David, for 14 years of your creative, thought-provoking articles.

Tom Kellogg
Aptos, California

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

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

1949

1974

1999

◖ February 1949

Einstein Effect "In the early 1930's, Dr. R. J. Trumpler, of Lick Observatory, found certain stars in the sky which showed an abnormal red shift in the lines of their spectra. These were all very hot stars of class *O*, and it was proposed that the red shifts were caused by an Einstein shift — the effect of gravity retarding the escape of light from the surfaces of very dense stars. . . .

"At the Dominion Astrophysical Observatory, Dr. J. A. Pearce has made a detailed spectroscopic analysis of HD 215835, [one such star in] Cepheus. . . . Dr. Pearce found double lines, indicating [it is] a spectroscopic binary. [But the components'] densities are about 4/100 that of the sun. . . . The estimated maximum mass of 62 suns is large, but normal for stars of this type. . . . The present work does not support the relativity red-shift hypothesis for this star."

In 1954, Daniel M. Popper measured a true gravitational redshift in spectra of the white dwarf 40 Eridani B.

◖ February 1974

Pioneer 10 "Mankind has just extended its bounds of exploration by the bold voyage of a probe far beyond the orbit of Mars for a closeup examination of Jupiter. . . . The most striking finding is the exceedingly strong concentration of the trapped radiation toward the plane of the magnetic equator. . . . In the giant planet's vicinity, Kinard's meteoroid detector was penetrated by some 10 particles, fewer than he had expected . . . If this planet should have a thin equatorial ring of particles, like Saturn's rings, it could not have been detected by any of the Pioneer experiments, because of the spacecraft's rapid transit through such a ring."

Tom Gehrels's indirect prediction was borne out five years later, when Voyager 1 did detect Jupiter's diaphanous ring.

◖ February 1999

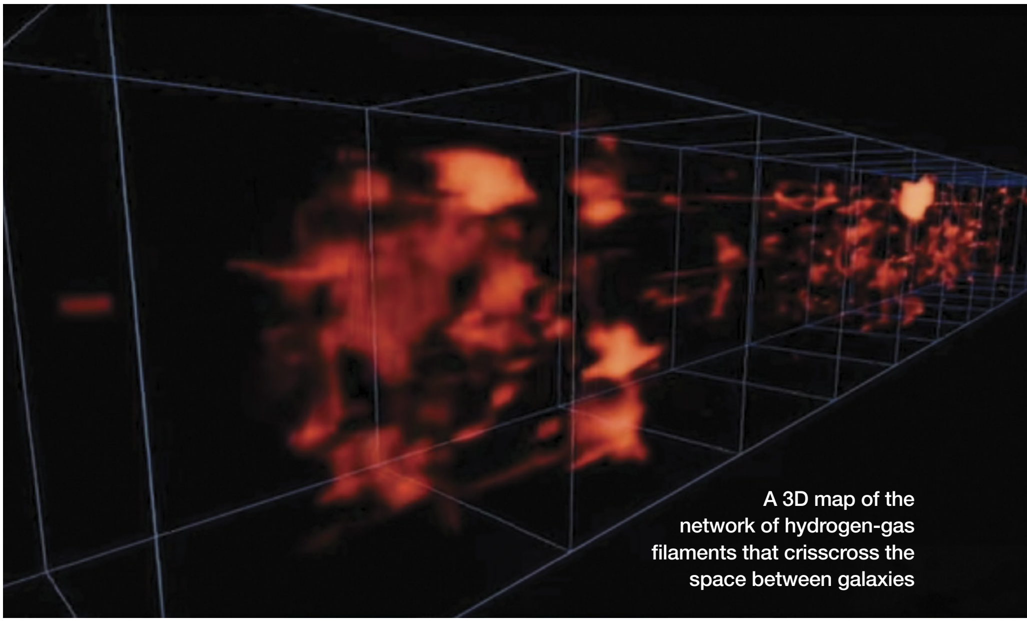
Unexpected Double "The innermost Eta Carinae nebula, one of the most spectacular objects imaged by the Hubble Space Telescope, is not what it appears to be.

"We seem to see an extremely luminous star that has ejected two massive, smoky lobes of gas and dust . . . The lobes appear to have erupted from the star about 150 years ago, when Eta Carinae, [about 6th-magnitude,] flared to magnitude –0.8, making it the second-brightest star in the night sky . . .

"'This situation of a nebula that is chemically more advanced than the central star cannot be reached by the evolution of a single star,' write Henny Lamers [and colleagues]. 'The star whose spectrum now dominates the nucleus was not the star that ejected the nebula.' . . . If this unseen second star . . . blew off the nebula, it presumably began life with an even greater mass and luminosity than the star we call Eta Carinae today."

COSMOLOGY

Astronomers Directly Image the Cosmic Web



A 3D map of the network of hydrogen-gas filaments that crisscross the space between galaxies

ASTRONOMERS HAVE MAPPED the visible, gaseous part of the *cosmic web*, capturing the faint network of filaments that feed galaxies with new material like rivers draining into myriad seas.

Christopher Martin (Caltech) has seen these structures before; in 2015, he used the Palomar Cosmic Web Imager to simultaneously image and take spectra of a small section of a filament lit up by a brilliant quasar. Inspired by those findings, Martin and his team designed the Keck Cosmic Web Imager at the W. M. Keck Observatory in Hawaiʻi to probe filaments that are not so conveniently illuminated.

The imager is more technically an imaging spectrometer, designed to find the faint, 121.5-nanometer emission that comes from hydrogen atoms, known as *Lyman alpha*. The farther away this emission comes from, the more it will have shifted toward the red end of the spectrum. By looking between 350 and 560 nanometers, the team can detect the cosmic web in the distant universe, where its light originated 10 to 12 billion years ago. The result is a "data cube," which contains both an image of the region as well as a forest-like spectrum, with each "tree" representing emission from gas located at different points in space and time.

This emission is faint and spatially extended, so detecting it directly requires a unique method known as "nod and shuffle." The instrument images two fields, then subtracts the light in one from the other and vice versa in order to remove brighter signals closer to home.

The hydrogen emission that remains in turn traces the distribution of dark matter. "We are basically creating a 3D map of the cosmic web," Martin says. Astronomers now have "a whole new way to study the universe," he adds.

Having published these findings Sept. 28th in *Nature Astronomy*, the team now continues the work with the Keck Cosmic Reionization Mapper, extending coverage to longer wavelengths and thus pushing further back in space and time.
■ **COLIN STUART**

SOLAR SYSTEM

"Planet X" May Have Left Our Solar System Billions of Years Ago

A NEW UNDERSTANDING of far-off worlds in the outer solar system suggests that if "Planet X" ever existed, it has long since left the vicinity.

When Sedna was discovered more than a decade ago, its orbit — far beyond that of Neptune — baffled astronomers. Another two followed. Some encounter with a larger object must have placed these "Sednoids" on their paths. Might an undiscovered Planet X lurk in the outer reaches of the solar system?

Based on the orbits and related evidence, astronomers have been searching for this undiscovered planet for years (*S&T:* Oct. 2017, p. 16). But so far they've come up empty.

Now, new work presented by Yukun Huang (University of British Columbia, Canada) at the 55th meeting of the Division for Planetary Sciences of the American Astronomical Society suggests that there is no such planet — at least, not anymore.

Huang first asked, what if there is no undiscovered planet in the Kuiper belt? In that case, the Sednoids' orbits should have been stable over time. Only the combined gravitational effects of the four giant planets would affect those orbits, but only by rotating them, not by changing their shape.

So, using a computer simulation, Huang ran the solar system backward in time for billions of years. He found that the Sednoids' orbits shared some remarkably similar properties in the distant past: Not long after the birth of the solar system, their perihelia clustered

Sedna and Its Companions

Name	Semimajor axis	Perihelion	Inclination
Sedna	506 a.u.	76 a.u.	12°
2012 VP113	262 a.u.	81 a.u.	24.1°
Leleākūhonua (2015 TG387)	1,090 a.u.	65 a.u.	11.7°

▶ Sedna has two known companions in the outer solar system.

CALTECH / R. HURT (IPAC)

ASTRONOMY & SOCIETY

A New Hope? Taming the Satellite Swarm

ONE MILLION SATELLITES and counting. This is the future, according to filings with the International Telecommunication Union (ITU). The question is, how many of these satellites-to-be will become reality?

The ITU filings, which detail how many satellites will go up, which orbits they will occupy, and what frequencies they will use for operations, have skyrocketed in recent years. Some member states have filed for tens or even hundreds of thousands of satellites. At least some of this paperwork is almost certainly speculative, similar in concept to the land speculation that occurred back in the "Wild West" — but this time in space.

In the October 12th *Science*, political scientist Andrew Falle (University of British Columbia, Canada) and colleagues suggest this situation may provide an opportunity: "The ITU filings are the warning, and also part of the solution," they write.

On November 20th, representatives from governments and industries around the world come together for the World Radiocommunication Conference to review and revise rules for the ITU. In addition to proposals already on the table, Falle and team suggest that the ITU might also limit the number of satellites in individual constellations/orbits and/or require higher fees or similar consequences for large filings.

"The rules would mostly help us understand how big the problem is going to be, but that's important," says Jonathan McDowell (Center for Astrophysics, Harvard & Smithsonian). "It's hard to know how to prepare mitigation strategies when the number of satellites that are really going to go up is uncertain by a factor of 10 or more."

Regardless of what happens at the WRC, low-Earth orbit remains premium real estate. In addition to Starlink's 4,968 satellites and OneWeb's 634 satellites (those numbers accurate as of press time), Amazon just launched two prototypes for its planned 3,236-satellite Project Kuiper. Other projects are underway, too. It's possible new ITU rules may stem this coming tide; the main advantage for astronomers, though, will be simply knowing the size of the beast they're dealing with.

■ **MONICA YOUNG**

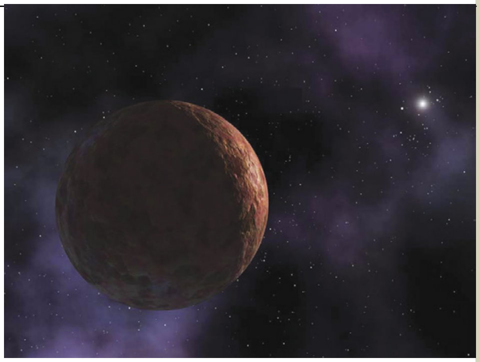
Read further details on the filings submitted so far as well as proposed rule changes at https://is.gd/ITUfilings.

---

at the same solar longitude, and their *apsidal lines* (the line passing through perihelion, the Sun, and aphelion) were also nearly coincident.

This orbital clustering is a telltale sign that a single event occurred in the solar system's youth — more than 4 billion years ago — that put the Sednoids onto their present paths. Nothing has disturbed the slow evolution of those orbits since.

Huang's work showed that the culprit could have been a primordial planet that was ejected from the solar system only 100 million years after its formation. Other explanations — such as a star from the Sun's birth cluster passing close by — are also plausible, but calculations haven't yet borne them out. More work is needed on those scenarios.



NASA / JPL-CALTECH

▲ An artist's concept of Sedna, a small world in the outer solar system

If the "early planet" hypothesis is true, then any new Sednoids ought to share the same orbital characteristics. Astronomers surveying the sky for more distant solar system worlds may find out that Planet X has left the building.

■ **EMILY LAKDAWALLA**

IN BRIEF

Found: Castaway Stars

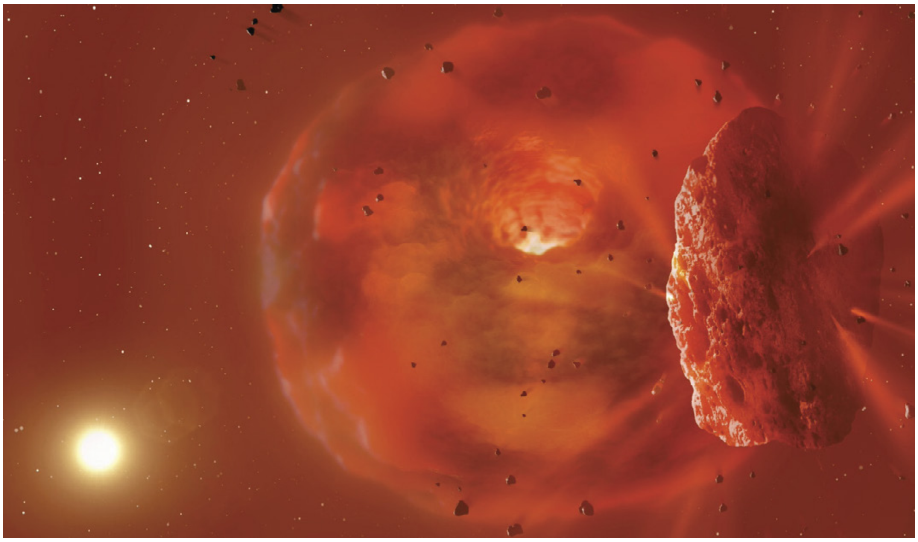
After decades of searching, scientists have found 13 stars accompanying the Magellanic Stream, a giant ribbon of gas discovered more than 50 years ago. Drawn from the Large and Small Magellanic Clouds, a pair of dwarf galaxies currently falling into the Milky Way, the gaseous stream stretches over three-quarters of the sky. Vedant Chandra (Center for Astrophysics, Harvard & Smithsonian) and colleagues were taking spectra of more than 200 stars at the Milky Way's outskirts using the 6.5-meter Baade Telescope at Las Campanas Observatory in Chile when they discovered 13 stars that followed the same motion as the stream's gas; the chemical signatures are consistent, too. The astronomers also used their observations to trace the stars' trajectories back to the Clouds. The researchers presented their findings in the October 20th *Astrophysical Journal*. "We've been looking for so long, like since the 1980s, to try and find these stars," says Gurtina Besla (University of Arizona), who wasn't involved in the study. "That there's now pretty convincing evidence that the stars exist is just exciting."

■ **KATYA GOZMAN**

Psyche Launches for Metal Asteroid

NASA's Psyche mission launched successfully atop a SpaceX Falcon Heavy rocket on October 13, 2023, before placing Psyche on course for its first planetary encounter, with Mars in May 2026. Before the mission zooms past the Red Planet, Psyche will use xenon fuel accelerated through ion engines to widen its orbit around the Sun. The Mars swingby will then send the spacecraft onward to the target asteroid, also named Psyche. Final approach to the metallic asteroid will begin in May 2029, and following gravitational capture in July 2029, two years of observations will commence. Cameras on the spacecraft will map the asteroid's surface. Other instruments onboard include gamma-ray and neutron spectrometers as well a magnetometer. The mission will also conduct radio science to peek inside the rock's interior. Once Psyche's images start arriving on Earth, they will immediately be posted to a public website: **https://science.nasa.gov/mission/psyche/multi-media-raw-images/**

■ **EMILY LAKDAWALLA**



▲ This visualization shows a huge, glowing body produced by a planetary collision. In the foreground, fragments fly away from the collision; they'll later cross between Earth and the star seen in the background.

EXOPLANETS

Two Worlds Ended — and Created Something New

ASTRONOMERS MIGHT HAVE caught two infant worlds slamming together around a young, Sun-like star more than 1,800 light-years away in Puppis. Calculations show that such an impact would vaporize both planets, creating a huge cloud of debris that still orbits the host star. Ultimately, the vaporized material would settle to form a new, much larger world — and astronomers are watching it all as it happens.

In late 2021, the All-Sky Automated Survey for Supernovae (ASAS-SN), a league of 24 sky-monitoring telescopes, sent out a notice regarding the star's sudden dimming. Over the next several months, ASAS-SN recorded a deep dive in brightness before it gradually recovered back to baseline.

The alert caught the eye of Matthew Kenworthy (Leiden University, The Netherlands), who led a team that analyzed data taken by the Las Cumbres Observatory Global Telescope Network and the Wide-field Infrared Survey Explorer before and after the sudden drop-off in the star's light. The researchers found that 2½ years prior to the star's months-long dimming, a new source of heat (and hence, infrared emission) had appeared around the star. Whatever occurred then, in 2018, warmed material to some 1000K (1,340°F) — and that material has stayed hot ever since.

To explain both the appearance of a new heat source in 2018 as well as the sudden dimming of the star in 2021, the team suggests in the October 12th *Nature* that a giant impact occurred between 2 and 16 astronomical units (a.u.) from the star, when two planets between Earth and Neptune in size collided. Now, the beginning of a new, larger planet is forming out of their remains. Debris from the collision is what blocked the star's light in 2021.

The team's calculations show that such a collision would vaporize both worlds, with a relatively small amount escaping to orbit the star. Most of the mass remained gravitationally bound, albeit in vaporized form.

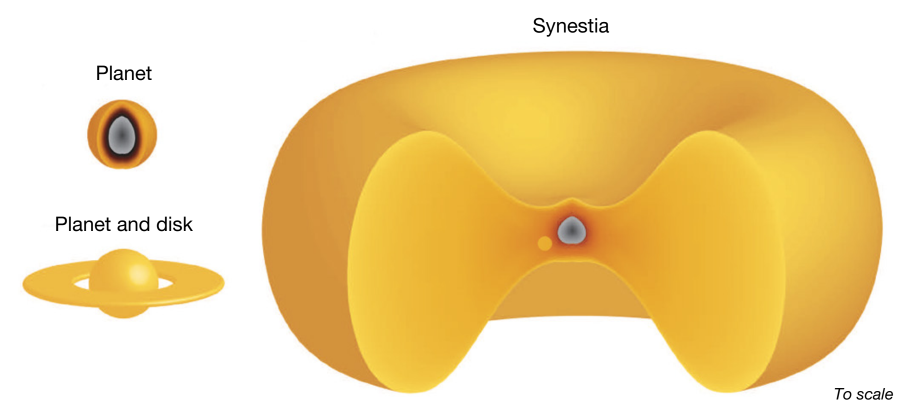
Team member Simon Lock (University of Bristol, UK) previously proposed that such remnants might take the shape of a *synestia*, a donut-shape cloud with a bit of material padding the middle. The collision provides an opportunity to test that idea.

But a collision isn't the only explanation. "Observationally, there is no doubt that the scale (the amount of mass) in this violent collision breaks the record," says Kate Su (University of Arizona), who was not part of the research team. "The question is, what's the 'correct' interpretation."

Another team, led by Jonathan Marshall (Academia Sinica Institute of Astronomy and Astrophysics, Taiwan), published a different explanation in the September 10th *Astrophysical Journal*, suggesting that a close (0.2 a.u.) dusty disk surrounds the star, perhaps originating from the breakup of comets. That team notes a marked similarity between this system and the curious Boyajian's Star (*S&T:* June 2017, p. 16).

Both ideas could explain the observations, and more work needs to be done to distinguish between the two scenarios. Kenworthy, for one, is already planning to ask for time on the Webb telescope to observe the system.

■ **MONICA YOUNG**



▲ This diagram shows the structure of a planet (top left), a planet with a disk (bottom left), and a synestia (right), all of the same mass.

SYNESTIA ARTIST'S CONCEPT: MARK GARLICK; DIAGRAM: SIMON LOCK AND SARAH STEWART

STARS

Intergalactic Blue Flare Defies Explanation

AN EXPLOSIVE BURST of blue light appeared in intergalactic space, thousands of light-years from the nearest galaxy. Now, astronomers are trying to narrow down what caused it.

The Zwicky Transient Facility in California was scanning the sky in April 2023 when it picked up the flare. Owing to the short shelf life of such transients, astronomers wasted no time in following up with a prepared sequence of multi-wavelength observations. A team led by Ashley Chrimes (ESA, The Netherlands) summarized the results in the January *Monthly Notices of the Royal Astronomical Society*.

The flare turned out to be a member of a rare class of fleeting phenomena known as *luminous fast blue optical transients* (LFBOTs), of which "the Cow" was the first (*S&T:* May 2019, p. 10). Officially designated AT2023fhn, this one was soon dubbed "the Finch."

LFBOTs are brilliant — up to 100 times brighter than typical supernovae — and maintain a persistent blue color throughout the entirety of their quick evolution, rising to peak and fading again within a matter of days.

Most LFBOTs occur in star-forming galaxies, so some have suggested they're a type of supernova. But the Finch differs from previous LFBOTs in that it lies unusually far from the two nearest candidate host galaxies: 54,000 light-years from a large spiral galaxy and 17,000 light-years from the spiral's satellite, a much smaller dwarf galaxy.

Chrimes and colleagues calculated that, unlikely though it may be, it is possible that a massive progenitor star originated in one of the galaxies and raced to its current isolated position before exploding. They add, however, that an unseen globular cluster in the vicinity might have hosted the Finch but eluded observation.

Other scenarios exist that could explain the explosion, such as a *tidal disruption event*, in which a star is ripped apart by a black hole or neutron star. That alternative "should be taken seriously," according to Brian Metzger (Columbia University), who was not involved in the study.

We can expect many more similar transients as the Vera C. Rubin Observatory comes online in Chile; it should see first light by late 2024.

■ **KIT GILCHRIST**

SPACE WEATHER

Alpine Tree Rings Reveal Ancient Solar Storm

ANCIENT PINE TREES in the French Alps hold the record of an atmospheric event 14,373 years ago — most likely a massive solar storm.

Edouard Bard (College of France) and a team of researchers recorded an abrupt increase in the radioactive isotope of carbon, carbon-14, within a single year's growth of the pines. The researchers propose that a solar storm might have caused the abrupt change.

During a solar eruption, high-energy particles may escape and head toward Earth. When these solar particles react with our atmosphere, they convert nitrogen-14 to carbon-14. Trees then absorb that extra radiocarbon, preserving it within the currently growing layer of wood.

Over the past 25 years, Bard's team has been collecting and analyzing samples from hundreds of ancient trees buried alongside rivers in the French Alps. The team dates the trees by counting tree rings. "It is of course not possible to go back to 14,000 years ago with just a single tree," Bard explains. "Instead, long chronologies are made of many trees that are crossmatched by using recognizable patterns of successive tree-ring widths."

The researchers then compared tree-ring dating against carbon dating. During years in which the two dating methods differ, the atmosphere's carbon-14 content appears to have fluctuated. Longer-term changes have other explanations, but fluctuations within a single year — such as the one the team found — are most probably due to a sudden increase in solar activity.

This particular solar storm was 10 times more powerful than the strongest storm on record: the Carrington Event that disrupted telegraph transmissions and produced widespread aurorae in 1859.

The researchers compared the information gleaned from the pines in the French Alps with an absolutely dated reference derived from German pines to achieve higher accuracy, putting the event at exactly 14,373 years ago.

▲ Tree rings are visible in a buried subfossil tree in Drouzet River in the French Alps.

The scientists also looked at levels of beryllium-10 (also a radioactive isotope) in ice cores taken from Greenland. Beryllium is also produced when high-energy particles interact with our atmosphere, and while the beryllium dating is less precise than carbon dating, the ice cores confirm the sudden change found in the trees. The team published the results in the November 27th *Philosophical Transactions of the Royal Society A*.

"I think a solar energetic particle event, as the authors state, is the most likely cause of the spike," says Gavin Schmidt (NASA Goddard), who wasn't involved in the study.

This event is on a short list of other known spikes of atmospheric radiocarbon, known as *Miyake events*. The other events occurred in AD 993, AD 774, 660 BC, and 7175 BC. This latest discovery is by far the most ancient and may provide insights into past solar activity and its effects on Earth.

■ **LIV EIEN**

CÉCILE MIRAMONT (IMBE, AIX-MARSEILLE UNIVERSITY)

VOLCANOES LOOM The trio of Tharsis mounts draw a line across Mars's surface in the first image obtained from the Emirates Mars Mission.

EMIRATES MARS MISSION

Hope at Mars

The orbiter of a nascent space agency is giving scientists a big-picture view of the Red Planet's atmosphere.

On February 9, 2021, a new spacecraft arrived in Mars orbit. It wasn't American, European, or Indian — and the Russians have long been out of the game. It belonged to the United Arab Emirates, a small nation on the Arabian Peninsula, which seven years earlier didn't even have a space agency. In fact when Neil Armstrong set foot on the Moon, the UAE didn't exist as an independent country.

The Emirates Mars Mission (EMM), also called *Al-Amal* or "Hope," was designed to obtain a comprehensive view of Mars's atmosphere and answer specific questions about the Martian climate and weather. To do so, Hope flies in a wider orbit than any other spacecraft does around the planet, giving it a clear vista of an entire hemisphere at once. It carries a multiband camera and two spectrometers that can analyze the light coming from Mars in wavelengths ranging from infrared to extreme ultraviolet.

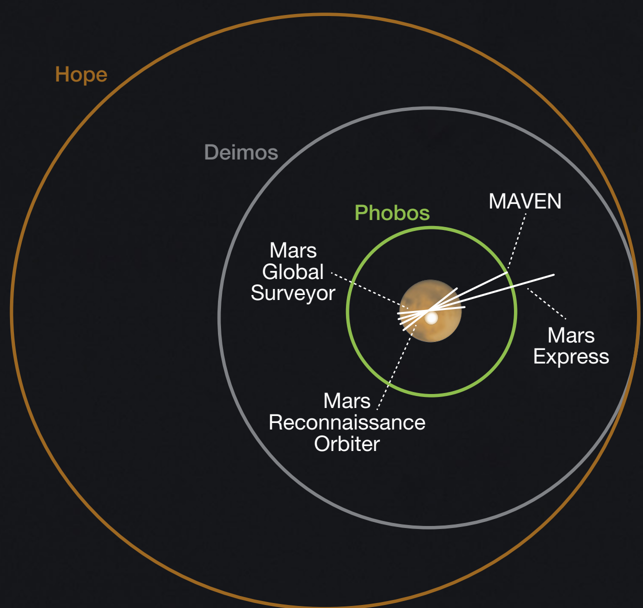
Hope's vantage point and high-cadence observations are already providing a unique view of evolving processes such as cloud formation, dust storms, and atmospheric loss. It has discovered previously unknown phenomena, including a new kind of aurora. Other spacecraft, such as NASA's Mars Atmosphere and Volatile Evolution (MAVEN) mission, have captured glimpses of Martian aurorae, but scientists didn't know their full scale.

Several flybys have also brought the spacecraft unprecedentedly close to Mars's outer moon, Deimos. The observations appear to refute one popular theory for Deimos's origin, shining new light on this mysterious satellite.

Hope remains in orbit, and its mission has been extended for another year. The success places UAE on the shortlist of space agencies that have reached the Red Planet (five at the time of its arrival) and makes the Emiratis the third to successfully reach Mars on the first try. Let's take a deeper look at what the mission has achieved so far.

A New Look at the Martian Atmosphere

One of the reasons the UAE embarked on this mission was to develop the country's science and engineering capabilities. Emiratis didn't want to just replicate what others had done in the past — they wanted to produce new science that would lead to scientific progress and international collaborations.



▶ **UNIQUE ORBIT** The Emirati Hope spacecraft has a bird's-eye view of Mars, looping far beyond the orbits of other active craft (white). The orbit is inclined 25° to the Red Planet's equatorial plane, unlike the pole-looping paths of the other orbiters.

LEAH TISCIONE / *S&T*, SOURCE: H. E. S. AMIRI ET AL. / *SPACE SCIENCE REVIEWS* 2022

This objective required combining their technical capabilities and budget with a goal worth pursuing, so they took a careful look at what the Mars science community was demanding. "There was this gaping hole in Mars science about active weather processes and escape rates," says Christopher Edwards (Northern Arizona University), who presented results from the orbiter's Emirates Mars Infrared Spectrometer (EMIRS) at the 2023 European Geosciences Union in Vienna. While other spacecraft in and around Mars have provided closeup views of these processes, putting together a global vision that combined observations of both the upper and lower atmosphere was challenging. "No mission was doing things in a really coordinated way."

EMM is designed to change that. Over the course of the mission, initially planned for a whole Martian year, the researchers have made daily observations of the whole atmosphere and tracked how it changed from season to season. "With the Emirates Mars Mission we want to get a holistic view of Mars," says the mission's science lead, Hessa Al Matroushi (Mohammed Bin Rashid Space Centre). "We want to get a global view of Mars, to get the diurnal variation from day to night to understand what is happening, and we want to take that from different layers of the atmosphere." Scientists will use this information to improve global circulation models — computer programs that simulate the behavior of the Martian atmosphere.

To obtain this global view, Hope orbits Mars in a high-altitude elliptical orbit ranging from 20,000 to 43,000 km (12,400 to 26,700 miles). From there, it can see the whole atmosphere, including the flow of particles escaping to space.

▲ **NOSE TO THE GRINDSTONE** Scientists and engineers labored to design, build, and test the EMM craft in about half the time of a normal mission. Construction began in 2015, and testing ran from late 2019 until days before the 2020 launch.

EMIRATES MARS MISSION (3)

Since Mars rotates slightly faster than Hope, the craft's instruments can watch global weather patterns as they evolve. This information helps paint a complete picture of the Martian atmosphere, complementing the more granular views collected by closer-in satellites, such as ESA's ExoMars Trace Gas Orbiter and NASA's MAVEN.

EMM also adds an unprecedented perspective to the temporal dimension. Most missions around Mars have local-time-locked orbits, passing above the same locations at the same local time every orbit. "If you only had a weather satellite on Earth that looked at 3 a.m. and 3 p.m., it'd be pretty hard to tell you what was going on in the middle of the day," Edwards says. EMM can look at things like how water vapor, dust, and water ice vary on a daily and seasonal basis. "That's something that we haven't really had before."

On the Shoulders of Giants

If going to Mars wasn't already an ambitious goal, Emirati bigwigs imposed a stringent timeframe: The spacecraft had to reach Mars before the country's 50th anniversary in 2021. That gave the team a total of six years to plan, build, and launch the mission, not including the nearly seven-month cruise to Mars.

To save time and minimize risks, Emirati scientists decided to play it safe and stick to what had worked in the past. They established collaborations with international *knowledge transfer partners*, as they call them, who could teach them how to do new things. This strategy had served them before when they launched a series of three Earth-observing satellites between 2009 and 2018: The first two were co-built, then the third was built domestically.

For EMM, the UAE Space Agency partnered with the University of Colorado, Boulder; Arizona State University; and the University of California, Berkeley, to develop the spacecraft and its instruments, including many U.S.-based researchers on the mission's science team (such as Edwards).

Also, rather than new instruments developed from scratch, the observing tools onboard Hope are updated versions of previous instruments successfully used in other space missions. EMIRS is based on the Thermal Emission Spectrometer (TES) included in the Mars Global Surveyor spacecraft and, more recently, as the OSIRIS-REX Thermal Emission Spectrometer (OTES). The Emirates Mars Ultraviolet Spectrometer (EMUS) is a new riff on a two-element imaging spectrograph, similar to previous instruments such as Cassini's UVIS but updated to be the most sensitive ultraviolet spectrometer ever sent to Mars.

Lastly, the Emirates Exploration Imager (EXI) is Hope's visible-light and near-ultraviolet camera. It can capture high-resolution images and even 4K-quality video. Its design is similar to other imaging systems, such as the Mars Color Imager (MARCI) onboard NASA's Mars Reconnaissance Orbiter.

"EMM is standing on the shoulders of giants but looking farther than anybody's seen before," says Justin Deighan (University of Colorado, Boulder), EMUS instrument lead scientist and EMM's deputy science lead. "[It's] really pushing the limits of what we know in a lot of areas and painting in that coverage that we had just little glimpses of in the past."

A Dynamic Atmosphere

EMM completed its first Martian year of science observations in April 2023, and scientists have yet to distill all the results from its seasonal coverage. However, it has already provided new insights into the workings of the Martian atmosphere. Specifically, it has improved our understanding of weather circulation in the lower atmosphere, the mechanisms that drive the upward transport of energy and particles, and the subsequent escape of these atmospheric particles to space.

Solar radiation helps drive loss from the upper atmosphere. It breaks down H_2O and CO_2 molecules, freeing oxygen and hydrogen atoms, which sometimes shoot off to space, never to come back. EMUS can see these atoms and how they are spread throughout the extended corona around the planet.

Meanwhile, EMM provides a global view of the distribution of dust, clouds, and water vapor across all times of day and all seasons, and it does so simultaneously for the upper and lower atmosphere, which is important for understanding how these layers are coupled. This is particularly critical for understanding how water from the lower atmosphere is transported to the upper atmosphere, where it may break up and escape.

"We are learning how these energetic atoms are made, and how they get out of the thermosphere and into space," Deighan says. "A lot of the earlier missions, they're deeply embedded in this corona — it doesn't matter where you look, you're just seeing what's right in front of your face."

Emirati scientists presented several findings related to Martian weather at the 2023 EGU meeting in Vienna. Khalid Badri (Mohammed Bin Rashid Space Centre), for example, showed Hope data taken while monitoring several weeks-long, regional dust storms. The global coverage, combined with hourly observations, enabled researchers to track the amount of dust the storms mobilized and its distribution to all longitudes, increasing the dust load over most of the planet. These observations can be useful for understanding the behavior of dust in the atmosphere, which is one of the main drivers of atmospheric dynamics on Mars.

Meanwhile, Hope researchers are using the EXI instrument to look at the cloud patterns across Mars during the day, almost like a weather satellite. They have observed that ice clouds tend to form early in the morning at low latitudes, gradually dissipating by midday. Maryam Yousuf (Mohammed Bin Rashid Space Centre) showed the seasonal and daily variations of *orographic clouds* in the Tharsis Montes region. Even on Mars, clouds can greatly influence ground temperatures by reducing the amount of heat lost to space. Current climate models, however, aren't very good at accounting for clouds' effects. Researchers hope the new data will help them improve those models.

While other missions have observed these processes before, EMM's global coverage and systematic, almost simultaneous observations at infrared, visible, and ultraviolet wavelengths are giving researchers a new, more detailed perspective. Mission scientists like Al Matroushi think that scientists outside the team are just realizing the possibilities that these integrated atmospheric data offer, and more external collaborations are starting to roll in. "That speaks of the gaps that we had before," she says.

Unexpected Aurorae

One of the most surprising EMM achievements so far is its new insights into Martian aurorae, including the discovery of a new kind. The mission wasn't planned with geomagnetism in mind, so these observations come as a bonus.

On Earth, charged particles from the Sun are redirected by our planet's magnetic field towards the poles, giving us our beautiful high-latitude aurorae (*S&T:* Oct. 2023, p. 74). Mars doesn't have a global magnetic field, but it still has an atmosphere that can interact with the solar wind. It also has *crustal paleomagnetism*, local magnetization engraved on lava fields that solidified when the planet still had its global magnetic cloak (*S&T:* Dec. 2023, p. 34). As a result, Martian aurorae take many forms and can occur at any latitude.

Incoming protons are responsible for *diffuse aurorae*, which occur on the nightside at low altitude, and *patchy proton aurorae*, which appear on the dayside. *Discrete aurorae*, on the other hand, are produced by electrons hitting the upper layers of the atmosphere. Other orbiters have previously detected several examples of them, but Hope is the first to provide a global view.

"It's almost like a zoo," says EMM science team member and Martian aurora expert Robert Lillis (University of California, Berkeley). "The last two years we've seen so many different shapes, and sizes, and brightnesses, and patterns, but they sort of fall roughly into three categories."

The first type of discrete aurora is called *crustal field aurorae*. These are bright and localized. They occur in areas where the crustal magnetic field is strong and vertical and funnels electrons into the thin atmosphere, increasing the flux and therefore the aurora's brightness.

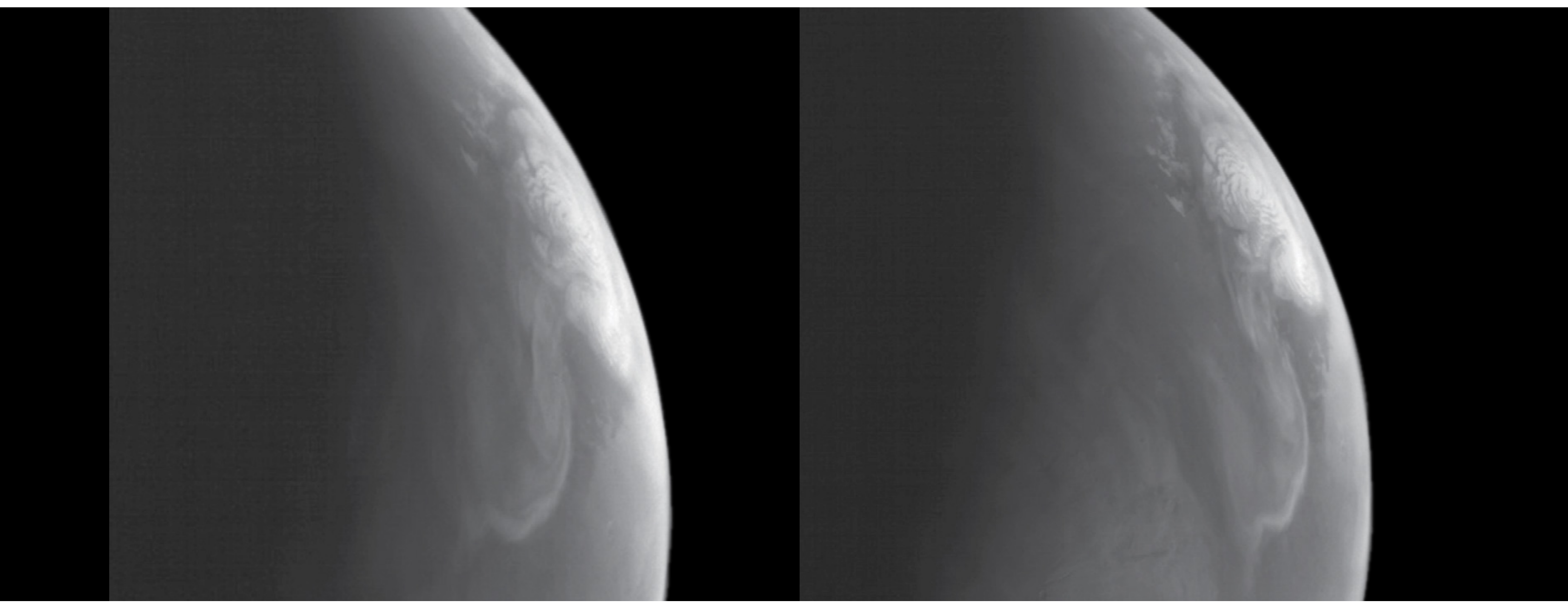
Then there are the *patchy aurorae*. These are the most common type and appear as broad areas of emission, many thousands of kilometers across on the nightside. They aren't related to crustal fields.

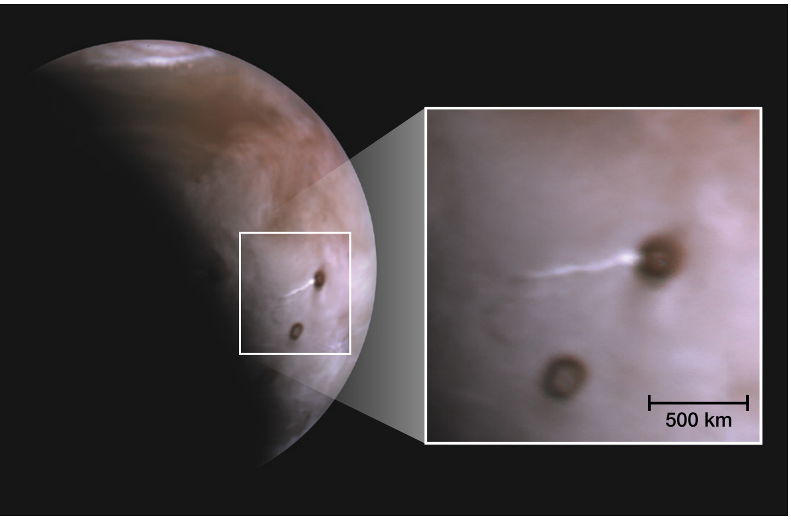
Scientists knew of these two kinds of discrete aurora before EMM, but the orbiter has revealed a third: snake-like aurorae that extend for many thousands of kilometers from the dayside in the northern hemisphere into the nightside. These *sinuous discrete aurorae*, as researchers have called them, seem to form away from crustal magnetic fields. They occur both at dusk and dawn but are twice as frequent at dusk.

It isn't entirely clear if sinuous aurorae are bright enough that a human standing on the surface of Mars could see them. "If they were really obvious, the cameras on the rovers might have seen them," Lillis says. However, "human eyes can become very accustomed to the dark, and therefore very sensitive, so we think it would be possible," he adds.

EMM has also captured new details of *patchy proton aurorae*. NASA's MAVEN team first reported these aurorae in 2018 as a smooth glow. But EMM's EMUS has revealed that proton aurorae can become irregular during solar storms, suggesting that when the magnetic environment around Mars gets

DUST IN THE AIR These images from the EXI instrument track the long, winding front of a dust cloud on Mars on September 10, 2021. The images are each separated by two to three hours, and the cloud largely stayed put from beginning to end. The storm's large atmospheric front was unusual for the location and season.





◀ **CLOUD PLUME** A water-ice cloud streams some 600 km westward of the volcano Ascraeus Mons. Before EMM, observations of these early-morning plumes had been rare, because the ground tracks of most Mars orbiters favor afternoon coverage. Hope, however, has seen a large number of them.

disturbed, the solar wind interacts directly with the crustal magnetic fields.

"It amazes me because just a different perspective can tell you more about these phenomena in a better, informative way that hadn't been possible before," Al Matroushi says.

Deimos Flyby

Hope's wide orbit around Mars provided a unique opportunity to attempt a flyby of Mars's outer moon, Deimos.

Deimos circles the Red Planet at a distance of just under 23,500 km, putting it near EMM's closest approach to Mars. Flight engineers repositioned Hope's orbit without changing the distance to the planet, so it could continue normal science operations between flybys. The maneuver synchronized the spacecraft and satellite orbits, enabling a series of flybys approximately every two weeks. The closest approach occurred on March 10, 2023, when the spacecraft was only 103 km away from Deimos' surface. The last time a spacecraft came closer to Deimos was the Viking 2 orbiter in 1977.

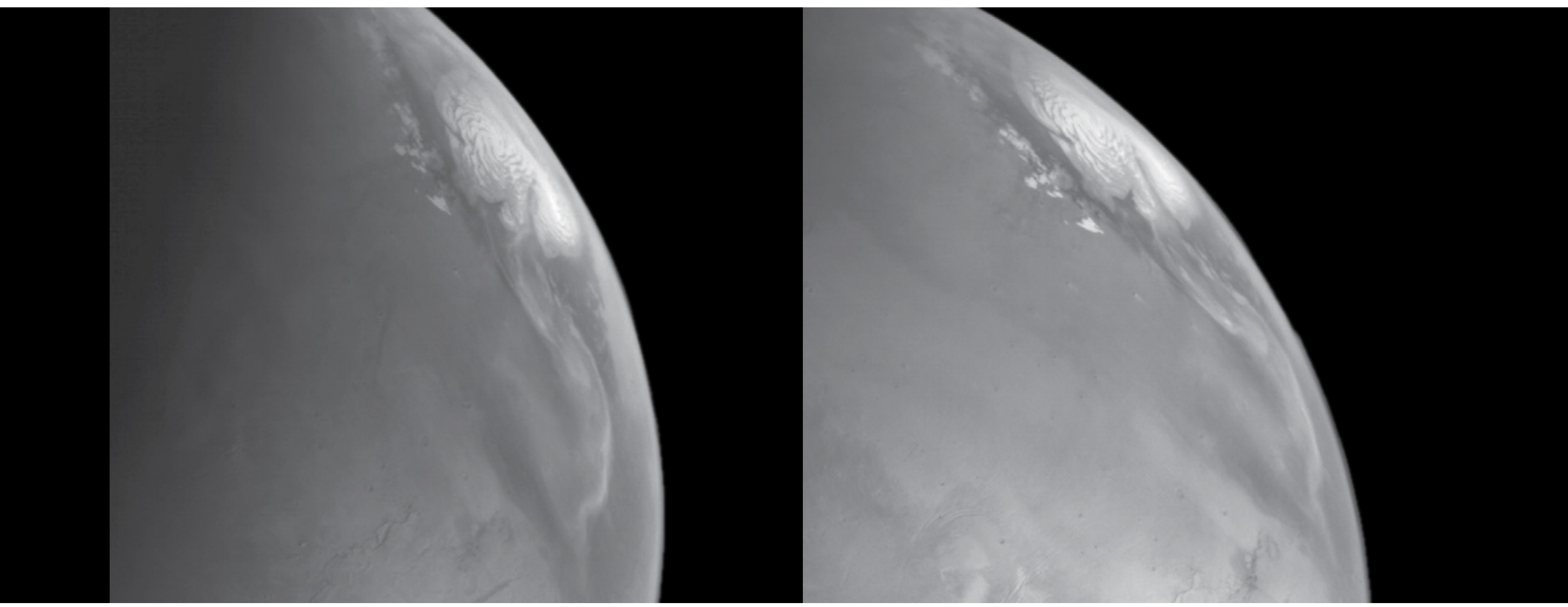
Hope was able to map almost the whole moon with a resolution of 10 meters per pixel. It has also given us our first look at Deimos's farside. (Like Earth's Moon, Deimos only points one face at its planet.) High-resolution spectroscopy with EMUS and EMIRS revealed details of the moon's surface composition and temperature, hinting that it's made of the same stuff as Mars.

The origin of Mars's natural satellites — Phobos and Deimos — has been heavily debated (*S&T:* Apr. 2021, p. 34). Since both moons are extremely dark and have similar spectral features to D-type asteroids, some researchers have argued that they could be captured space rocks, trapped in Martian orbit long ago.

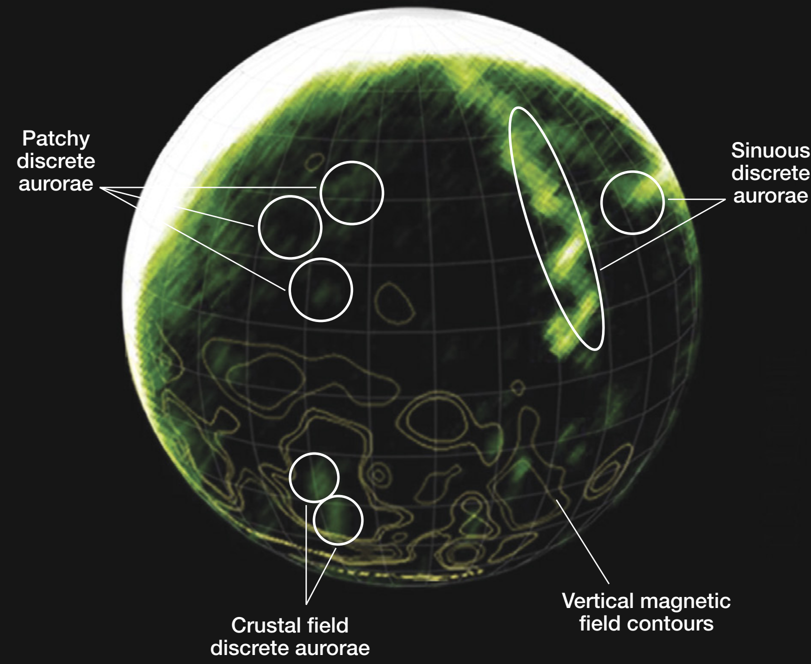
However, it's very difficult for a captured asteroid to wind up in a nearly perfect circular orbit like the moons both have. Thus, scientists have imagined other theories for their origin, most of them variations of a giant-impact scenario, in which the impact launched enough material into space to form the moons. While in some versions the moons coalesce directly from the debris, in others one or several moons form first, only to break down over time, giving birth to puny Phobos and Deimos from their leftovers.

Hope revealed two important things about the composition of Deimos. On one hand, the moon lacks carbon-rich minerals, a mismatch with D-type asteroids. These asteroids formed beyond Jupiter's orbit and are expected to be rich in water, organics, and other volatiles. On the other hand, the infrared spectrum of Deimos's surface seems similar to that of basalt, a volcanic rock abundant on Mars.

EMIRATES MARS MISSION



DEIMOS UP CLOSE This composite image from Hope's EXI instrument shows Mars's outer moon, Deimos, with the Red Planet in the background.



MARTIAN AURORAE Mars has a complex interaction with the solar wind, creating a zoo of aurora patterns in its wispy atmosphere. This spectroscopic image catches several aurorae in a single observation. It's upsampled for clarity and layered over a wireframe of the planet, with contours marking crustal magnetic fields.

These findings go against the capture scenario. "Regardless of the exact composition, what we can say is it's not consistent with a D-type asteroid," Edwards says. "Are Phobos and Deimos identical, or are they different parts of the same major ejection event? I don't think we can say that yet."

One of the most challenging parts of the flyby, Edwards says, was actually finding Deimos. There's a system used to locate objects in the solar system called SPICE that is typically used to plan observations and determine where the instruments need to look. "Their model for Deimos is pretty old, it just hasn't been refined," he says. While for most instruments this isn't a problem — the object will likely fall within the field of view anyway — it becomes critical when planning a flyby from 100 km away.

"Our original projections were that it could be 50 kilometers off in the wrong location," Edwards says. "If the body is over here and we look the other way, we're just looking at space." To address the problem, Hope took lots of images of the moon as it approached, and planners used them to narrow down the positional uncertainty.

With the first set of flybys accomplished, the team will likely attempt more in the future, when different lighting conditions might reveal new details about the moon.

From Mars to the Future

The science coming out of the EMM mission is just one part of an ambitious plan the UAE is setting in motion for development both in space and on the ground. In space, they have stated a desire of colonizing Mars by 2117. On the ground, they are using their space program to promote science careers among young people, looking to increase the country's scientific output and technological capabilities. (Incidentally, this is where the spacecraft takes its name from: It's meant to inspire hope among Arab youth for a brighter future.) Additionally, all the data gathered by the mission are publicly available, to foster international collaborations.

According to Al Matroushi, a few years ago young Emiratis didn't understand how a career in science would play out, other than to become teachers. "We put a lot of efforts from the program itself to do a lot of outreach activities to increase awareness within the country that there are a lot of paths when it comes to studying science, whether it is in the space field or others," she says. "Now I see a lot of programs within the universities in UAE focused on physics or on space science, and there is a lot of demand."

Women have already taken the lead in these fields. In fact, about 80% of Emirati mission scientists are women, something unlikely in most Western countries.

"I get this question a lot, whether I did have any difficulties in the path of getting what I needed, but honestly not," Al Matroushi says. "It's not about gender. It's more about what you bring to the team, and if you have the expertise, and you have the skills, then you get the position."

The mission's extension for another Martian year brings new science opportunities, especially as the solar cycle is entering its active phase. "Being able to see another part of a Mars year at high solar activity is going to give us a very different picture," Deighan says. This will enable scientists to better discern how increased solar activity changes atmospheric dynamics. They also expect more frequent and severe dust storms. "Just continuing to do the same types of observations we've been doing, we're going to learn more than we have just in the primary mission alone."

■ **JAVIER BARBUZANO** is a freelance science journalist who covers astronomy and geoscience.

EMIRATES MARS MISSION (2)

 by Dan Falk

Astronomers are peering into space — and into the past — to map the cosmos. Along the way, they hope to shed light on the mystery of dark energy.

When it opened on the summit of Arizona's Kitt Peak in 1973, the Nicholas U. Mayall telescope was the second-largest optical telescope in the world. Today, its 4-meter primary mirror no longer ranks in the top 20. But no matter: It has been given new life as the home of an ambitious project called the Dark Energy Spectroscopic Instrument (DESI) survey — a five-year effort to map the universe in three dimensions and provide our clearest picture yet of cosmic history.

The DESI device at the heart of the survey takes its name from the mysterious force, discovered only a quarter century ago, that seems to be causing the universe to expand at an accelerated rate (see page 26). Scientists have dubbed this force *dark energy* as a kind of placeholder; for now, no one knows exactly what it is or what role it played over the universe's nearly 14 billion-year history. "We know the universe is accelerating," says DESI collaboration member Stéphanie Juneau (NSF's National Optical-Infrared Astronomy Research Laboratory, or NOIRLab). "But how exactly is it accelerating? We need measurements to really pinpoint the answer."

DESI, which saw first light in 2019, has already yielded impressive cosmological measurements. Using data collected in late 2020 and early 2021 during the instrument's survey validation phase, astronomers have made the most precise measurements yet of *baryon acoustic oscillations*, an imprint in the distribution of galaxies left by sound waves that traveled through the early universe before it had cooled enough to allow the first atoms to form. Much more is expected by the end of DESI's five-year run, including data that may illuminate the fate of the universe itself. That fate will be decided by two competing forces — gravity, which tries to pull everything together, and dark energy, which appears to be pushing everything apart.

Dark Energy: A Celestial Surprise

The discovery of dark energy in 1998 came as a shock. In the Big Bang model of cosmology, the universe is thought to have come into existence when spacetime began expanding almost 14 billion years ago. That expansion carried galaxies along with it, so one can think of those galaxies as rushing away from one another. But we also know that gravity causes matter to attract matter, which ought to slow the outward march of the galaxies. And that did indeed happen, for the first several billion years.

Then it began to speed up.

Has dark energy's push been constant over all that time, or might it have varied? Astronomers have a reasonably clear picture of how the universe began, and a very good idea of what it's doing now — but key elements of the intervening story are missing. "There's 13.8 billion years in between, which we don't understand well enough yet," says DESI director Michael Levi (Lawrence Berkeley National Laboratory). "So that's a lot of history to fill in."

Because DESI is a spectroscopic instrument, it reveals not only where galaxies are in the sky but also their motion toward or away from us. If a galaxy is receding from us, its spectrum shifts to longer, redder wavelengths. The degree of that redshift is proportional to the galaxy's distance. Thanks to this correlation, DESI astronomers can map the universe's largest structures at various epochs in cosmic history.

Along with gravity and dark energy, there's a third player that complicates the picture: Galaxies receive help from dark matter, an unknown substance that also exerts a gravitational tug, so much so that it holds vast clusters together and warps the light from background galaxies. To understand cosmic history, then, scientists need to untangle dark energy's push from gravity's pull, taking into account that some of that pull is from unseen dark matter. Data from DESI will help researchers tease apart these competing influences.

"The nice thing about DESI is that we're going to have so much data going back so many billions of years that we can 'time-slice' the data," says Levi. "So we can ask the question, what was the universe doing a billion years ago? What was the universe doing five billion years ago? What was the universe doing 10 billion years ago?"

The New Cosm

RAYS OF GALAXIES This visualization highlights early data released from the DESI project. Detailed images taken in 20 different directions on the sky resulted in a 3D map of 700,000 objects. DESI is now filling in the gaps between those regions.

DAVID KIRKBY / DESI COLLABORATION

3D Atlas of
ic History

Reaching out into Space — and Back in Time

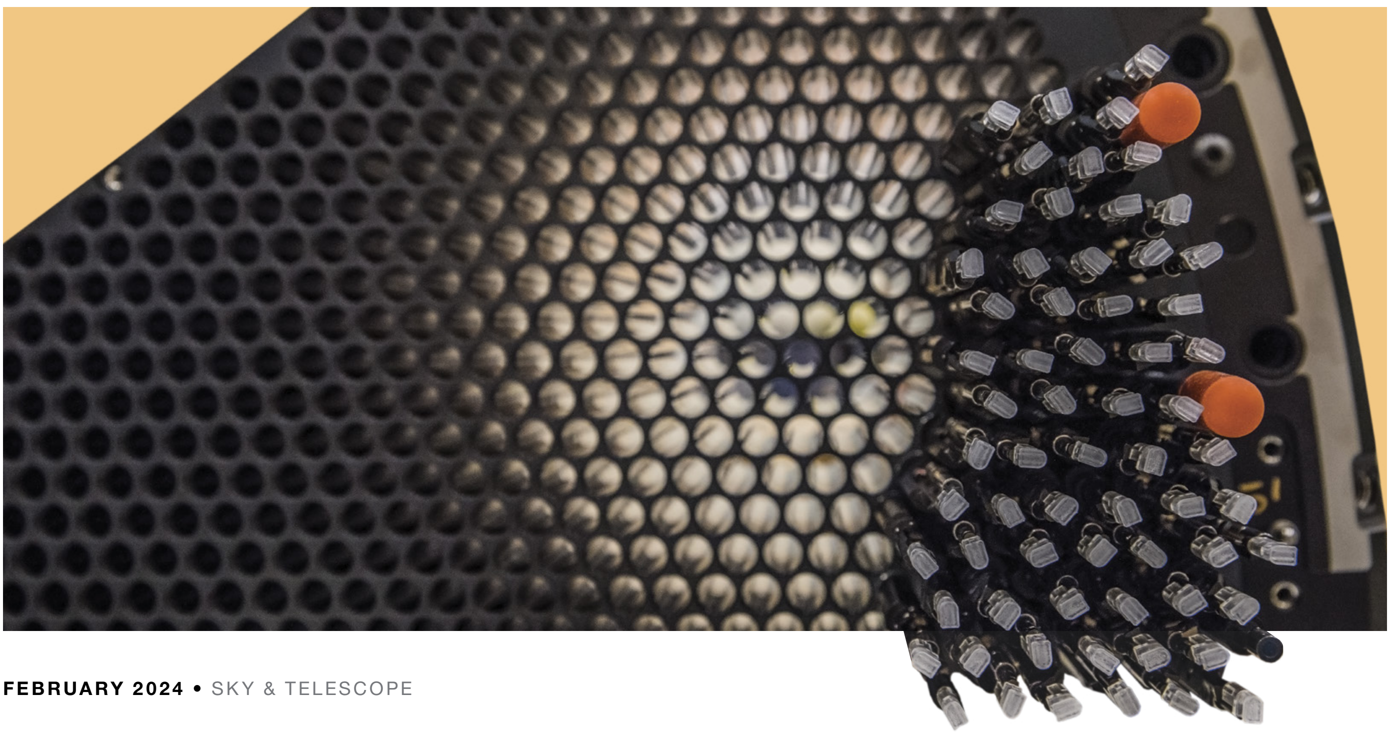
Although many newer telescopes are larger than the Mayall — the Keck telescopes in Hawaiʻi, for example, have mirrors more than twice its diameter — the half-century-old machine turns out to be perfectly suited for DESI. For starters, it has a wide field of view, which has been made even wider with a specially designed set of corrector lenses. The 9-ton assembly holds six corrector lenses, each roughly a meter across, and rests on a metal frame some 15 meters (50 feet) above the observatory floor. Luckily, the Mayall was "built like a battleship," says Arjun Dey (NOIRLab). "It was one of the few telescopes that had enough structural integrity to be able to hold what is essentially a giant school bus up above its mirror and not have it all collapse." The corrector lenses give the telescope an effective field of view of just over 3° — equivalent to six times the apparent size of a full Moon. The wide field of view is essential for efficiently covering large swaths of sky. DESI will ultimately map one-third of the celestial sphere — some 14,000 square degrees.

With its wide field of view, DESI can record thousands of galaxies at a time; it's currently collecting some 100,000 spectra per night. That's where DESI's most remarkable innovation comes in: its "robot army" of 5,000 miniature, automated positioners that feed the incoming light from each galaxy into one of 10 identical spectrographs via fiber-optic cables, one fiber per galaxy. After obtaining spectra from all the galaxies in a particular patch of sky, the telescope swivels over to the next patch, and the little robots spring into action, reconfiguring the positioners so that the fiber-optic cables line up with new targets. The whole repositioning procedure — a precisely choreographed dance of 5,000 little robots — takes only a couple of minutes.

◀ **OVERHAULED** In order to install the DESI instrument, the entire top half of the Mayall telescope (pictured here) was replaced.

DESI's technological innovation is even more apparent when contrasted with its predecessor, the Sloan Digital Sky Survey, which began mapping the sky in 2000 using a telescope in New Mexico (*S&T:* Jan. 2023, p. 20). Although the SDSS telescope also now employs robots to position fiber-optic cables, for many years those fibers had to be placed by hand. To that end, engineers would drill about 1,000 tiny holes in an aluminum plate that was put at the telescope's focal plane. A human would then connect the cables manually to each hole. Whenever the telescope was aimed at a new part of the sky, a new aluminum plate (with a completely different set of drilled holes) had to be inserted and the fibers re-attached. With DESI's robot army, no plates and no drilling are required; the robots simply move the fibers to where they need to be. (Juneau keeps one of the old Sloan plates in her office, propped up against a wall — a relic of how astronomical surveys were done not all that long ago.)

▼ **ROBOT HELPERS** DESI's focal plane, which sits high atop the Mayall telescope, carries 5,000 robotic positioners, distributed among 10 wedges with 500 positioners each. (Part of a single wedge is shown here.) Each robot holds a fiber-optic cable, which it positions for a single target for every observation. The movements are carefully choreographed to avoid collisions. Visit **https://is.gd/DESIrobots** to see the fiber-positioners in action.



DESI has faced setbacks along the way: COVID-19, of course, and more recently wildfires, which raged across the mountain and came dangerously close to the telescope in the summer of 2022. The flames badly damaged several buildings but, luckily, left the scientific equipment intact. Even so, the project is now ahead of schedule: As of press time, DESI has already cataloged redshifts for more than 26 million galaxies and quasars — more than all previous surveys combined.

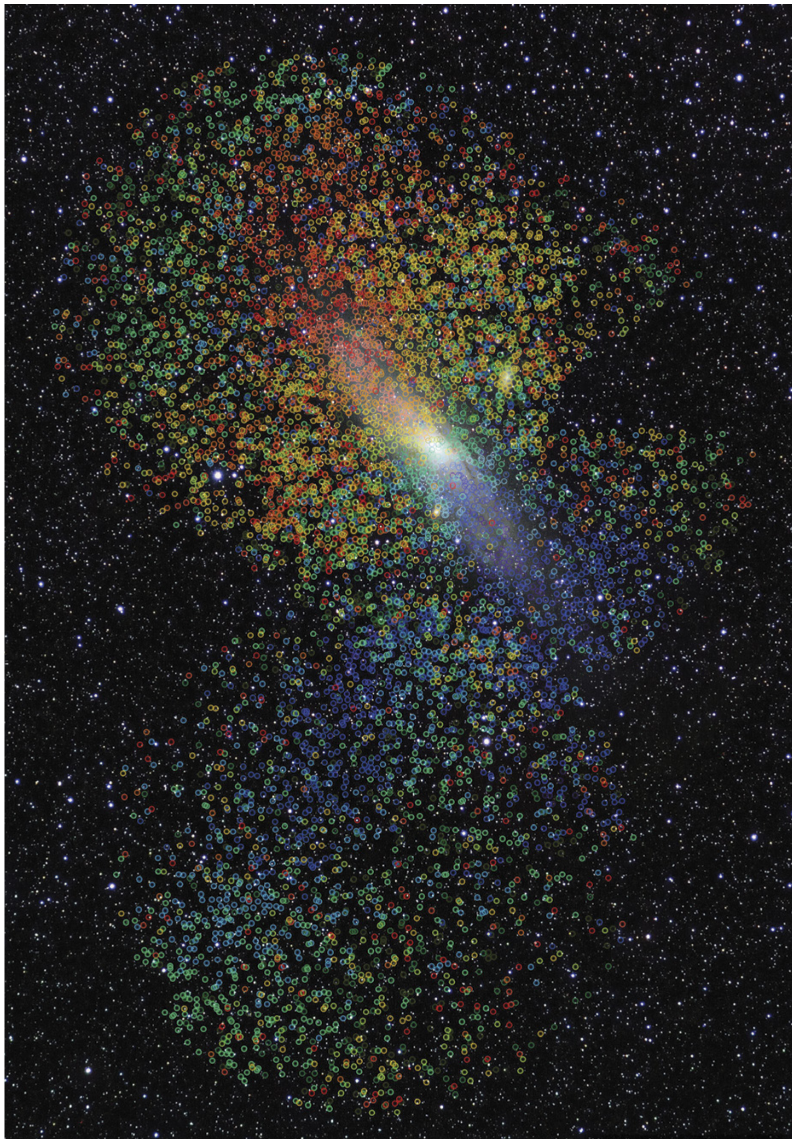
First Results and Persistent Puzzles

The first scientific results from DESI, gleaned from the project's validation phase, have the DESI team beaming with satisfaction and anxious to see the full results from the project's five-year run. The early results stem from an analysis of 2,480 exposures encompassing nearly 2 million objects, obtained between first light and the start of the instrument's official science run. Already, DESI has shown in detail how stars are moving around the Andromeda Galaxy, providing insights into the galaxy's evolution. It has also found distant quasars that formed when the universe was less than 2 billion years old.

Most exciting of all, it has yielded a precise measurement of baryon acoustic oscillations (BAO). We think of space as being silent, but, back when the universe was just thousands of years old, sound waves (that is, oscillations in pressure) permeated the cosmos. The universe was a dense soup of electrons and *baryons*, heavier particles like protons and neutrons. There were also photons — in fact, they outnumbered all of the other particles — but they were trapped, unable to travel any significant distance before hitting a baryon or electron. That primordial soup, known as a plasma, was uniform but not perfectly so: Tiny irregularities, sparked by quantum fluctuations, had been blown up to macroscopic size by cosmic inflation during the first tiny fraction of a second of the universe's existence (*S&T:* June 2023, p. 34). The energy of those trapped photons exerted pressure, pushing matter from over-dense regions into less-dense regions, while gravity tried to pull them back. The result was a kind of back-and-forth sloshing.

But this period of oscillation didn't last. Around 380,000 years after the Big Bang, matter and light decoupled, allowing photons to move freely. The universe was now transparent to light — but no longer conductive to sound. Those primordial sound waves became "frozen" in place. Over time, those excessive baryon pileups would dictate where the greatest concentrations of galaxies would appear. In other words, the primordial waves left an imprint on the large-scale distribution of galaxies — an imprint that astronomers observe today.

Pick any two galaxies in today's universe: How far apart should they be? At first it might seem like the distance between them should be completely random. But thanks to the BAO imprint, there's a slight preference for them to have a specific separation now. The best estimate for that distance, based on the size of the irregularities seen in the *cosmic microwave background* (CMB), works out to about 450 million light-years. This means that, for any modern galaxy you might select, you should be slightly more likely to find another galaxy at a distance of 450 million light-years rather than 350 million light-years or 550 million light-years.



▲ **MASS MIGRATION** Each of the circles on this image represents an individual star in the Andromeda Galaxy's vast stellar halo. The motion of each star relative to the galaxy, calculated from DESI data, is color-coded from blue (moving toward us) to red (moving away from us).

KPNO / NOIRLAB / AURA / NSF / E. SLAWIK / D. DE MARTIN / M. ZAMANI

SDSS first detected this correlation in 2005, but DESI's measurement, presented at a meeting of the American Physical Society in April 2023, is far more precise. The evidence for BAOs shows up in a graph in which the separation between galaxies is plotted on the *x*-axis, and the likelihood of finding a pair of galaxies with that separation is plotted on the *y*-axis — what physicists call a *correlation function*. The graph shows a distinctive peak at a separation of about 450 million light-years. "That 'bump' is exactly what we've been looking for," says DESI spokesperson Nathalie Palanque-Delabrouille (Lawrence Berkeley National Laboratory). "We see it very clearly, even in just two months of data." The DESI team says the BAO detection has a *five-sigma* confidence level, meaning that there's only one chance in a million that the correlation is a statistical fluke.

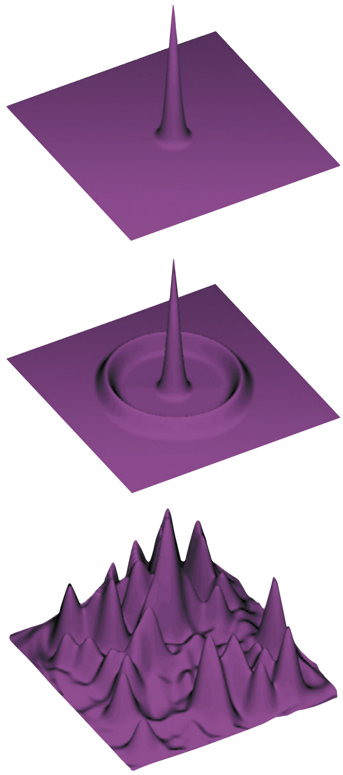
Because the BAO imprint started off at a specific physical size and grew as the universe expanded, it can be used to trace the universe's expansion rate at various times in its history. The apparent size of that imprint at any one time — as revealed by measuring the distribution of galaxies at specific redshifts — tells us how fast the universe was stretching at that time. And that data, in turn, may lead to a clearer understanding of the role played by dark energy.

Cosmic Questions

There remains the question of what dark energy actually is. The simplest proposal is the one that Einstein came up with in 1917 — the notion that seemingly empty space contains a small amount of energy. But what if the strength of dark energy changes over enormously long periods of time?

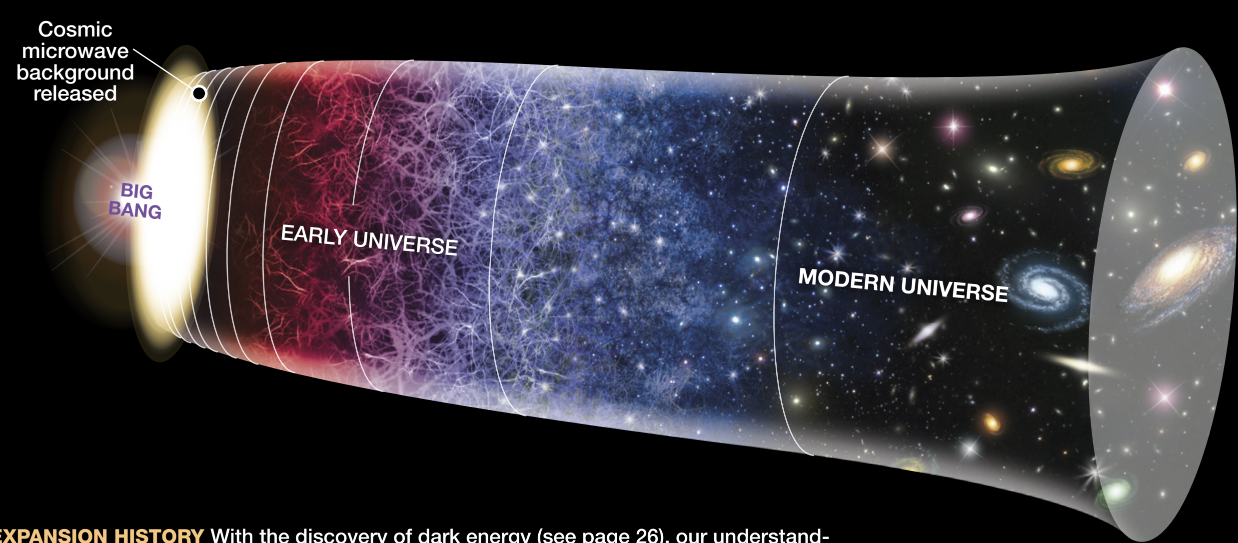
"The first step is to see whether the cosmological constant is really constant," says theoretical physicist Rocky Kolb (University of Chicago). "And the best handle on that — the only handle, perhaps — is measuring the expansion history of the universe." Which is precisely what DESI is designed to do.

So far, results from DESI appear to mesh with the most widely accepted cosmological model, in which the universe contains an unchanging cosmological constant along with cold dark matter (the so-called ΛCDM *model*). But a fixed, unchanging cosmological constant of some arbitrary value would be rather dull, says Palanque-Delabrouille. Finding that dark energy varies in strength over time would be far more tantalizing — the discovery of the century, perhaps. But it would mean physicists have a lot of work ahead of them. If dark energy can vary, "then there's something we haven't put in our theory," says Palanque-Delabrouille. "And so we really have to be opening our minds to new theories, to new approaches."



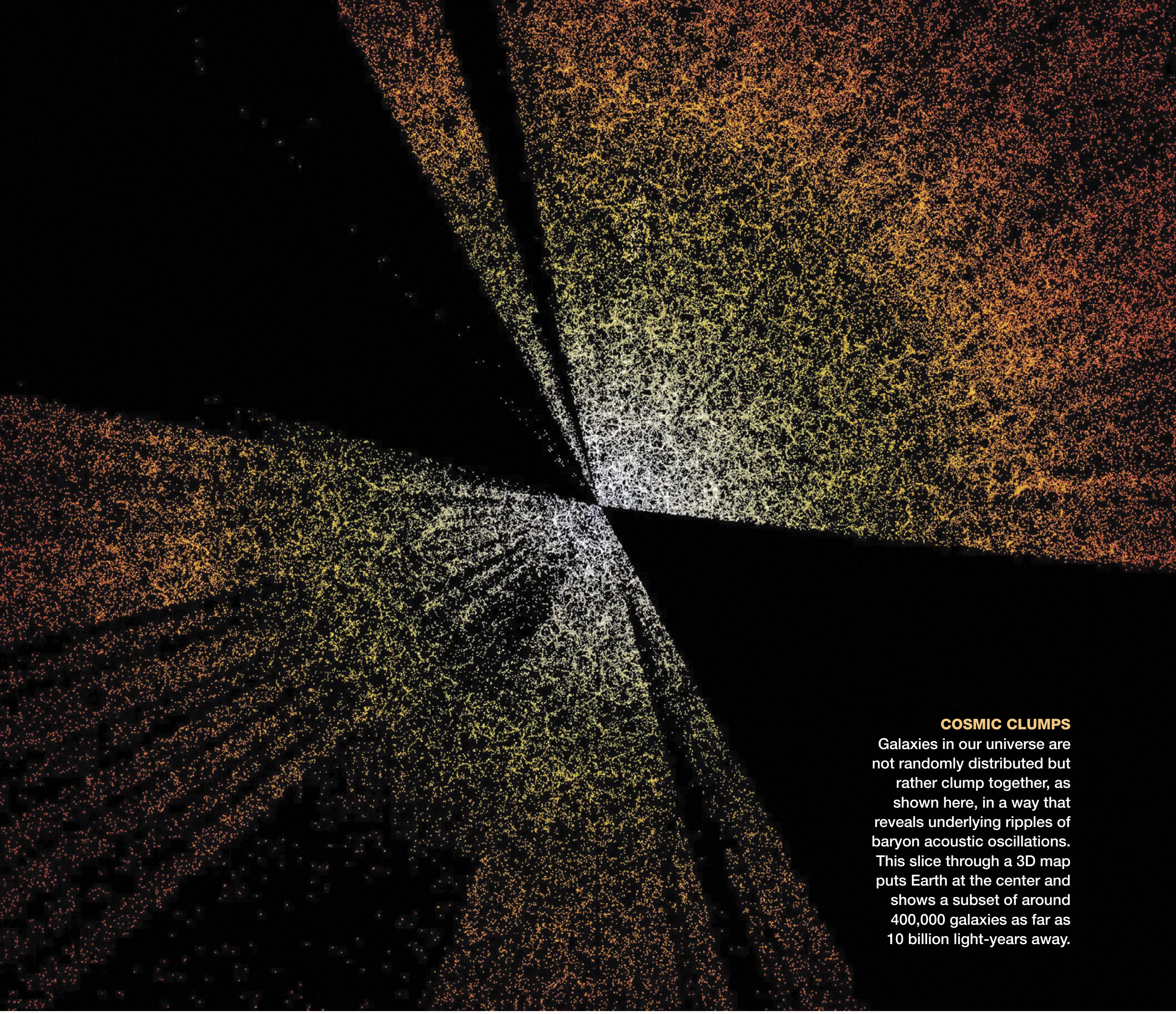
◀ **PRIMORDIAL SOUND** Just as a rock dropped in a pond creates a wave that ripples outward along the water's surface (*top* and *center*), so too did sound waves slosh through the early universe. Each region initiated its own sound wave, so resulting ripples overlapped (*bottom*), but the average imprint is still there.

Our understanding of gravity may also come under scrutiny. Newton showed that the strength of the gravitational attraction between two objects is proportional to their masses and inversely proportional to the square of the distance between them (a "one over *r*-squared," or $1/r^2$, law). Einstein's general relativity provides a more sophisticated version of this law, but it preserves Newton's foundation, still envisioning gravity as a $1/r^2$ force. But what if gravity behaves differently over cosmological distances? For decades, researchers have put forward various alternative gravity theories, generally gathered under the banner of *modified gravity*,



EXPANSION HISTORY With the discovery of dark energy (see page 26), our understanding of the more recent cosmic past has changed. Observations show that the universe is expanding faster and faster. More precise data from the long-ago universe will help astronomers determine whether and how that accelerating expansion will continue.

BARYON ACOUSTIC OSCILLATIONS: D. EISENSTEIN; EXPANSION HISTORY OVER TIME: S&T DIAGRAM



COSMIC CLUMPS Galaxies in our universe are not randomly distributed but rather clump together, as shown here, in a way that reveals underlying ripples of baryon acoustic oscillations. This slice through a 3D map puts Earth at the center and shows a subset of around 400,000 galaxies as far as 10 billion light-years away.

D. SCHLEGEL / BERKELEY LAB, USING DATA FROM DESI; ACKNOWLEDGMENT: M. ZAMANI (NSF'S NOIRLAB)

with proposed tweaks to the $1/r^2$ formula. If one of these modified-gravity theories turns out to be right, then it would mean a rethink of both dark energy and dark matter. Indeed, they might become superfluous. So far, however, there is no evidence that general relativity requires tweaking.

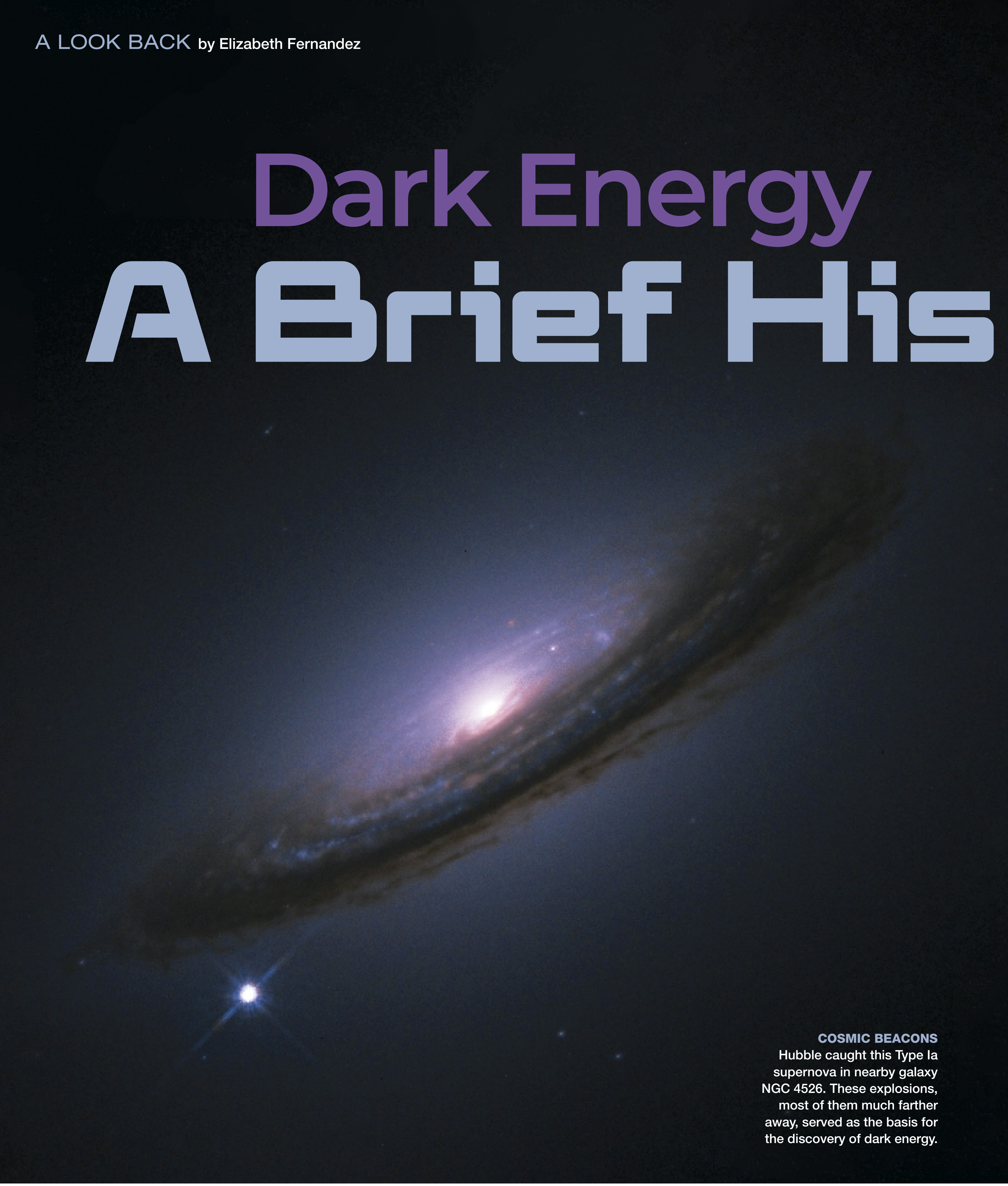
Cosmic history can be thought of as a tug-of-war between gravity and dark energy. If gravity wins, the universe may eventually contract in a reverse Big Bang, known as a Big Crunch. If dark energy proves mightier, the universe will continue to expand forever, at a faster and faster clip, becoming ever darker and colder. As far as cosmic questions go, muses Juneau, "the fate of the universe is a big one." For Juneau and her colleagues, the effort to get a handle on dark energy lies at the frontier of our understanding of the cosmos. "And with DESI, we're pushing the frontier," she says.

Human beings, with their penchant for questions, are latecomers in the universe's story, appearing on the scene only a few hundred thousand years ago. Now scientists can peer backward, bringing the billions of years that led to the present moment into sharp focus, along with a clearer picture of the far future. "We're all trying to add a chapter to the story of how the universe was created, how it evolved, how structure in the universe evolved, how the galaxies and the planets got here," says Levi. Or as Juneau puts it: "It's the nature of humans to be curious, to ask 'how does it work?'" Even — or perhaps especially — when the "it" is the entire universe.

■ **DAN FALK** (@danfalk) is a science journalist based in Toronto. His books include *The Science of Shakespeare* and *In Search of Time*.

 by Elizabeth Fernandez

Dark Energy
A Brief His



COSMIC BEACONS
Hubble caught this Type Ia supernova in nearby galaxy NGC 4526. These explosions, most of them much farther away, served as the basis for the discovery of dark energy.

A quarter century ago, data collected from far-off supernovae turned up something strange — a discovery that upended the fate of the universe.

tory

Sometimes, astronomy starts with philosophy. Beyond the pretty pictures and complex math, the motivating questions that drive astronomers are things like, "Are we alone?", "Why are we here?", or "Will the universe last forever?"

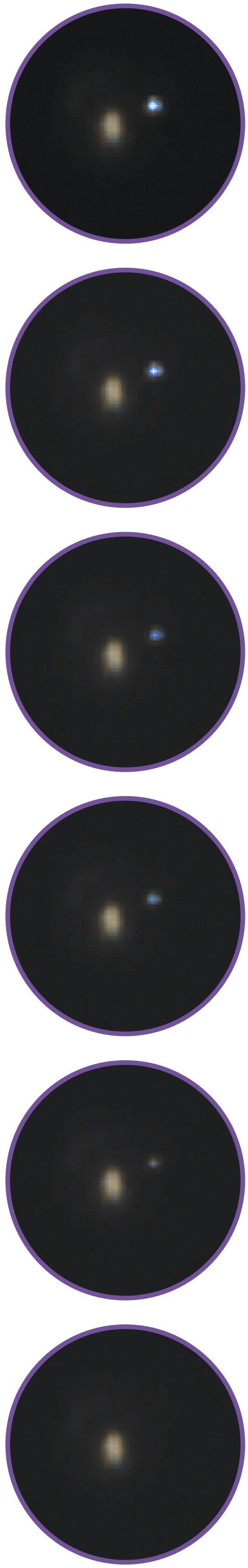
When Saul Perlmutter (now at University of California, Berkeley) was a graduate student in the 1980s, it was the fate of the universe that was keeping him up at night.

Since the early 20th century, astronomers had known the universe was expanding — but would it expand forever? Or would gravity eventually pull it all back together in a Big Crunch? There simply weren't enough data to decide.

The answer came down to the universe's density, which would be reflected in the "shape" of space itself. In a *closed universe*, density is high, and the mutual gravity of galaxies will eventually recollapse the cosmos, pulling everything back together again. In such a universe, parallel lines ultimately converge. In an *open universe*, on the other hand, there is not enough mass to put expansion in reverse, so the space between galaxies just keeps growing. In this universe, parallel lines diverge.

A third option lies in between: In a flat universe, in which parallel lines stay parallel, there's just enough mass to slow and eventually halt its expansion — but only after infinite time.

Yet, even though theory suggested the universe was indeed flat, astronomers didn't see enough matter to make it so. Without enough matter, and hence gravity, expansion would continue forever. Astronomers thus thought that determining how much matter there really was could help match observations with theory and thus predict our universe's future.



To address these big questions, scientists turned to exploding white dwarfs, which create *Type Ia supernovae*. The researchers could calculate how intrinsically luminous such an event becomes, compare that against the observed brightness, and deduce its distance. Pairing the distance with a measure of how rapidly the supernova's host galaxy is receding from us (that is, its *redshift*) reveals the expansion rate at that point. By gathering enough such measurements, astronomers could see how the expansion rate has changed over cosmological history, shedding light on the matter density and the fate of our universe.

Tricky Observations

Planning observations of supernovae is difficult. The explosions are rare and their locations unpredictable. To evade these problems, two groups of scientists — the Supernova Cosmology Project (SCP), cofounded by Perlmutter, and the High-Z Supernova Search Team, led by Brian Schmidt (now at the Australian National University) and Nicholas Suntzeff (now at Texas A&M) — masterfully coordinated telescope time on several telescopes around the world. The two teams imaged pieces of sky, collectively measuring tens of thousands of galaxies. A few weeks later, they'd snap another picture of the same sky patches. Comparing the before and after, the astronomers looked for points of light that weren't there before.

The observers would then follow up on newly discovered light sources with other ground-based telescopes, and then finally with Hubble. Feverishly, the two groups worked to find as many viable supernovae as possible, in a heated race with each other.

One of the astronomers on the High-Z team was Adam Riess (now at Johns Hopkins University), who was helping analyze the data coming in. If the universe's expansion were slowing down due to the mutual gravitational attraction of many galaxies, then the distant supernovae should be relatively bright. But that's not what Riess found. Instead, distant supernovae were much dimmer than expected — even more so than anticipated for an open universe.

"The answer I got from my computer was [that the universe had] negative mass," he says. "Now, that doesn't make sense." Of course the

◀ **FADE AWAY** The light from Type Ia supernovae, such as SN 1997cj pictured here, fades in a characteristic way, so astronomers can determine the intrinsic brightness without already knowing the object's distance.

TYPE IA SUPERNOVA: NASA / ESA / THE HUBBLE KEY PROJECT TEAM / THE HIGH-Z SUPERNOVA SEARCH TEAM; FADING SUPERNOVA: PETER GARNAVICH (CENTER FOR ASTROPHYSICS, HARVARD & SMITHSONIAN) / THE HIGH-Z SUPERNOVA SEARCH TEAM / NASA / ESA universe has mass, he thought. There had to be some sort of bug in the code.

Or maybe he had stumbled onto something bigger.

Riess sent an email to Schmidt. It contained a plot of supernova data and a simple subject line: "What do you think of this?"

"I could only think of what he might have done wrong," Schmidt recalled in a 2006 essay. As far as he knew, Perlmutter's SCP team was finding that the universe's expansion was decelerating. "It is one thing to get a different answer than the competition, it is quite another to get a different answer and have your answer be crazy."

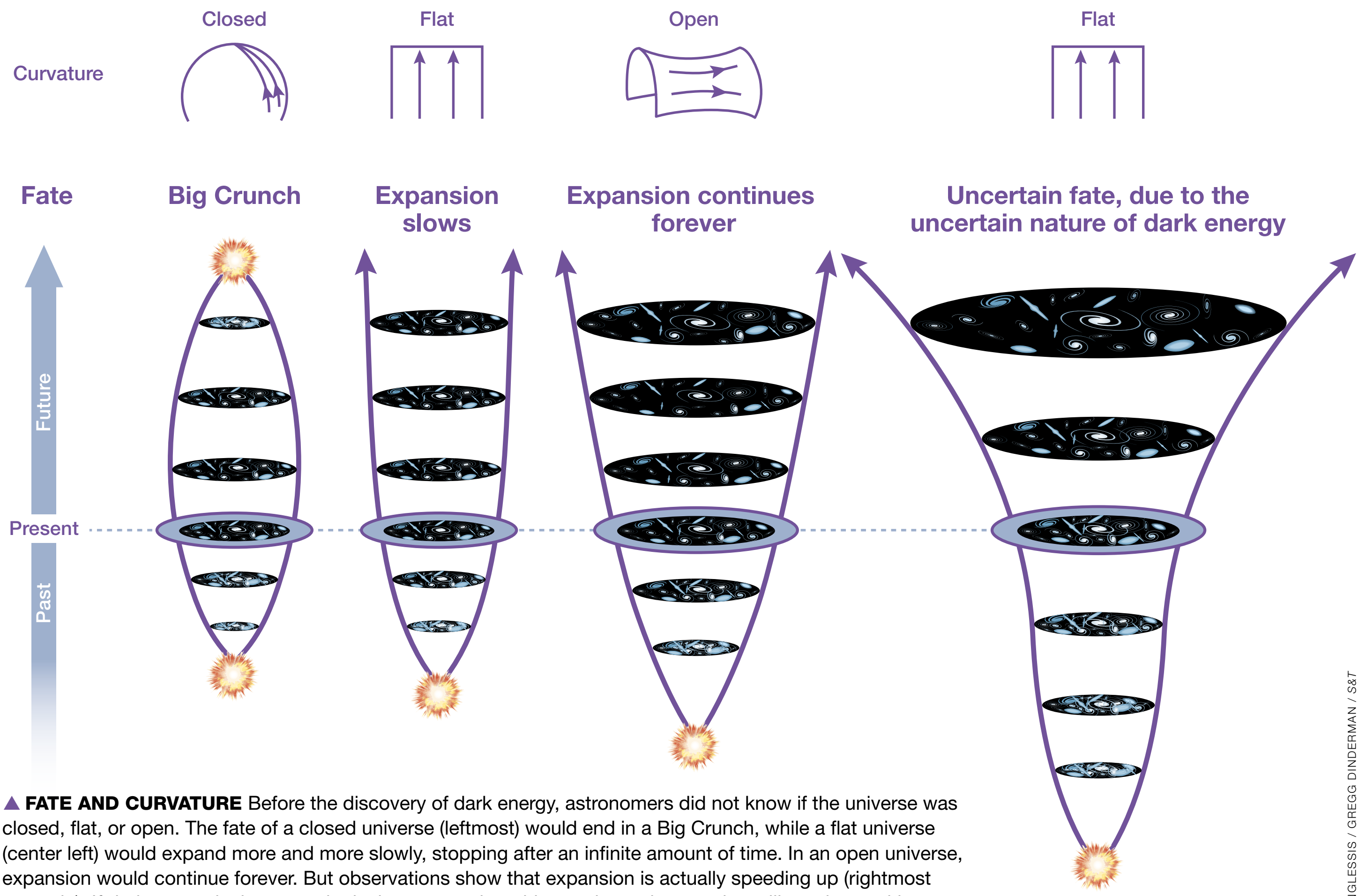
Meanwhile, unbeknownst to Schmidt, the SCP team was actually finding the same odd result.

Perlmutter recalls, "We had the main job of a scientist . . . 97% of your time is trying to figure out how you're going wrong." They checked if the way supernovae evolve changed over cosmological time. They checked if there was some weird "gray dust" that scatters all wavelengths of light, dimming distant supernovae without being detectable itself. They even checked if the gravity of intervening galaxies had bent the light of some supernovae in such a way as to make it fainter. Or perhaps there really was just a bug in the code.

Dark energy is a big unknown . . . The universe may continue to accelerate or, if dark energy proves changeable, it may yet recollapse.

But if the data held up, then there seemed to be a choice between two possibilities: Either the universe contained a negative amount of mass (which was obviously untrue), or something was working against gravity, pushing the cosmos apart at an ever-faster clip.

The idea of a mysterious energy working against gravity wasn't new. Albert Einstein had suggested that a *cosmological constant* (denoted lambda, Λ) could hold the universe motionless and keep it from collapsing under its own gravity. However, once it was discovered that distant galaxies were moving away from one another, Einstein discarded the idea. James Peebles (Princeton) invoked the constant again in the 1980s to up the energy density of the universe and allow space to



▲ **FATE AND CURVATURE** Before the discovery of dark energy, astronomers did not know if the universe was closed, flat, or open. The fate of a closed universe (leftmost) would end in a Big Crunch, while a flat universe (center left) would expand more and more slowly, stopping after an infinite amount of time. In an open universe, expansion would continue forever. But observations show that expansion is actually speeding up (rightmost scenario). If dark energy is the cosmological constant, then this accelerated expansion will continue, with space growing at a faster and faster rate — even though observations now confirm the theoretical idea that our universe is flat. Dark energy thus works with curvature to decide the universe's fate.

BEATRIZ INGLESSIS / GREGG DINDERMAN / S&T

be flat, even though the matter density seemed to be low. The teams' data suggested Peebles was right.

Yet, invoking a mysterious and unknown energy is a big deal. Both groups wanted to be sure. In his book *The Extravagant Universe*, High-Z team member Robert Kirshner (Harvard University) recalls an email he wrote: "I am worried . . . you might need some lambda. In your heart, you know this is wrong, though your head tells you [that] you don't care and you're just reporting the observations."

Debates, Arguments, and Results

Today, a quarter century later, there is still no clear consensus about what happened next. But events unfolded something like this.

In late 1997, Perlmutter and colleagues presented their work to physicists at various departments. Wanting to be cautious, the researchers stressed that their results were preliminary. But at the end of one of Perlmutter's talks, physicist Joel Primack (University of California, Santa Cruz) stood up. Barely able to contain himself, he explained to everyone in the room that these results were amazing, because they implied that there was a cosmological constant.

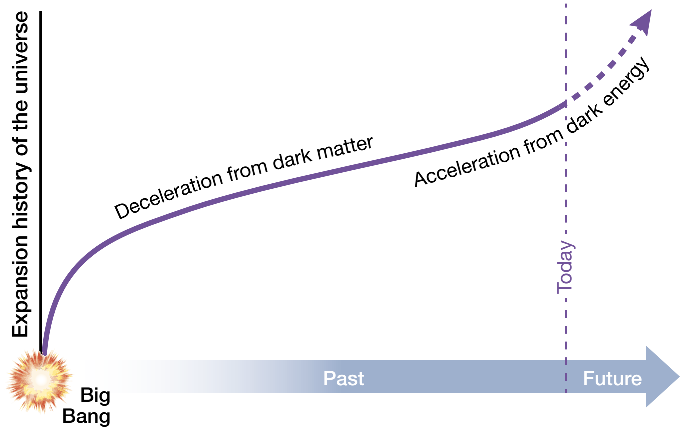
The next month was the January 1998 meeting of the American Astronomical Society, one of the biggest gatherings in the astronomy community. Both supernova groups presented there, telling a similar story: Our universe has low matter density and will continue to expand forever. Ariel Goobar (Stockholm University, Sweden), a member of the SCP team, stated in a press release that "astrophysicists may have to invoke Einstein's cosmological constant" if the results from the supernova data held up.

At the same press conference, another team, composed of Ruth Daly and Eddie Guerra (both then at Princeton), looked at galaxies with extensive jets shooting from their cores. By comparing the jets' observed lengths with that predicted by their evolution, the researchers calculated each galaxy's distance. In their January 1998 press release, they indicated that their data showed that the universe would not only expand forever but that its expansion was accelerating.

Other corroborating evidence came out around the same time, such as work from Neta Bahcall and Xiaohui Fan (also both then at Princeton) on the evolution of galaxy clusters, which also indicated a low matter density in the universe.

Both supernova teams met again in February at a conference. In front of a hushed audience, Alexei Filippenko (University of California, Berkeley) of the High-Z Supernova Search Team proclaimed in plainer language that they had the evidence: There was "antigravity" in the cosmos — the thing we today call *dark energy.*

Commotion followed. The media jumped in. By the time of a workshop in May 1998, a straw poll indicated two-thirds of the scientists thought the supernova evidence made a strong case for dark energy. The discovery was named *Science* magazine's Breakthrough of the Year, and members of both supernova teams were awarded the 2011 Nobel Prize in Physics.



▲ **INCONSTANT UNIVERSE** Measurements of the universe's expansion history, based on observations of distant Type Ia supernovae and other phenomena, now show that our universe's expansion rate did slow at one time, just not permanently. Matter's gravity decelerated the expansion during the first half or so of cosmic history, then dark energy took over. Now expansion is accelerating.

GREGG DINDERMAN / *S&T*

Changing Cosmic Understanding

In retrospect, it may seem surprising that the scientific community was so eager to accept the existence of a force dubbed dark energy when even now, 26 years later, we still don't know what it is. However, the agreement between two highly competitive and extremely thorough research groups helped the idea gain acceptance. "All the i's have been dotted, all the t's have been crossed," says Riess.

Also, not long after the announcements, an entirely independent method used observations of the Big Bang's afterglow, known as the *cosmic microwave background*, to confirm both the universe's low matter density and the existence of dark energy. Additional data from extensive galaxy and supernova surveys, as well as studies of how galaxy clusters evolve over time, have all confirmed that dark energy makes up more than two-thirds of the universe. Energy, not matter, dominates our cosmos and its fate.

The geometry of our universe is currently flat, but that doesn't mean it will expand forever. Dark energy is a big unknown, including how it will evolve with time. The universe may continue to accelerate or, if dark energy proves changeable, it may yet recollapse.

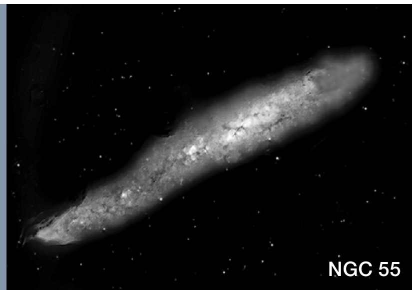
Today, dark energy continues to be one of the greatest discoveries — and mysteries — in astrophysics. The irony isn't lost on Perlmutter. "The odd thing about this result was that all the questions I thought we'd get to answer, we didn't get to answer," he says. "So we still don't know whether the universe is going to last forever, and we still don't know whether it's infinite or not."

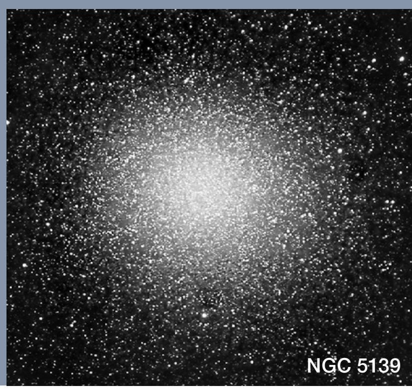
These questions await the next generation of scientists.

■ **ELIZABETH FERNANDEZ** is a science writer with a PhD in astronomy. She writes about science and society and has read *S&T* since she was young.

Winter Observing in the South


NGC 1360


NGC 55


NGC 5139


NGC 5128

Feast your eyes from dusk until dawn on a selection of targets well-suited to more southerly latitudes.

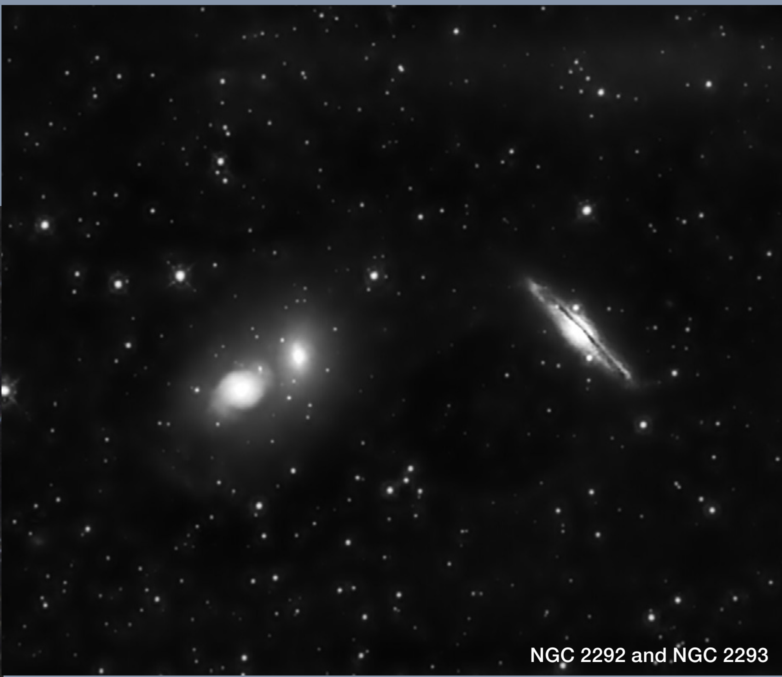
When I retired, I bought a home in Naples, southern Florida, to escape the harsh Massachusetts winters. I took a 14-inch Celestron Edge there in order to catch those wonderful deep-sky objects that are hard or impossible to observe or image from my home up north (where I have my 32-inch telescope). To my delight, the extra 20° of latitude brought a multitude of fascinating southerly targets to a much higher altitude. In February 2023, I was finally able to attend my first Winter Star Party in the Florida Keys — it's an excellent dark-sky site, and I anticipated observing unfamiliar objects low in the southern sky.

To my astonishment, a large number of attendees who had lugged telescope gear from all across North America were concentrating their efforts on deep-sky objects they could see from home! Harking back to the excitement of my first forays into southern skies in Naples, I suggested "new" targets to my fellow observers, which they warmly accepted. That experience has led to this article. Hopefully northern observers, who may find themselves at southerly latitudes this winter, can explore exciting deep-sky objects with which they may not be familiar. We'll start by covering targets west of the Milky Way that should be observed before they set in the early evening, followed by some winter Milky Way quarries, and, lastly, objects east of the Milky Way as they rise in the morning hours. In the following, "smaller" scopes refer to those around 3 to 4 inches, by "medium" I mean 10 to 14 inches in aperture, and finally with "larger" I'm referring to those 16 inches and up.

Early Evening

As twilight deepens, start off by exploring the many wonderful galaxies that are too low to fully appreciate at northern

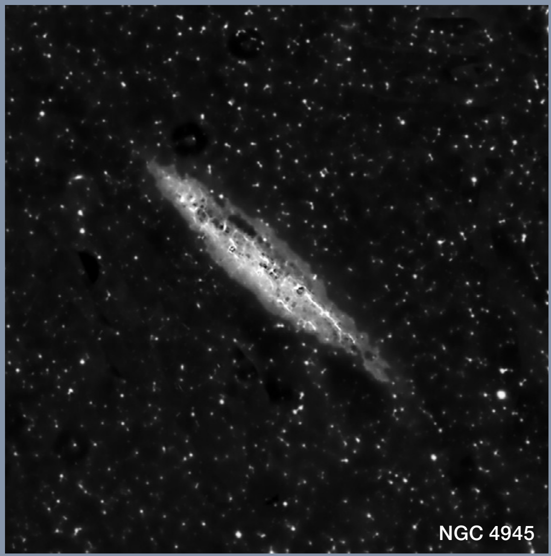
ALL IMAGES BY MARIO MOTTA



NGC 2292 and NGC 2293

M83

NGC 2736



NGC 4945

OBSERVER AND IMAGER The author not only enjoys visual observing, but he also relishes imaging the targets he sees in the eyepiece, some of which are shown here. He used his 32-inch f/6 telescope (see *S&T:* May 2011, p. 32) for objects that he can observe from his home in Massachusetts and his Celestron C14 f/7 for those only visible at the latitudes of southern Florida. To acquire the images, he fitted a ZWO ASI6200 camera with RGB and narrowband filters and processed the images with *PixInsight*. The author has a lifelong interest in galactic evolution and is especially fond of barred spirals (as the images in these pages attest!) and interacting galaxies. He doesn't neglect other targets, though, and points his scopes at them, too. North is up in all images.

latitudes. Sculptor harbors some of the most beautiful barred spiral galaxies in the entire sky, and first up on our list — as it will set very early — is **NGC 55**. It's a large galaxy some 32′ long and at 8th magnitude is easily observed even in small telescopes. In larger scopes, look for knots in the spiral arms and a dust lane close to the core. Robert Burnham, Jr., in his classic *Burnham's Celestial Handbook*, calls NGC 55 "one of the outstanding galaxies of the southern heavens." For those star-hopping, you'll readily find it 3¾° northwest of 2.4-magnitude Alpha (α) Phoenicis.

Next jump north to **NGC 253** in Sculptor, another bright, 29′-long galaxy located a bit more than 7° degrees south of 2nd-magnitude Beta (β) Ceti. This galaxy, normally low in northern skies, now is glorious and — at magnitude 7.2 — easy to snag in any size telescope.

After this, we'll turn to Fornax, starting with the impressive galaxy **NGC 1097**. Find this 9.5-magnitude beauty by locating 4.5-magnitude Beta Fornacis, then slewing a smidgen more than 2° north-northwest. Smaller apertures will reveal the large, 9′-long central bar, but even with a modest scope in dark sky you should be able to spot the two fainter spiral arms emanating from either end of the bar.

Now, let's go to one of my favorite galaxies in the entire sky: the classic **NGC 1365**, an incredible 10th-magnitude barred spiral with widely splayed-out arms. Find this target by centering on 4.2-magnitude g Eridani (itself a nice orange star), then point west some 3.2°. I can readily detect the 11′-long central bar in my 6-inch scope with a magnification of 100×, but a 16-inch scope will reveal the galaxy's far-flung spiral arms.

To bring this run of galaxies to conclusion, we'll head north into Eridanus to get to the impressive barred spiral **NGC 1300**. This beautiful, 10.4-magnitude galaxy is smaller in overall size at 6′ than the previous targets, but you should have no difficulty detecting it in an 8-inch scope at magnification 120×. To find it, locate the yellow, 3.7-magnitude star τ^4 Eridani and then slew directly north some 2.3°.

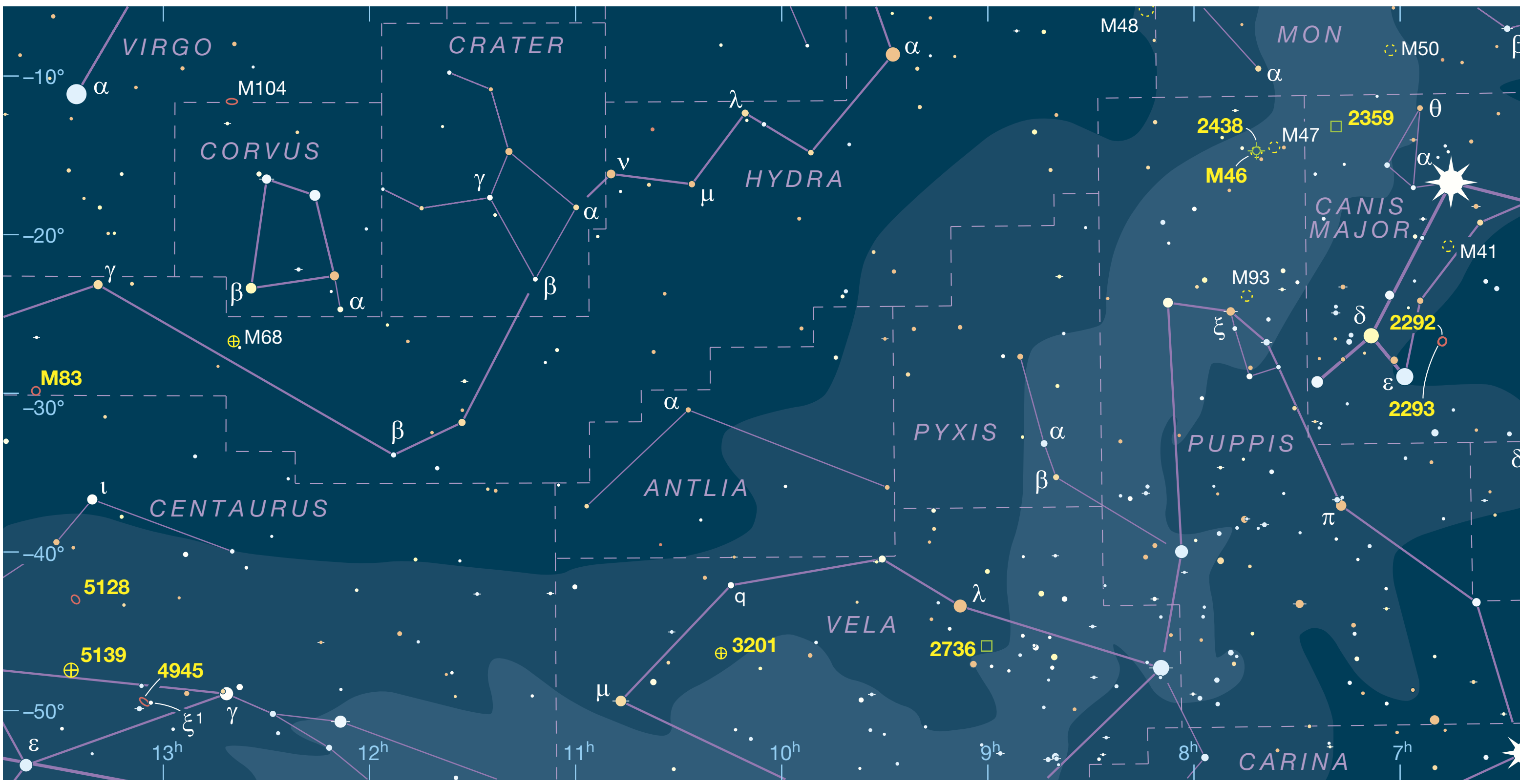
You can guess by now that I'm partial to galaxies, but let's return to Fornax for something different — **NGC 1360**, the Robin's Egg Nebula, a fairly large and bright (magnitude 9.4) planetary wider than 6′ in diameter. In more light-polluted areas use an O III filter; under a dark sky the filter will show subtle detail, and you should easily see the central star. For best results, use an 8-inch telescope at magnification 120×. The planetary shines a pleasing blue-green hue, and you'll find it by extending the line joining Beta to Alpha (α) Fornacis toward the northeast by almost the same distance.

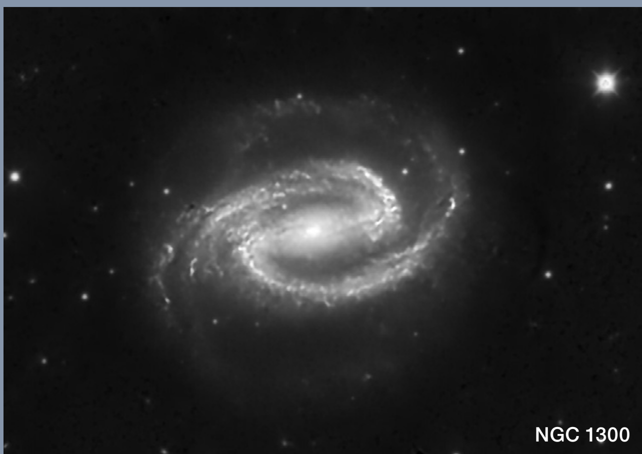
In the Middle of the Night

By this point in the night, Orion is on the meridian. If you must take your 1,000th view of M42, go ahead and enjoy it, but make it a brief visit so that you can explore other objects in the winter Milky Way south of there.

Start with a double galaxy in Canis Major. From 2nd-magnitude Delta (δ) Canis Majoris, nudge due west 4.6° and

▼ **FROM DUSK TIL DAWN** This sky tour is designed so you can observe all night long from more southerly latitudes. Should you plan to attend the Winter Star Party in the Florida Keys in February, that would be a great place to use this guide.





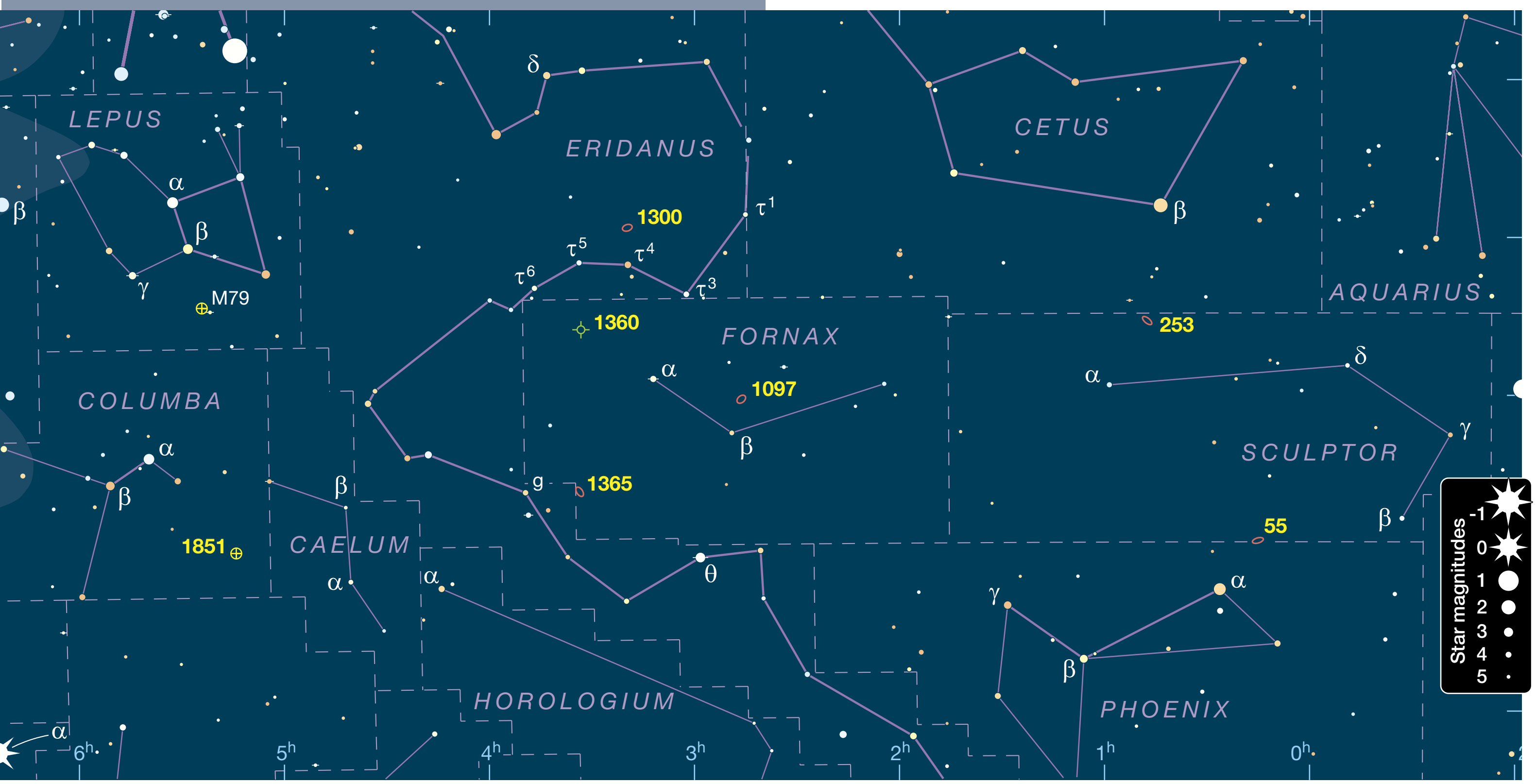
you'll land on a trio of galaxies — two of which, **NGC 2292** and **NGC 2293**, are merging. They're a delightful, compact sight, both 11th magnitude, and once you've located them they take high power (e.g., 300×) well.

Head southwest and pop into Columba to visit a very nice, large globular cluster. **NGC 1851**, at magnitude 7.1, is a pleasing sight in a moderate-power (60–100×) eyepiece, and with its dense inner core it resembles a smaller version of the globular M3 in Canes Venatici. From 2.6-magnitude Alpha Columbae, head just a bit shy of 8° southwest to find your target.

Back in Canis Major we'll move on to a treat: the diffuse nebula **NGC 2359**, also known as Thor's Helmet. To find it, you can either slide 8.7° northeast of Sirius or 6° east-southeast of 4th-magnitude Theta (θ) Canis Majoris, the celestial Dog's nose. This is a stunning sight if you employ an O III filter and a beautiful object to behold. It's a bright emission nebula powered by a massive Wolf-Rayet star (see, e.g., *S&T:* Aug. 2019, p. 28) — strong stellar winds sculpted and distorted the nebula into the shape as seen on page 35. I suggest low-power views in your 8-inch telescope.

Puppis holds our next quarry, which is the delightful open cluster **M46** (NGC 2437) that has the planetary nebula **NGC 2438** superposed on it. Use a wide-field eyepiece for the

◀ **BARRED SPIRALS** Among the author's favorite targets, galaxies feature prominently in his observing, as he himself admits. These two barred specimens — NGC 1365 in Fornax and NGC 1300 in neighboring Eridanus — are sights to behold. They are pleasing in any size telescope, but in dark skies with a 14-inch or larger, you'll start noticing the beautiful detail of the spiral arms and the knots of hydrogen-alpha regions.



open cluster, but a high-power eyepiece enhanced with an Ultra High Contrast or O III filter will yield pleasing views of the planetary. From 3.3-magnitude Xi (ξ) Puppis, move your telescope about 10° north-northwest, and then use the 5th-magnitude star 140 Puppis to home in on your target — the 6th-magnitude cluster will be just ½° northeast.

Next we'll visit the delights of Vela. Another striking object is **NGC 2736**, also known as the Pencil Nebula (or Herschel's Ray), a bright streak of light that's an outer section of the Vela Supernova Remnant and its most easily visible portion. The eastern edge is sharp, while the western side widens in a way that visually resembles the quill of a pen. Find this object by locating 2nd-magnitude Lambda (λ) Velorum and then pointing almost 3° degrees southwest. If you want to try for a challenge object, go for the main body of the supernova nebula, a complex web of shock-wave nebulosity. It's faint, and you'll need dark sky and a very wide field of view. I recommend a small, low-f/ratio refractor fitted with an O III filter. Start at the Pencil Nebula and look directly west about 30′. The nebula is very large, and you'll only glimpse parts of it at a time. Large telescopes will simply zoom in too far, lowering the contrast and making it difficult to see.

We'll end our trip through Vela by moving east to the easy globular cluster **NGC 3201**. It's very bright at 7th magnitude overall, and at 20′ it's equal in size to M13, the great globular in Hercules. From 3.8-magnitude q Velorum drop south some 4.3°. This is one of the best globular clusters in the sky.

Morning Marvels

We're heading into the early morning hours, but some fantastic sights await those willing to stay up to observe the third leg of our southern sky delights. Let's begin with the more northerly galaxy, **M83**, which will be rising after midnight. As it climbs into the sky you'll see why it's one of the most spectacular barred galaxies to behold. A moderate telescope will reveal its imposing bar and spiral arms, while users of larger telescopes can revel in the fine detail in their eyepieces. Look for this 7.5-magnitude beauty in Hydra, just over the border with Centaurus — you should readily spot it starting at 3rd-magnitude Gamma (γ) Hydrae and moving southeast about 7.8°.

Now, end your night with a bang with three of the most eye-catching (I think!) objects in the night sky, all located in Centaurus. Observing these will give you fond memories and bragging rights back home. Begin with the spectacular radio galaxy **NGC 5128**, also known as Centaurus A. The most likely scenario for its amazing appearance is a collision between a large elliptical galaxy and an edge-on spiral. It's visually large — it spans ½° — and bright at magnitude 6.8. With an 8-inch scope and magnification 100× you should easily see the dark lane that characterizes this incredible

Southerly Winter Targets

Object	Type	Constellation	Mag(v)	Size	RA	Dec.
NGC 55	Barred spiral	Sculptor	7.9	32.4′ × 5.6′	00^h 15.1^m	–39° 13′
NGC 253	Intermediate spiral	Sculptor	7.2	29.0′ × 6.8′	00^h 47.6^m	–25° 17′
NGC 1097	Barred spiral	Fornax	9.5	9.3′ × 6.3′	02^h 46.3^m	–30° 16′
NGC 1365	Barred spiral	Fornax	9.6	11.0′ × 6.2′	03^h 33.6^m	–36° 08′
NGC 1300	Barred spiral	Eridanus	10.4	6.2′ × 4.1′	03^h 19.7^m	–19° 25′
NGC 1360	Planetary nebula	Fornax	9.4	6.4′	03^h 33.2^m	–25° 52′
NGC 2292	Interacting galaxy	Canis Major	11.0	4.1′ × 3.6′	06^h 47.7^m	–26° 45′
NGC 2293	Interacting galaxy	Canis Major	11.2	4.2′ × 3.3′	06^h 47.7^m	–26° 45′
NGC 1851	Globular cluster	Columba	7.1	12.0′	05^h 14.1^m	–40° 03′
NGC 2359	Emission nebula	Canis Major	—	9′ × 6′	07^h 18.6^m	–13° 12′
M46 (NGC 2437)	Open cluster	Puppis	6.1	20′	07^h 41.8^m	–14° 49′
NGC 2438	Planetary nebula	Puppis	10.8	1.3′	07^h 41.8^m	–14° 44′
NGC 2736	Supernova remnant	Vela	—	20′ × 3′	09^h 00.3^m	–45° 57′
NGC 3201	Globular cluster	Vela	6.9	20.0′	10^h 17.6^m	–46° 25′
M83 (NGC 5236)	Barred spiral	Hydra	7.5	12.9′ × 11.5′	13^h 37.0^m	–29° 52′
NGC 5128	Lenticular/Elliptical	Centaurus	6.8	25.7′ × 20.0′	13^h 25.5^m	–43° 01′
Omega Centauri (NGC 5139)	Globular cluster	Centaurus	3.9	55.0′	13^h 26.8^m	–47° 29′
NGC 4945	Barred spiral	Centaurus	8.4	20.0′ × 3.8′	13^h 05.4^m	–49° 29′

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

object. It rises at about 1:30 a.m. local time in February, and later in the morning hours it will be well-placed. Look for it 6.3° south-southeast of 3rd-magnitude Iota (ι) Centauri.

Next, feast your eyes on the largest globular cluster in the Milky Way, **Omega Centauri**. This eye-popping globular is almost twice the size of the full Moon at 55′. It's so large that astronomers speculate that it may be the core of a small galaxy captured by the Milky Way. You'll need a wide field to see it in its entirety, for example a 4-inch scope at 50×. You can't miss it as it rises majestically over the Straits of Florida.

And finally, if you have the stamina, there's an overlooked — but large — galaxy about 4° southwest of Omega Centauri. You'll find 8.4-magnitude **NGC 4945** some 3′ east of 4.8-magnitude Xi[1] (ξ^1) Centauri. This 20′-long object is surrounded by several smaller galaxies.

By now you may be packing up for the night. If you have a water view, end your spectacular night by looking south before morning twilight to see the top stars of the Southern Cross peeking just above the horizon.

■ **MARIO MOTTA** is a cardiologist and has served as president of the Massachusetts Medical Society and the governing board of the American Medical Association. A lifelong amateur astronomer, he's passionate about combating light pollution and has an asteroid named after him (133537 Mariomotta).

VARIETY IS THE SPICE The author pointed his telescope and camera at a plethora of objects. NGC 2359 is a fine example of a bright nebula powered by a massive star, while NGC 3201 is a delightful globular. And at left we have the barred spiral NGC 1097. He acquired the images for NGC 1097 and NGC 2359 with his 32-inch in Massachusetts, and he used his Celestron C14 from Florida to capture NGC 3201.

Driveway Planetaries for the Winter and Spring

Here's a selection of planetary nebulae that you can observe from most any location.

I last wrote about planetary nebulae in the July 2023 issue, where I covered eight of my favorite targets that are visible in summer and autumn and observable from my suburban home. Now, I'll round out the year by sharing some of my favorites that I can see from my driveway during winter and spring months. I live in Houston, Texas, surrounded by a vast urban sprawl and its inevitable skyglow. Nevertheless, I'm able to tease out some nifty objects with a variety of techniques, such as using a black head drape and narrowband eyepiece filters. For those of you observing under similar conditions, I hope you'll derive some enjoyment from snagging these planetaries.

Most of the objects in this article aren't on any "must-see" list. But each endeared me with its unique charm, and I felt I must reciprocate by writing about them. Some of the planetaries elated, evaded, or fascinated me; others I included just because they or their settings are simply pretty.

▲ **PLEASING PLANETARIES** Join the author on a celestial tour of some of his favorite planetary nebulae, such as NGC 2610 in Hydra. The nebulae are all well placed for observing during these winter and upcoming spring nights. The image above was acquired with a 6-inch scope.

PETER GOODHEW

As with my previous article, I observed each of these targets using my 3½-inch and 7-inch Questar Maksutov-Cassegrains, often with an O III filter, so you might want to make sure you have one handy. I also employed a customized eyepiece with an occulting bar to reduce the glare of a nearby brighter star when present. Most star-hopping suggestions are couched to guide you to a "pointer star" along with the target nebula inside a 25′-wide eyepiece field or smaller. Enjoy!

From Cassiopeia to Camelopardalis

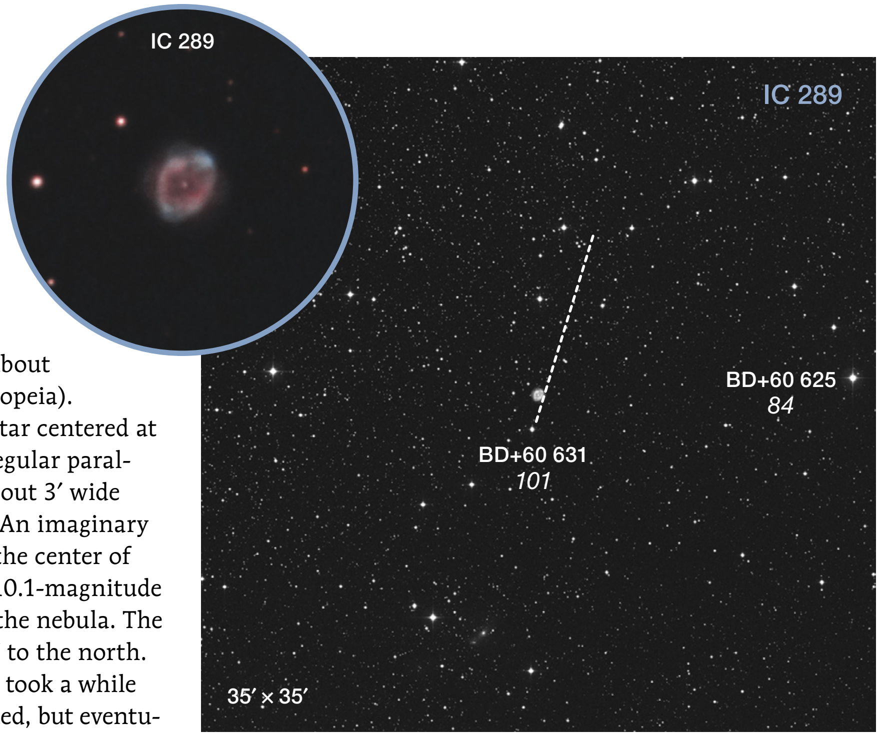
To track down the first target, which is in Cassiopeia, start in the neighboring constellation to the east by locating the 4.2-magnitude blue supergiant CS Camelopardalis in your finderscope. **IC 289** is approximately three-quarters of the way between CS Camelopardalis and 6.6-magnitude HD 18757 some 3.5° to the northwest. Look for the planetary about 16′ east of 8.4-magnitude BD+60 625 (in Cassiopeia).

A 25′-wide eyepiece field in my 7-inch Questar centered at the coordinates of IC 289 revealed an almost regular parallelogram of 10th- and 11th-magnitude stars about 3′ wide and 4′ tall to the planetary's north-northwest. An imaginary line extended about 10′ south-southeast from the center of the northern edge of the parallelogram to the 10.1-magnitude star BD+60 631 intersects the western edge of the nebula. The 13.2-magnitude, 48″-wide planetary is just 1.8′ to the north.

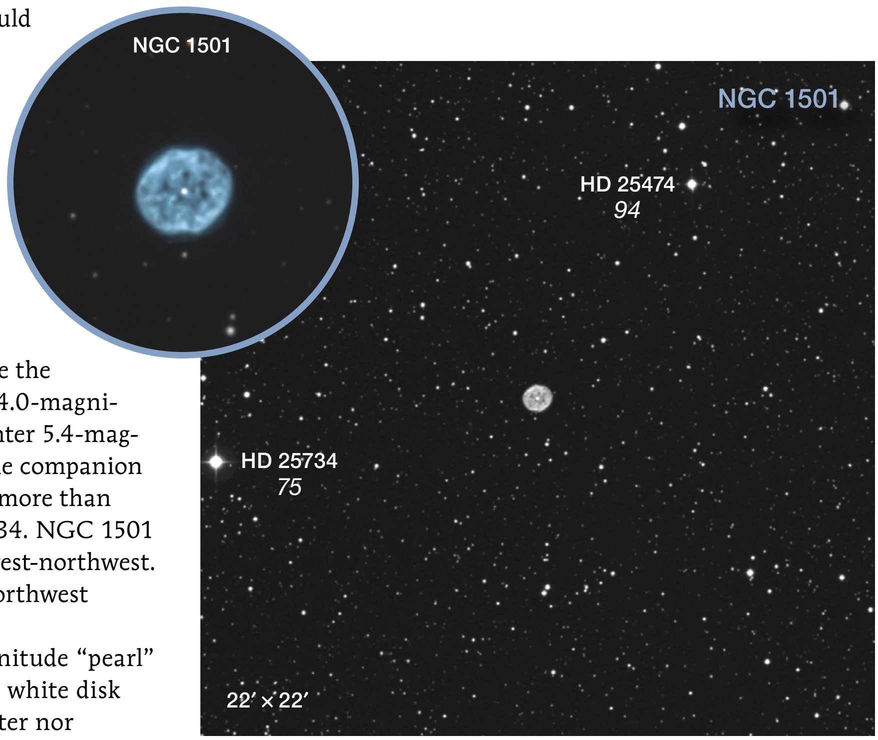
As I was observing the nebula one January, it took a while before good seeing and clement weather coincided, but eventually I saw the gray planetary using the O III filter at 318× in a 9′-wide field as it blinked in and out of averted vision. It appeared about 15″ in diameter, and I didn't detect its central star. Each time I've observed IC 289 I could see it only intermittently, which suggests it is near the limiting magnitude of my 7-inch Questar when equipped with the O III filter.

NGC 1501, or the Oyster Nebula, in Camelopardalis is a sleeper that I ignored for some time because of its neck-cracking circumpolar coordinates. When it reaches a position in the sky that allows my eye to squarely meet the eyepiece of my 3½-inch, the nebula's size (52″) and magnitude (11.5) make viewing it a more pleasant experience. To locate the planetary, slew west-northwest about 5° from 4.0-magnitude Beta (β) Camelopardalis until you encounter 5.4-magnitude HD 27245 (which has an 8th-magnitude companion some 4′ northwest). From there continue a bit more than 1.5° west-northwest to 7.5-magnitude HD 25734. NGC 1501 is a smidgen more than 10′ farther on to the west-northwest. The 9.4-magnitude star HD 25474 some 8.5′ northwest accompanies the planetary.

I didn't detect either the central, 14.5-magnitude "pearl" or the annulus of the Oyster Nebula; only the white disk was visible at 130×. Neither using the O III filter nor increasing magnification to 260× improved the image significantly. Nevertheless, NGC 1501, to me, is just a soothing, mind-calming sight.



▲ **QUARRY IN CASSIOPEIA** The objects here are faint, and it behooves the observer to use nearby stars and surrounding patterns to hunt down their targets, as described in the text and illustrated above for IC 289.



▲ **CELESTIAL OYSTER** NGC 1501 is fondly known as the Oyster Nebula, with the central star designated the "pearl." The image above highlights this imagery well. Can you detect the pearl in your scope?

ALL DSS IMAGES: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY; GARY IMM (2)

Orion's Duo

Lambda (λ) Orionis is about 5½° northwest of Alpha (α) Orionis, aka Betelgeuse. **NGC 2022** lies about two-thirds of the distance along that line from the famous red supergiant. There's a 7.5-magnitude star (HD 37786) about 12′ northwest of the planetary. NGC 2022 is the object that inspired my second survey of planetary nebulae using my 3½-inch Questar (see *S&T:* Jul. 2023, p. 28). As a result of the first survey, I had concluded the limiting magnitude of this telescope was about 11.3 from my location when paired with the O III filter. Imagine my surprise when I easily spotted the 11.6-magnitude, 39″-diameter NGC 2022 with the filter *in situ*. The seeing and transparency were superior that night, and those conditions continued for several more. (During that epiphanous week, I recorded several planetaries dimmer than magnitude 11.3, including the Jonckheere siblings J 320 and J 900, with magnitudes of 11.9 and 11.7, respectively.)

My other favorite planetary in Orion is **Abell 12**, a 12th-magnitude nebula with a diameter of 37″ located about 50″ northwest of Mu (μ) Orionis. The glare from the 4.3-magnitude star overwhelms the view of the nebula in my 7-inch telescope. I found I can circumvent this issue by fitting an eyepiece with an occulting bar. I pre-focused the O III filter, hid Mu Orionis just behind the bar, and immediately saw the ovate gray disk of Abell 12 at 212×. Increasing the magnification to 424× didn't improve the view; I wasn't able to detect its central star nor any color.

A Pair in Gemini

Locate 3rd-magnitude Epsilon (ε) Geminorum in your finderscope and scan southwest about 1½° to the easternmost member of a flattened, inverted triangle of 6th- and 7th-magnitude stars, some 30′ across at the base. Center the westernmost star of the triangle, 6.5-magnitude HD 47020, then switch to your telescope eyepiece before slewing the final 34′ south. This is to ensure that you'll see the white, 10th-magnitude "pointer" star, TYC 1880-1003-1. It plays several key roles at the site of **M 1-7**.

Driveway Planetaries

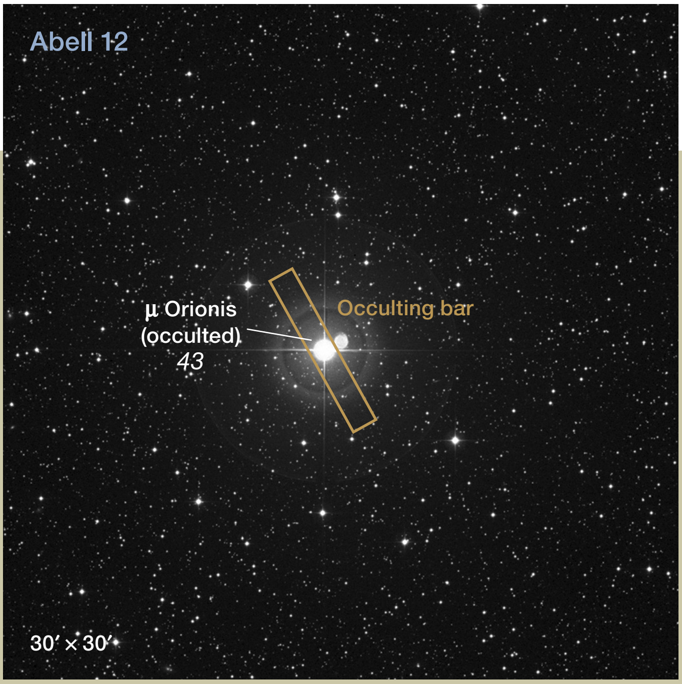
Object	Mag(v)	Size	RA	Dec.
IC 289	13.2	48″	03ʰ 10.3ᵐ	+61° 19′
NGC 1501	11.5	52″	04ʰ 07.0ᵐ	+60° 55′
NGC 2022	11.6	39″	05ʰ 42.1ᵐ	+09° 05′
Abell 12	12.0	37″	06ʰ 02.3ᵐ	+09° 39′
M 1-7	13.0	37″	06ʰ 37.3ᵐ	+24° 01′
Abell 21	10.3	615″	07ʰ 29.1ᵐ	+13° 15′
M 1-16	13.0	14″	07ʰ 37.3ᵐ	–09° 39′
NGC 2610	12.7	42″	08ʰ 33.4ᵐ	–16° 09′

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

TYC 1880-1003-1 is the brightest of a small triangle of stars and forms its southeastern vertex. The western point of the triangle's base is a bluish, 13.1-magnitude star 2.4′ west-northwest of the pointer. From there, an 11.7-magnitude white star 2.1′ northeast delineates the northern limit of the base. The triangle points toward M 1-7, which is located 1.1′ southeast of TYC 1880-1003-1.

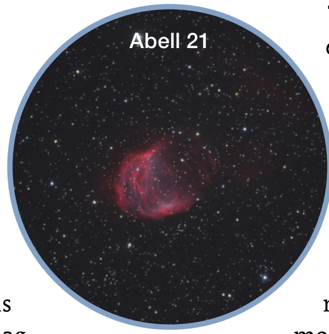
Employing an eyepiece with an occulting bar and the O III filter at 212× in my 7-inch Questar, I positioned the bar over the eye-distracting (yep, you guessed it) TYC 1880-1003-1. When better seeing arrived, I spotted 13th-magnitude M 1-7

▲ **INSPIRATIONAL TARGET** NGC 2022 is the planetary that encouraged the author to test his scope and techniques on a variety of other objects and resulted in a comprehensive survey.



▲ **PEEKABOO** The faint light from Abell 12 is overwhelmed by the glare of Mu Orionis — the way to get around this is to apply an occulting bar as shown above. An occulting bar will prove useful for other targets, too.

on the eastern side of the bar as a grayish ball about 10″ in diameter. In images, as in the one below, its elliptical shape subtends 37″, but I didn't notice any elongation, nor did I see a central star. The edges of the nebula appeared smooth to my eye, but I couldn't detect its outline after I removed the filter.



Moving southeast, the Medusa Nebula, as **Abell 21** is familiarly known, is a dim, rotund (615″ across), crescent-shaped planetary curved toward the southeast near the Canis Minor-Gemini border. To better pinpoint the planetary, you might avail yourself of some of the brighter stars in its vicinity. From 4.5-magnitude 6 Canis Minoris, 6.6-magnitude HD 59152 is about 45′ north-northwest, and from there 8.8-magnitude HD 59151 is another 7′ farther north. The planetary is about halfway from there to the 7.9-magnitude star HD 59178 that lies about 17′ north of the center of Abell 21.

Before viewing the nebula in my 7-inch telescope, I visited neighboring Orion where I saw six of the stars in the Trapezium at 318×, which boded good seeing and transparency. Then, I set my telescope on the coordinates of Abell 21 and, observing from under a black drape and with the O III filter, I saw it at 80× as a large (about 10′ across), gray, patchy object in a 34′-wide field. To me, its magnitude (10.3) belies its dimness.

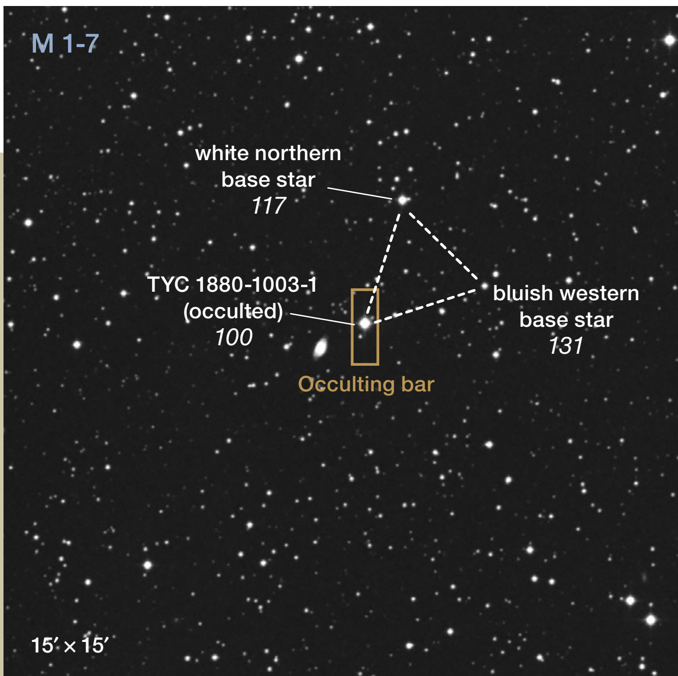
I needed averted vision initially, but as my eyes adapted, I began to detect one, then two marginally brighter areas at each end of a discontinuous, fat C shape. The brighter southern "cusp" seemed to be elongated towards the northwest. Ditto for the smaller, less distinguishable northern "cusp," which was just a blur some 8′ to 10′ northeast from its southern counterpart. I didn't notice any trace of the nebula when I doubled the magnification in an attempt to gain more contrast.

The Medusa Nebula is the most difficult planetary nebula in my skies to snag with my 7-inch scope due to the nebula's low surface brightness. One wonders if its namesake was really the serpent-coifed Gorgon of Greek mythology or the aquatic jellyfish it so resembles?

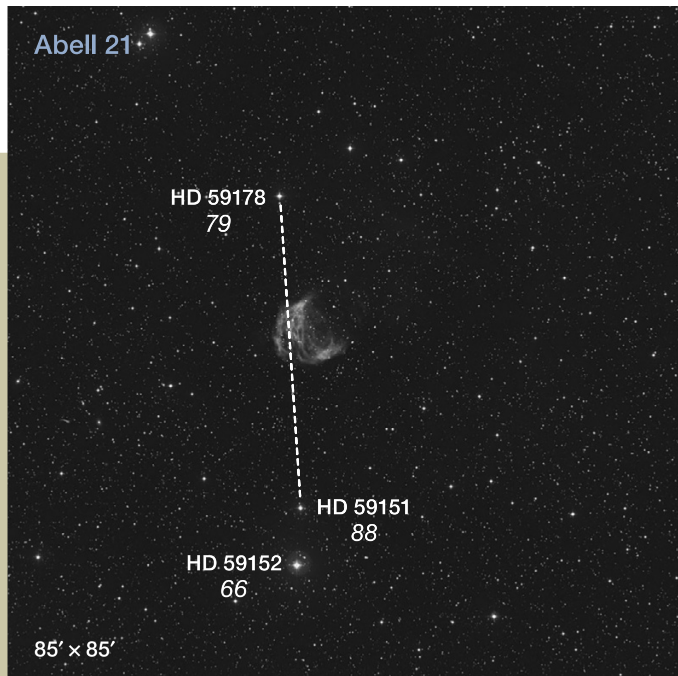
Ending in Monoceros and Hydra

My planetary tour is rounded out with two of my more southerly targets. **M 1-16** is slightly more than 1° west of 3.9-magnitude Alpha Monocerotis. A 17′-wide eyepiece field at this position showed the 8.9-magnitude star HD 60991 (the brightest star in the field) about 10′ west-northwest of the nebula. I centered my 7-inch at the coordinates of the 13th-magnitude, 14″-diameter planetary using the O III filter at 318× and quickly spotted a dim, pale blue disk. M 1-16's blue hue was not as intense as that of M 1-74 (*S&T:* Jul. 2023, p. 33), but its disk was larger and didn't flicker.

I generally associate faint planetary nebulae with the color gray, so the blue tints of 12.9-magnitude M 1-74 and 13th-magnitude M 1-16 were a surprise. However, a qualitative survey of more than 60 planetaries observed with my 7-inch telescope using the O III filter suggests that a surface brightness of 10.6 magnitudes arcmin^{-2} is about the threshold for the detection of the bluish hues of planetaries in order



▲ **FIRST OF A PAIR** M 1-7 is the first of two planetaries you can visit in Gemini, the Twins. As with Abell 12, an occulting bar placed as shown above will better help you snag this faint planetary.



▲ **COSMIC MEDUSA** The tendrils of Abell 21 are reminiscent of the jellyfish that inhabit our oceans and seas. You might not see all this detail in your scope but imagine it when you cast your eye upon this target.

STEFAN BINNEWIES / CAPELLA OBSERVATORY

Coda

During the 40 years that I've lived at my current location, the mercury-vapor streetlight at the eastern end of my driveway was replaced with a high-pressure sodium-vapor light source. In addition, my town recently installed a dazzling LED streetlight, rendering observing nigh impossible. So, after all these years of ever-worsening light pollution, not to mention my failing eyesight, I sadly must hang up my observing hood and put away my telescopes.

But I'll never forget the joy of seeing the annular image of M57, the Ring Nebula, for the first time in the eyepiece of my Edmund Scientific 3-inch f/10.9 reflector. In the summer of 1959, I was already hooked on amateur astronomy, having viewed objects such as Saturn, Albireo, and the Trapezium in the Orion Nebula — but the Ring Nebula in Lyra sealed the deal for me.

It was a wonderful ride, and I've relished every light-year I've spanned. Now, Mr. Peabody, what to do with the Wayback machine in my garage, which consists of almost every issue of *S&T* from July 1967 onwards?

of increasing surface brightness. M 1-16 and M 1-74 have surface brightnesses of 9.6 and 7.2 magnitudes arcmin^{-2}, respectively. Thus, their blue colors agree with my observations.

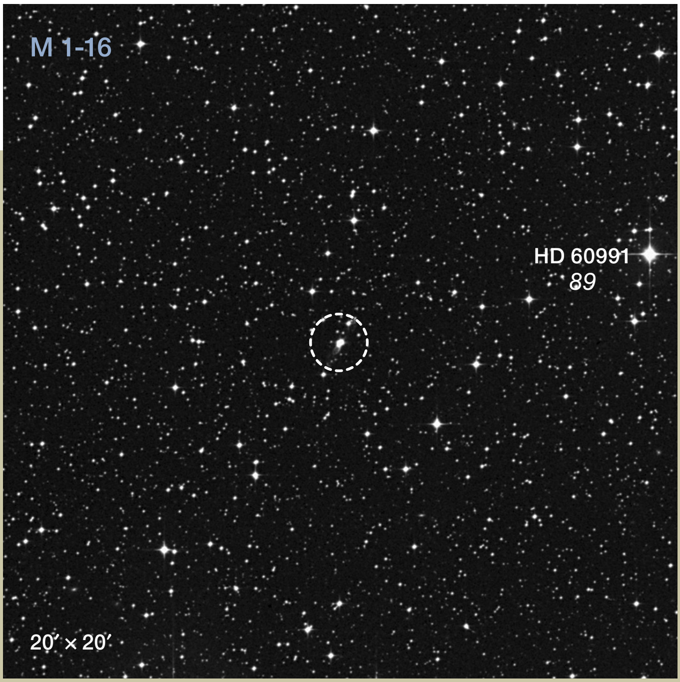
To get to our last target, start at 4.9-magnitude 9 Hydrae and slew about 2° west, passing two prominent 8th-magnitude stars (HD 73716 and HD 73282) en route. **NGC 2610** hugs the inside of the eastern leg of a bright, inverted equilateral triangle of stars about 9′ on a side. The "pointer" star is 6.6-magnitude HD 72665, the easternmost (and brightest) star of this stellar triangle.

The 12.7-magnitude, 42″-diameter planetary nebula is a bit more than 3′ southwest of the star. To spot this dim nebula I used the occulting-bar eyepiece at 212× in my 7-inch to block the two brightest stars at the top of the triangle. Then I maneuvered the telescope so that the 8.3-magnitude southern vertex star HD 72591 was just outside of the 13′-wide field. Adding the O III filter revealed a grayish nebula about the size of the globe of Saturn (with the same setup). I couldn't see the annulus or a central star.

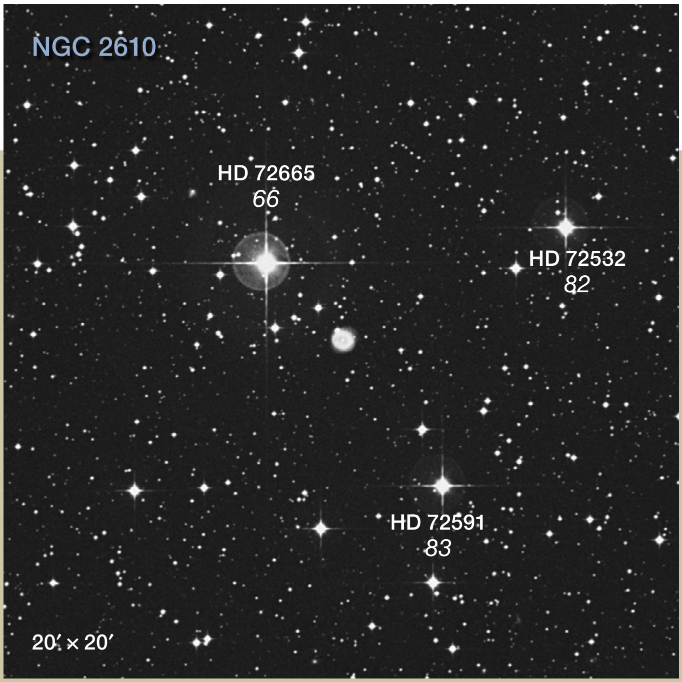
About a year later, I detected NGC 2610 using the O III filter at 160× in the 7-inch without the occulting bar or manipulation of the telescope tube, lending more credence to observing on nights of better conditions. This planetary's setting is more spectacular than the nebula, and I cannot imagine any amateur observing this object without mentioning the site. It's a beauty.

This eye-catcher, along with those I covered in the July issue, concludes my list of favorite planetary nebulae that I've observed from my driveway. Who am I kidding? I've yet to meet a planetary I didn't like. They're all my favorites.

■ Despite not being able to observe, **DON FERGUSON** is working on his latest project with the working title of "A Celestial Scavenger Hunt," in which planetary nebulae are only mentioned in passing. Contact him at **dferg28571@aol.com**.



▲ **IN MONOCEROS** When the author examined the SDSS image of M 1-16, he noted that the nebula is roughly shaped like a reversed contour integral symbol (a circle with an elongated reversed S through it).



▲ **LAST BUT NOT LEAST** Head to the celestial Water Snake to look for the final target in this list of planetary nebulae for winter and spring months. Which one is your favorite?

1 **MORNING:** In the hours before dawn, the waning gibbous Moon and Spica, Virgo's brightest star, shine high in the south. Less than 1° separates the pair. Turn to page 46 to see more on this and other events listed here.

5 **MORNING:** The waning crescent Moon follows the smoldering supergiant Antares by some 5½° as they rise above the southeastern horizon.

7 **DAWN:** Find an unobstructed view to the southeast to see the lunar crescent, Venus, and Mars forming an isosceles triangle with sides a little less than 7° in length. Catch this sight before the rising Sun washes it away.

12 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 11:43 p.m. PST (see page 49).

14 **DUSK:** The waxing crescent Moon gleams around 4° right of Jupiter high in the southwest. The gap between the duo shrinks as they sink in the west during the course of the evening.

15 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 8:32 p.m. PST (11:32 p.m. EST).

16 **DUSK:** Look high in the south to see the first-quarter Moon about 3½° left of the brightest star in the Pleiades, Alcyone, in Taurus. Binoculars will help tease out the fainter cluster stars.

18 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 8:21 p.m. EST.

20 **DUSK:** The waxing gibbous Moon hangs 1½° lower right of Pollux in Gemini high in the east after sunset.

22 **DAWN:** Venus and Mars are a mere ½° apart very low in the east-southeast before sunrise. You'll need a clear view toward the horizon and binoculars to take in this sight.

23 **DUSK:** The almost-full Moon is in Leo, less than 3° left of Regulus. Watch as they climb higher in the east-southeast during the evening.

28 **DAWN:** Look toward the southwest to see the waning gibbous Moon in Virgo about 1½° right of Spica.

—DIANA HANNIKAINEN

The image above shows the wisps of the ejected layers of the planetary Abell 21, fondly known as the Medusa Nebula, in Gemini. Even if your backyard scope won't show the same level of detail as this European Southern Observatory Very Large Telescope image, you can bear this picture in mind while you observe this target. Read more about planetary nebulae on page 36. ESO

FEBRUARY 2024 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart

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

NASA / LRO

MOON PHASES

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

LAST QUARTER
February 2
23:18 UT

NEW MOON
February 9
22:59 UT

FIRST QUARTER
February 16
15:01 UT

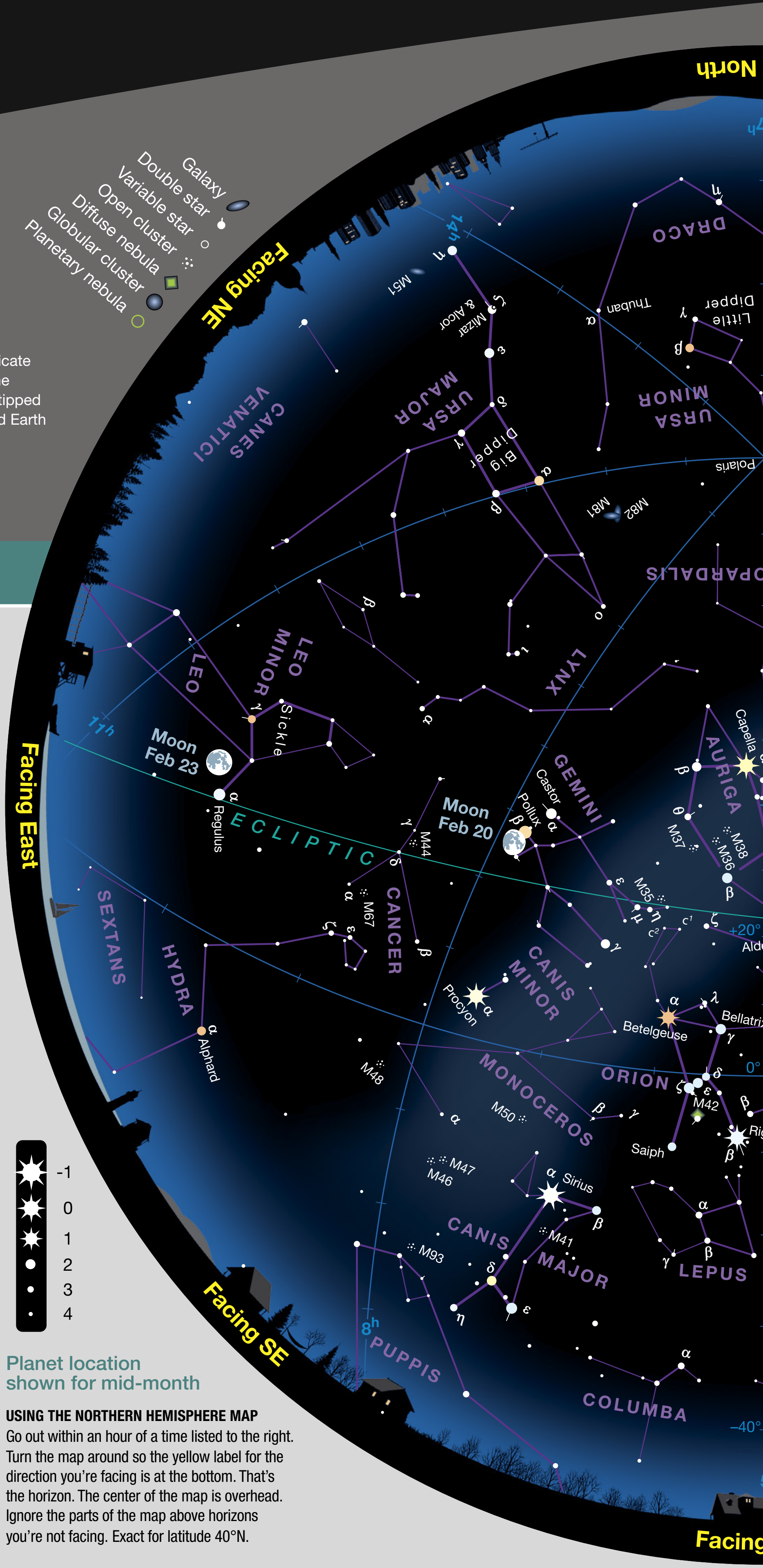
FULL MOON
February 24
12:30 UT

DISTANCES

Perigee	February 10, 19^h UT
358,088 km	Diameter 33′ 22″
Apogee	February 25, 15^h UT
406,312 km	Diameter 29′ 25″

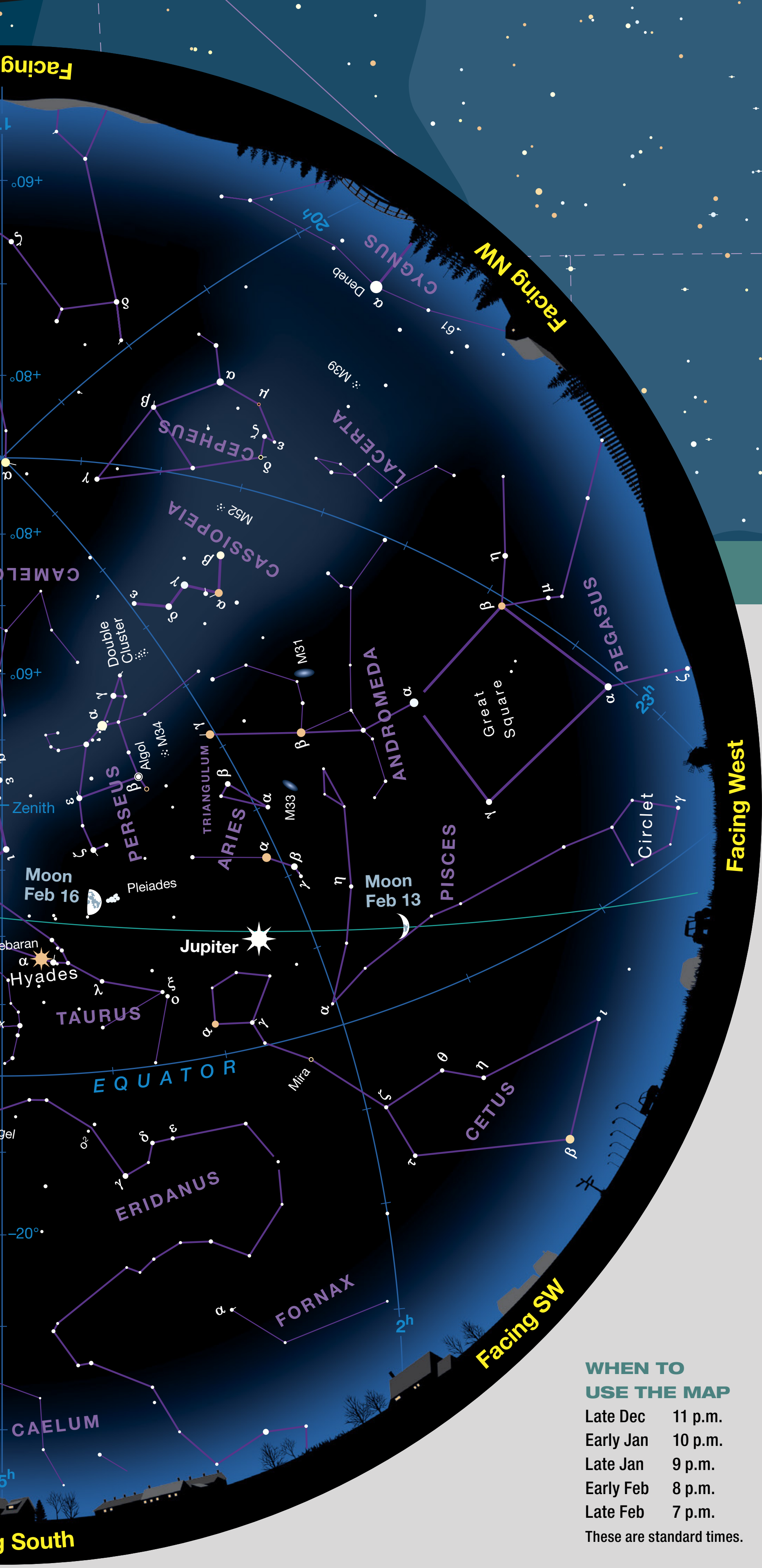
FAVORABLE LIBRATIONS

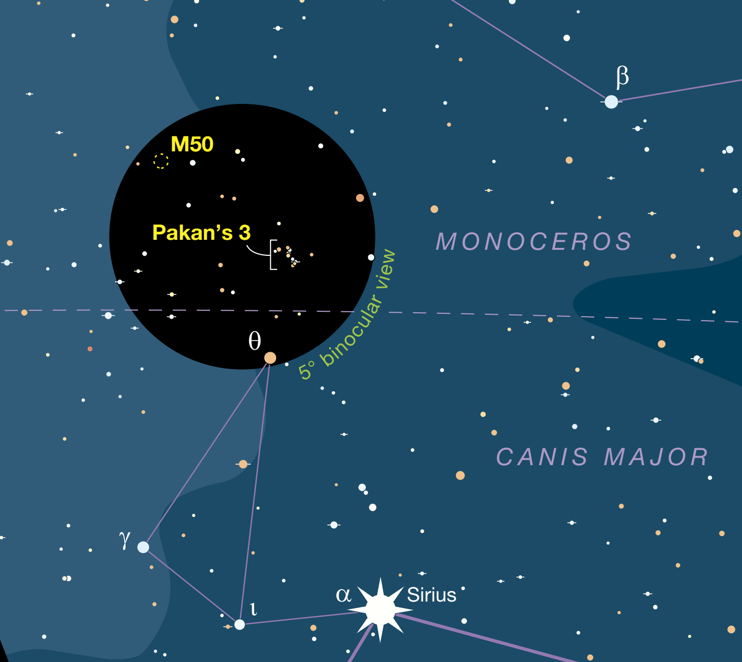
- Ulugh Beigh Crater — February 4
- Mare Smythii — February 14
- Gum Crater — February 19
- Lyot Crater — February 21



Planet location shown for mid-month

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





WHEN TO USE THE MAP

Late Dec	11 p.m.
Early Jan	10 p.m.
Late Jan	9 p.m.
Early Feb	8 p.m.
Late Feb	7 p.m.

These are standard times.

Binocular Highlight by Mathew Wedel

Three's Company

I tend to be omnivorous in my binocular observing, but I have a particular soft spot for asterisms. Most of us are not going to discover new star clusters or nebulae, but we can still find and share cool patterns of stars.

Our primary target this month is **Pakan's 3**, an asterism in the far southern reaches of Monoceros, the Unicorn. Amateur astronomer Randy Pakan of Edmonton, Alberta, first recognized it in the 1980s. To find it, we'll rely on the constellation of Canis Major, the Great Dog. Theta (θ) Canis Majoris, a 4th-magnitude orange giant, marks the nose of the Dog. Scan 2° north of Theta and look for two arcs of 9th- and 10th-magnitude stars making a numeral 3. Pakan's 3 spans about ½°, roughly the same diameter as the full Moon. Under reasonably dark skies it should be visible in 10×50 binoculars, although you might want to have them mounted or at least brace your elbows on something. In 15×70 binos it's a much easier catch.

As long as you're in the neighborhood, scan another 3° northeast to find the 6th-magnitude open cluster **M50**. There's nothing else comparably bright in the neighborhood, so it should pop right out even in 7×35s. The cluster is variously described as being heart-shaped or dagger-shaped, and the western margin is indeed a pretty sharp right angle, forming the point of the heart. M50's eastern margin is looser, and the heart shape only solidifies for me some of the time.

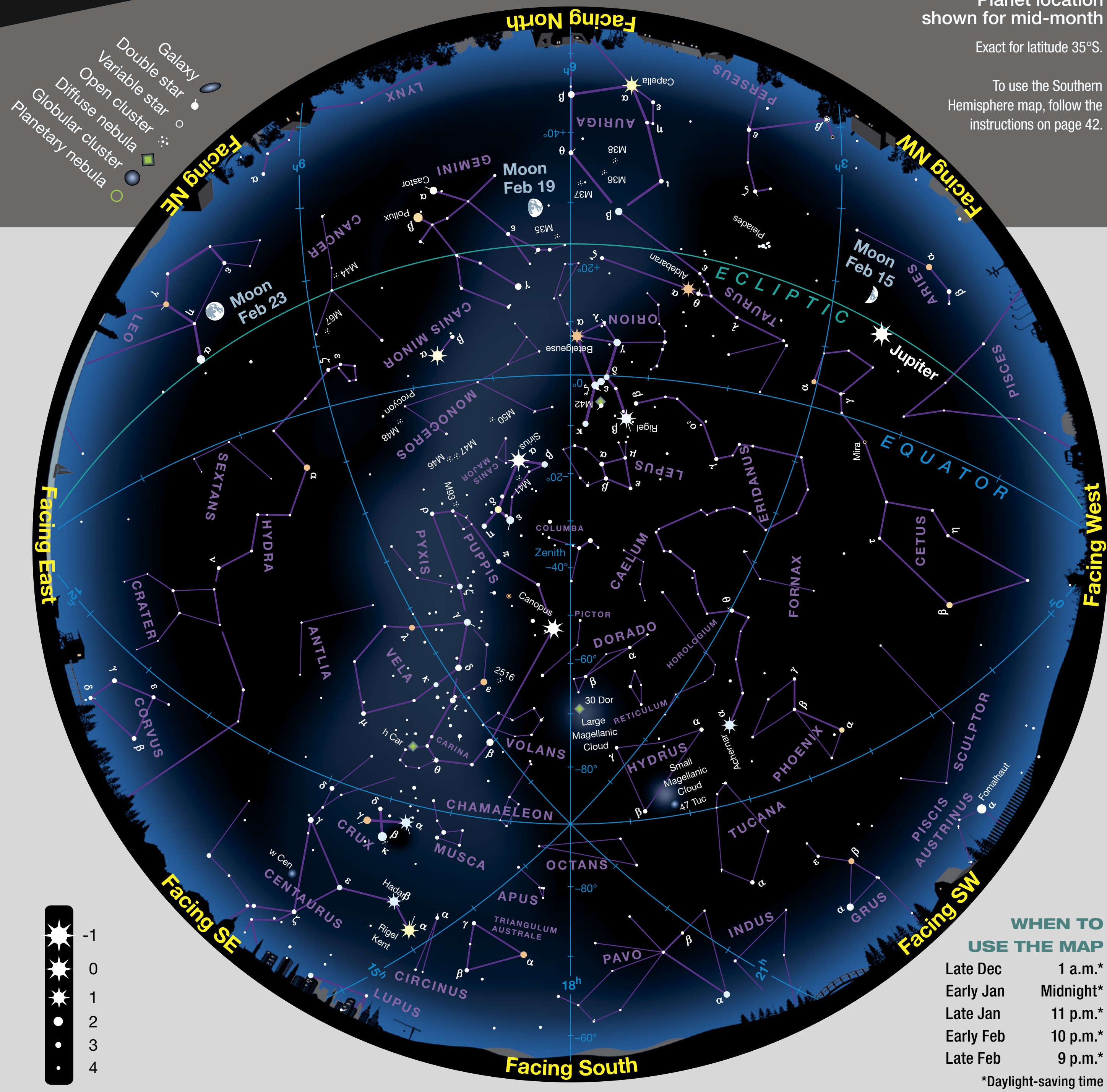
Monoceros is my favorite winter stomping ground, just jam-packed with open clusters, double and multiple stars, and asterisms. I'm sure that plenty of the latter remain to be discovered. Let's get to it!

■ **MATT WEDEL** thinks Monoceros is grossly underrated, even by people who like Monoceros.

FEBRUARY 2024 OBSERVING

Southern Hemisphere Sky Chart

by Jonathan Nally



WHEN TO USE THE MAP

Late Dec	1 a.m.*
Early Jan	Midnight*
Late Jan	11 p.m.*
Early Feb	10 p.m.*
Late Feb	9 p.m.*

*Daylight-saving time

HIGH IN THE SOUTH on February evenings is one of the brightest stellar beacons in the whole sky — **Canopus**, or Alpha (α) Carinae. Due to its far southerly declination, it's difficult or impossible to see from most of North America, but the star is nonetheless a friendly and familiar sight for south-of-the-equator stargazers. Blazing at magnitude –0.7, only Sirius (magnitude –1.5) in Canis Major outshines it. (Both luminaries approach the meridian in the chart above.)

Officially, Canopus is a blue-white bright giant of spectral type *A9*, but to my eye it has a slightly yellowish cast. It's also huge — its diameter is more than 70 times greater than our Sun's, and it's 10,000 times more luminous. And at a distance of roughly 300 light-years, it's also pretty close. No wonder it shines so prominently! ■

The Cave of Zeus

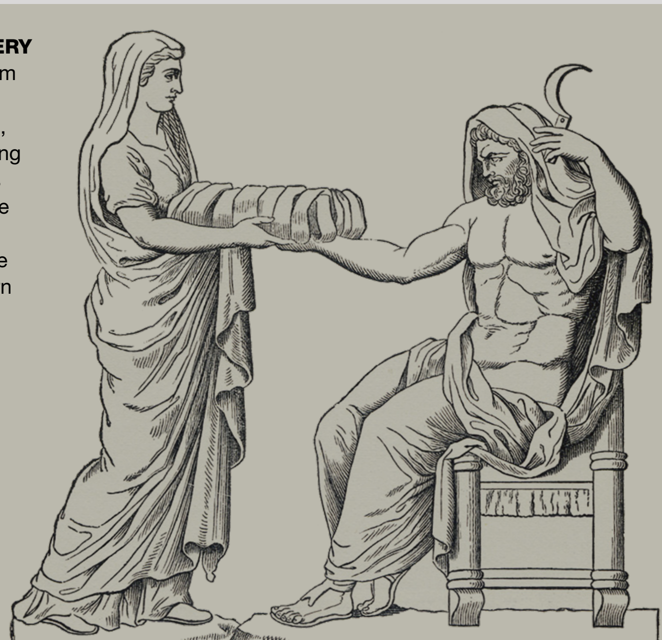
Here are three new ways to see the brightest stars of Auriga.

Our story begins with the Pentagon of Auriga and its lemon-yellow beacon, zero-magnitude Capella, Alpha (α) Aurigae, the sixth-brightest star in the night sky. The Pentagon is an *asterism* (a familiar pattern of stars) formed by Auriga's five brightest stars. As our all-sky chart on pages 42 and 43 depicts, in addition to Capella, the geometric shape includes Beta (β), Eta (η), Theta (θ), and Iota (ι) Aurigae and borrows Beta Tauri from neighboring Taurus. A fist held at arm's length will fit comfortably inside the Pentagon's vast celestial cavity. Factor in The Kids (the tiny triangle of dim naked-eye stars immediately southwest of Capella) and the Milky Way, and we have a scene worthy of contemplation.

Look again at our star chart. See how Capella and the Pentagon are close to the *zenith* (the imaginary point directly overhead) for observers at mid-northern latitudes. Such a lofty position seems fitting for our story, which involves Zeus, the supreme mythological deity of ancient Greece. Let's set the stage for our celestial drama.

Auriga is Latin for charioteer, but seeing such a figure among the stars takes a lot of imagination. For instance, one common way to depict the constellation involves a shepherd sitting in a chariot (or wagon), holding three baby goats while the mother goat watches over them from the shepherd's shoulder. This rendering is actually a fusion of figures — a celestial collage, if you will, created from fragments borrowed from different story lines over the ages. No wonder a simple Pentagon has become the constellation's popular default pattern — it's so much easier to visualize! But there are at least three other, more inspired ways to envision the stars of Auriga. Each is based on a myth linked to the births of both Zeus and the Milky Way.

The best-known story of the Milky Way's origin centers around the birth of Hercules — the illegitimate son of Zeus and the mortal princess Alcmene. To provide his son with immortality, Zeus held the child to the breast of his sleeping wife, Hera (goddess of childbirth), and let him suckle. So vigorously did Hercules feed that Hera awoke and pulled the child away, scattering the food of immortality across the vault of the heavens to become the Milky Way.



▶ **TALE OF TRICKERY** In this illustration from A. L. Millin's *Galerie Mythologique* (1811), Rhea is shown tricking her husband Cronos into receiving a stone wrapped in swaddling clothes in place of Zeus, her last-born child.

IVY CLOSE IMAGES / ALAMY STOCK PHOTO

Now let's look at a less-told tale. Cronus (King of the Titans) learned from a prophecy that a son of his would usurp his power, and so he swallowed every child born to him. When his wife Rhea discovered she was pregnant again, she secreted herself away to a cave on Mount Dicte in Crete and gave birth to her son Zeus. Rhea left her infant in the care of the she-goat Amalthea, who apportioned her divine milk between Zeus and her own newborn kids. Rhea then returned home to trick Cronus. After wrapping a stone in swaddling clothes, she presented it to Cronus to swallow. Before he did so, Cronus put what he thought was his child to Rhea's breast, whose milk splashed off the stone to form the Milky Way.

When Amalthea and her kids died, Zeus awarded them a place in the starry heavens. He had Amalthea's goat hide made into a shield whose supernatural powers helped him and the Olympians defeat his father in the War of the Titans. As seen in this light, the yawning cavity of Auriga's Pentagon becomes the open mouth of Zeus's cave, at the back of which we see Amalthea (as Capella; the name is derived from the Sumerian ÁŠ-KAR, "the goat star") nursing her two kids and the infant Zeus — the three stars of The Kids asterism.

We can also imagine the Pentagon simply as the stone that Rhea had presented to Cronus, off which we see her breast milk splashing toward the northwest and southeast as the Milky Way. Or we could choose to see the Pentagon as Martha Evans Martin imagined it in her 1907 book *The Friendly Stars*, as a "five-sided figure somewhat in the shape of a shield" — the aegis of Zeus.

By the way, transformation is a key element in Greek mythology, and Zeus was often party to it. Now you can play along as you look up at Auriga's Pentagon and enter the cave of Zeus.

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

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

Lunar Highs and Lows

The Moon rides the ecliptic, where it encounters several planets and Spica (twice).

THURSDAY, FEBRUARY 1

The **Moon** meets up with **Spica** twice this month, and of the two pairings the best one occurs early this morning around 3:30 a.m. EST. Less than 1° separates the two objects — something worth setting an early alarm for and bundling up against the chill of a February morning. The Moon is a waning gibbous (just 1½ days past last-quarter phase) sitting left of the star. When they next greet each other on the morning of the 28th, the Moon will again be a waning gibbous but positioned a little farther away and to the right of the star.

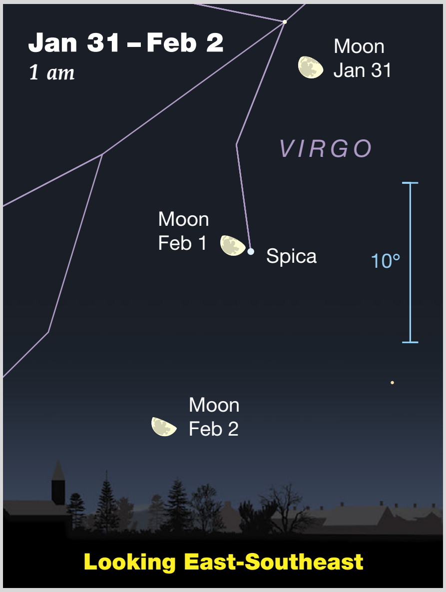
As noted last month, the Moon and Spica have some very special meetings in 2024, including not one but two (!) occultations — the first in July and the second in November. Those spectacles aside, this month's conjunctions are among the closest the Moon has with Spica this year and so fall into the "don't miss it" category.

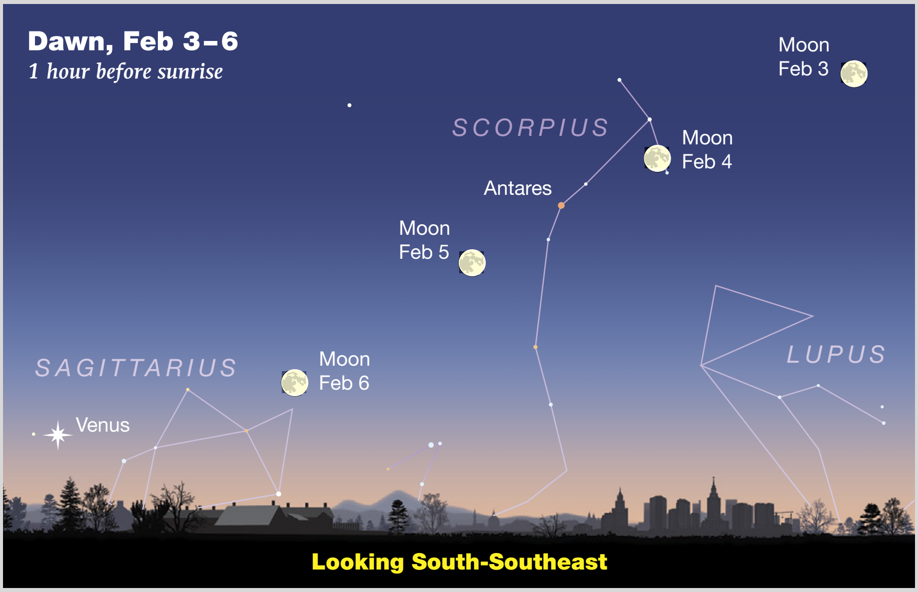
WEDNESDAY, FEBRUARY 7

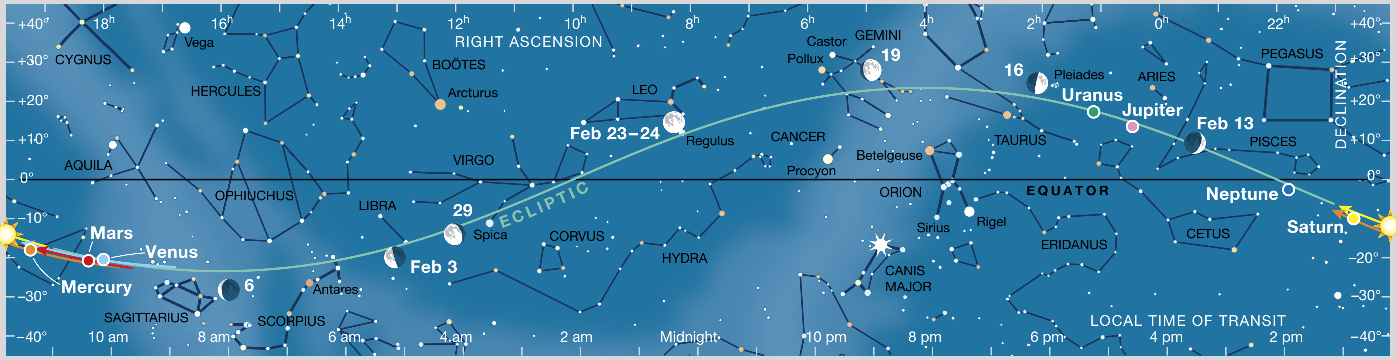
The **Moon** and **Venus** are separated by 7° as they have their monthly encounter this morning. For a little bonus luster, 1.3-magnitude Mars is below and left of the Morning Star.

Unfortunately, viewing conditions for this conjunction aren't exactly ideal. The reason is that the Moon sits just a few degrees above the southeastern horizon and at a declination of –28½°. That's very nearly as far south as it can get! There are even special terms for this situation: *lunistice*, or "major lunar standstill." So, what's going on here? The answer is two things at once. First, recall that the ecliptic is tilted by 23½° to the celestial equator. That means that the ecliptic's northern and southern extremities have declinations of +23½° (in Gemini), and –23½° (in Sagittarius). The second thing is that the Moon's orbit around Earth is inclined by 5°. If it reaches the northern extreme of its orbit at the same time that it arrives at the northernmost part of the ecliptic, the two factors add together for a declination of around +28½°. Similarly, when the two tilts combine in the south, the Moon dips to a declination of –28½°. These tilts coincide every 18.6 years, but the Moon appears unusually far north or south for several months before and after the date they max out. And now is one of those times. When the Moon rides low on the ecliptic, it's extra-low and when it's high, it's extra-high. The current major lunar standstill climaxes in January 2025, with the Moon's declination reaching plus and minus 28.725°!

▼▶ 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.





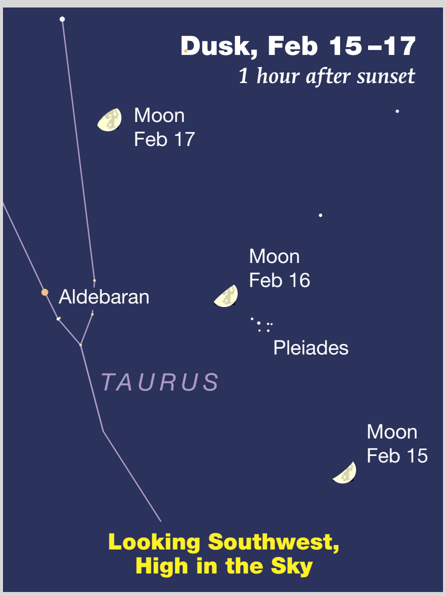


▲ The Sun and planets are positioned for mid-February; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

WEDNESDAY, FEBRUARY 14

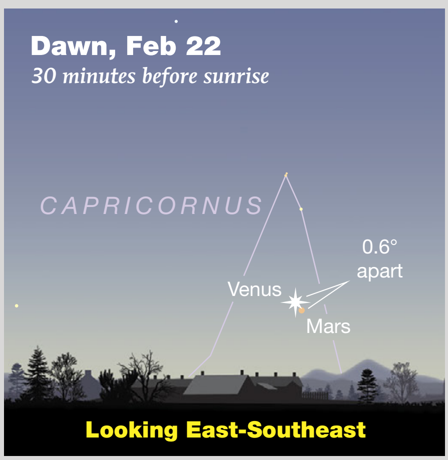
Although much of the action this month occurs in the morning sky, observers who prefer the evening hours aren't left out entirely. Tonight, the **Moon** and **Jupiter** get together. Since the waxing lunar crescent sits to the right (west) of the planet, the gap between them continues to narrow throughout the night while they sink toward the west-northwestern horizon. They'll be around 3° apart in the hour before midnight.

Jupiter's proximity to a waxing crescent Moon indicates that the planet is approaching the latter stages of its current apparition. Indeed, Jupiter was at opposition back in early November (when the full Moon was nearby) and will remain a rewarding telescopic target only for another two months. On this particular evening, it gleams impressively at magnitude –2.3 from its perch among the dim stars of southern Aries. With Saturn all but lost in the solar glare and setting just one hour after the Sun, Big Jove is the lone evening planet — a position it occupies until it's briefly joined by Mercury next month.



FRIDAY, FEBRUARY 16

Two nights after its encounter with Jupiter, the **Moon** visits the **Pleiades**, in Taurus. This pairing happens on a monthly basis, and with each passing month this spring, the Moon grows thinner, and the conjunction occurs lower and lower in the western sky. The last conjunction in this evening series occurs in May. Tonight, the Moon is roughly 55% illuminated and just half a day past first-quarter phase. You'll find the brightest Pleiad, 2.8-magnitude Alcyone, 3½° left of the Moon. Binoculars will be a big help for sighting the other, fainter cluster stars. If you find the sight slightly so-so, stay tuned. In both the March and April conjunctions the Moon is thinner and, as such, less overwhelmingly bright.

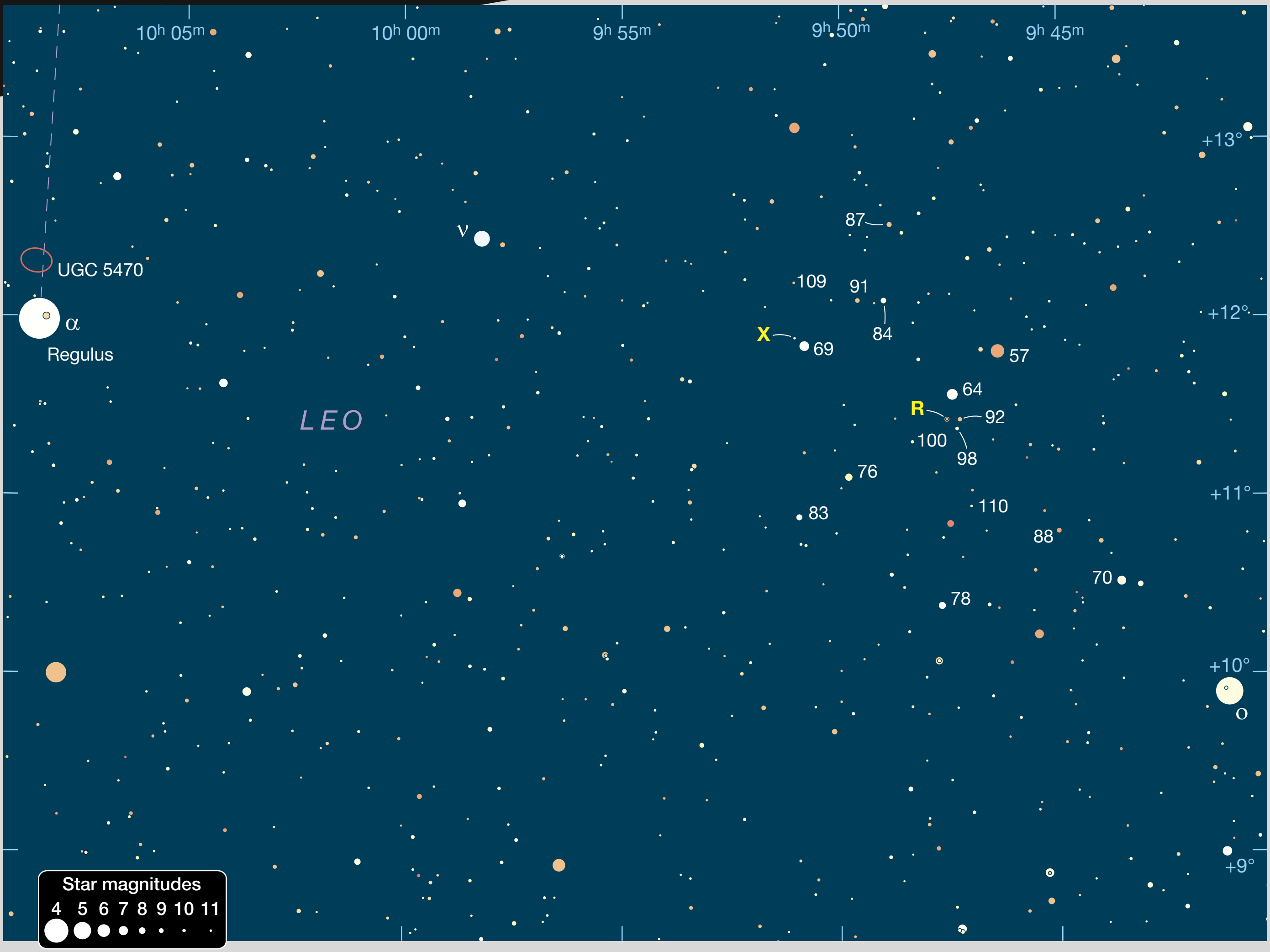


THURSDAY, FEBRUARY 22

For our final big event this month we return to the morning sky. However, this will be a tricky one to observe. You'll need the usual dose of good luck with the weather, but you'll also need an unobstructed view toward the east-southeast. And you'll (probably) need binoculars. If you have all that, then get ready for a very close planetary conjunction featuring **Venus** and **Mars**.

The two worlds are separated by less than 40′, which is a bit more than the apparent diameter of the Moon. The difficulty arises from the disparate brightnesses of the pair. Venus is a veritable beacon at magnitude –3.9, while Mars is a delicate 1.3-magnitude spark. That's a difference of 120×! And given that they rise only one hour before the Sun, you'll be trying to see them when they're near the horizon and during brightening twilight. Not a problem for Venus, but a struggle for poor Mars. Still, if you tried and failed to see the Red Planet on the 7th, your chances this morning are slightly better.

■ Consulting Editor **GARY SERONIK** enjoys tracking the Moon as it goes through its highs and lows.



▲ Use this chart to locate the variable stars R and X Leonis, roughly 5° west of Regulus. Comparison star magnitudes are given with their decimal points omitted (e.g., a magnitude 11.0 star is labeled “110”).

CHART: BEATRIZ INGLESSIS / *S&T*; STAR MAGNITUDES: AAVSO

A Pair of Leo Variables

Meet R Leonis and its next-door neighbor, X Leonis.

If you haven’t observed Leo’s brightest Mira-type variable star, stop by for a peek at R Leonis this month. A ruddy nugget tucked into a binocular asterism shaped like a bent fishing rod, R Leonis is located about 5° west of Regulus, Alpha (α) Leonis. As the variable expands and contracts over a period of 312 days, its visual brightness varies on average from about magnitude 5.8 to 10.0. During its contraction phase, the red giant heats up and brightens. When expanding, its surface cools and dims.

The star was previously at minimum light last autumn. Now awakened from its slumber, it’s on the rise. At the start of February, R Leonis should be visible in a 60-mm telescope and possibly 50-mm binoculars at about magnitude 8.5, then brighten to 7 or better by Leap Day. Maximum light should occur in late March or early April. If you observe the star once a week, you’ll notice its increasing brilliance soon enough. Its vivid red-orange color stands in marked contrast to other stars in the telescopic field of view, making it a cinch to spot.

When R Leonis exceeds 8th magnitude, I break out the binoculars to estimate its brightness. You can use the chart presented above or make your own with the help of the American Association of Variable Star Observers (AAVSO). Go to **aavso.org**, type in “R Leo” in the *Pick a Star* box and select *Create a finder chart*. You also have the option of creating charts at different scales — larger fields that contain the brightest relevant stars and narrower views to use when the star fades. Note that magnitudes shown in our map above have the decimal points omitted.

R Leonis became an early favorite when I first joined the AAVSO in 1982. To be honest, finding my first variable was anything but easy. It’s one thing to hunt for an extended object like a globular cluster and quite another to pin down a solitary point of light. But I eventually got the hang of it. Leslie Peltier, who wrote the beloved *Starlight Nights* about his experiences as a variable-star observer and comet hunter, recounted the same frustration when hunting for R Leonis, his very first variable.

Peltier was 18 years old when he encountered the star with his 2-inch brass refractor purchased with the money he made picking strawberries. He finally spotted R Leonis on March 1, 1918, after many unsuccessful attempts. It became a favorite. Peltier made certain to observe the star and estimate its magnitude each March to commemorate the night they first met.

If you decide to take the R Leo challenge this month, heed Peltier's words: ". . . I feel it is my duty to warn any others who show signs of star susceptibility that they approach the observing of variable stars with the utmost caution. It is easy to become an addict, and as usual, the longer the indulgence is continued the more difficult it becomes to make a clean break and go back to a normal life."

To entice you further down the variable-star rabbit-hole, take a look at X Leonis, located just 1° northeast of R. Although both fit into the same low-power field of view, the causes of their variability couldn't be more different. X Leonis is actually a binary star where an Earth-size white dwarf is paired in a tight orbit with a red dwarf. The white dwarf's powerful gravity strips gas from its companion and funnels it into a swirling accretion disk. Changes in the amount and rate of material flowing through the spinning disk causes the disk to heat up, triggering a sudden brightness spike.

In its quiescent state, X Leonis hovers around magnitude 16, but during a flare it can vault four or more magnitudes overnight to 12 — within reach of a 6-inch telescope under a dark sky. Use the AAVSO chart utility to make a closeup map showing comparison stars.

If you like surprises, dwarf novae like X Leonis are must-see astronomical targets. Let neighboring R Leonis take you there.

Young Moon Season Begins

LATE WINTER AND early spring are the best times of year to hunt for the young Moon at dusk. That's when the angle the ecliptic makes to the horizon from mid-northern latitudes pitches up so steeply that the waxing lunar crescent hovers almost directly above the setting Sun.

February's thin, sickle-like Moon will serve as a warm-up for its more challenging appearance in March. The February new Moon occurs at 5:59 p.m. EST on the 9th, making the fresh crescent at sunset on the 10th approximately 23.5 hours old as seen from the East Coast and 26.5 hours old from the West. A day-old lunar sliver is a great catch and gorgeous sight.

Bring binoculars and look low in the western sky starting about 20 minutes after sunset on February 10th, when the Moon hovers roughly 6° high from the East Coast and 8° from the West Coast. At that time, it stands about 14° from the Sun with an illuminated extent of 1.6%.

Things tighten up even more in March. New Moon is on the 10th at 5:00 a.m. EDT. By the time the Sun sets on that date around 7:00 p.m. local time, the waxing Moon will have aged just 14 hours as seen from the East Coast; 15 hours in the Midwest; 16 hours in the Mountain states; and 17 hours on the West Coast. The record for a visual sighting stands at 15 hours, 32 minutes — an observation made by *S&T* Contributing Editor Stephen James O'Meara in May 1990.

If you live in the eastern half of the U.S., you may not be able to meet the challenge, but if you reside in the western half you stand to see a rare delicacy. And you can try again the following evening when the crescent will be more fully illuminated and even higher. Although you won't be breaking any records, the Moon will still be delightfully thin.

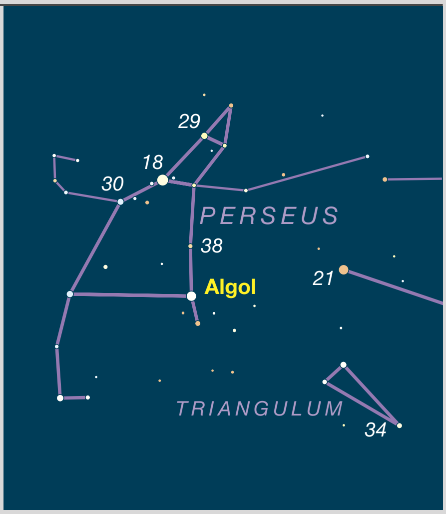
▲ A 1.3-day-old evening crescent Moon cuts a sharp figure low in the western sky on March 7, 2019. Observers will have several opportunities to spot successive young Moons at dusk this February and March. Binoculars are an aid in finding the lunar sliver in bright twilight.

BOB KING

Minima of Algol

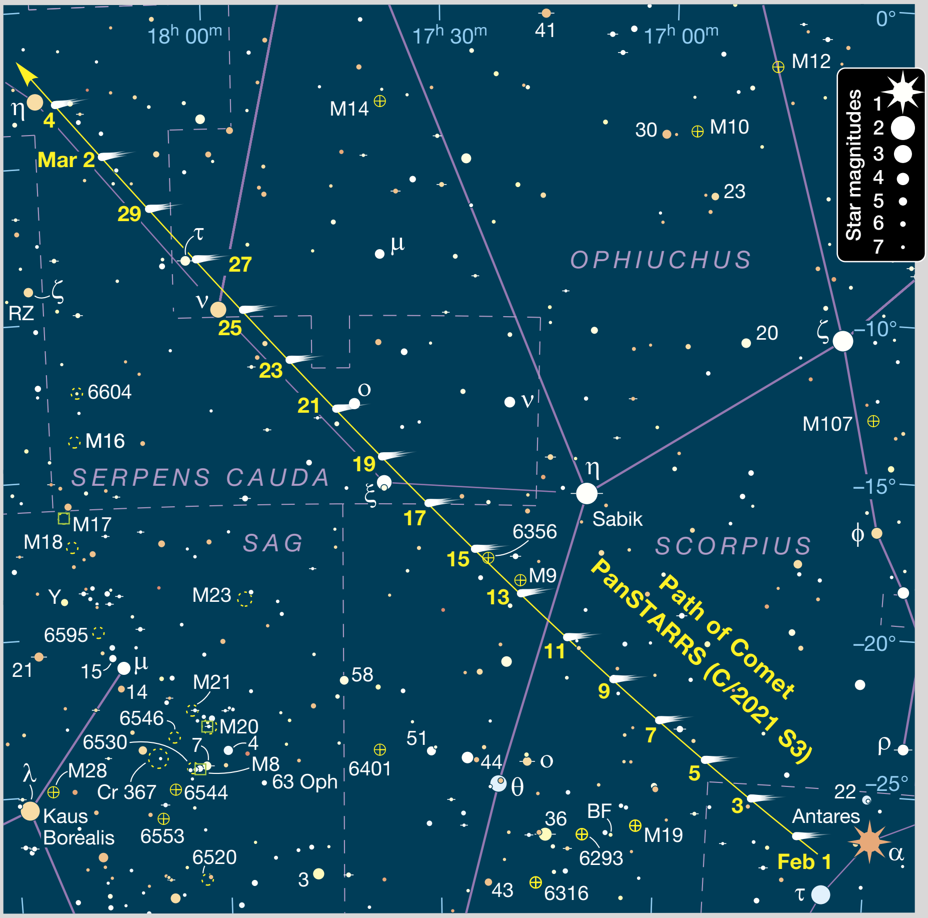
Jan.	UT	Feb.	UT
1	7:23	1	20:25
4	4:12	4	17:14
7	1:01	7	14:04
9	21:50	10	10:53
12	18:40	13	7:43
15	15:29	16	4:32
18	12:18	19	1:21
21	9:08	21	22:11
24	5:57	24	19:00
27	2:46	27	15:49
29	23:36		

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



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

Comet PanSTARRS at Dawn



THIS YEAR IS SHAPING up to be a comet-lover's dream, with a parade of (relatively) conspicuous visitors that includes 12P/Pons-Brooks in March–April, 13P/Olbers in June–July, and Comet Tsuchinshan–ATLAS (C/2023 A3) this coming autumn. Comet PanSTARRS (C/2021 S3) helps to move things along this month as it brightens to around magnitude 7.5 — good enough to be sighted in binoculars.

PanSTARRS traverses the morning sky from east of Antares on February 1st northeastward into Ophiuchus, a constellation known for its wealth of bright globular star clusters. On the morning of February 13th, the comet passes just 20′ east of the 7.8-magnitude globular cluster M9, and the next morning it comes even closer to the 8.2-magnitude globular NGC 6356.

Comet PanSTARRS was discovered with the PanSTARRS 2 telescope from Haleakalā in Maui, Hawai'i, on September 24, 2021. Perihelion occurs on Valentine's Day, February 14th, at a distance of 1.3 a.u. from the Sun. Closest approach to Earth takes place on March 14th with the comet 1.4 a.u. away. The object slowly fades to 8th magnitude in March, giving you plenty of time to observe it.

Action at Jupiter

ALTHOUGH JUPITER DOESN'T have its conjunction with the Sun until May 18th, as February opens the planet already transits the meridian at sunset and sets shortly after midnight. However, thanks to Jupiter's northerly declination (+13° on the 1st), its altitude remains great enough for satisfying telescopic viewing until around 9:30 p.m. in the evening. However, by month's end, that observing window closes an hour earlier. During February Jupiter's disk shrinks slightly from 39.7″ to 36.5″ as it dims from magnitude –2.4 to –2.2.

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

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

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

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

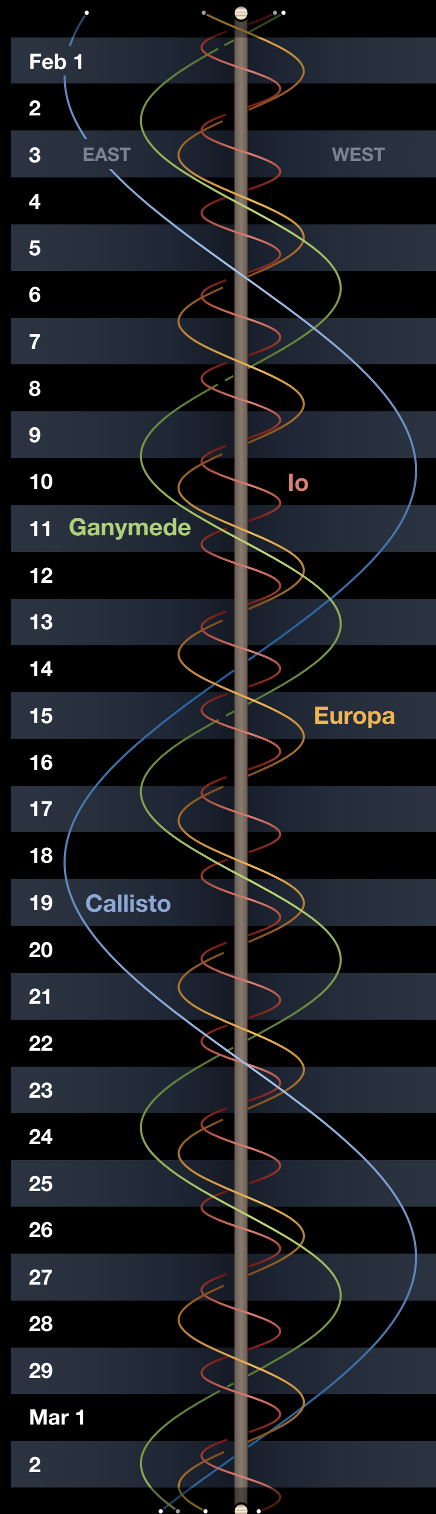
These times assume that the spot will be centered at System II longitude 52° on February 1st. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 52° and $1\frac{2}{3}$ minutes later for each degree more than 52°.

Phenomena of Jupiter's Moons, February 2024

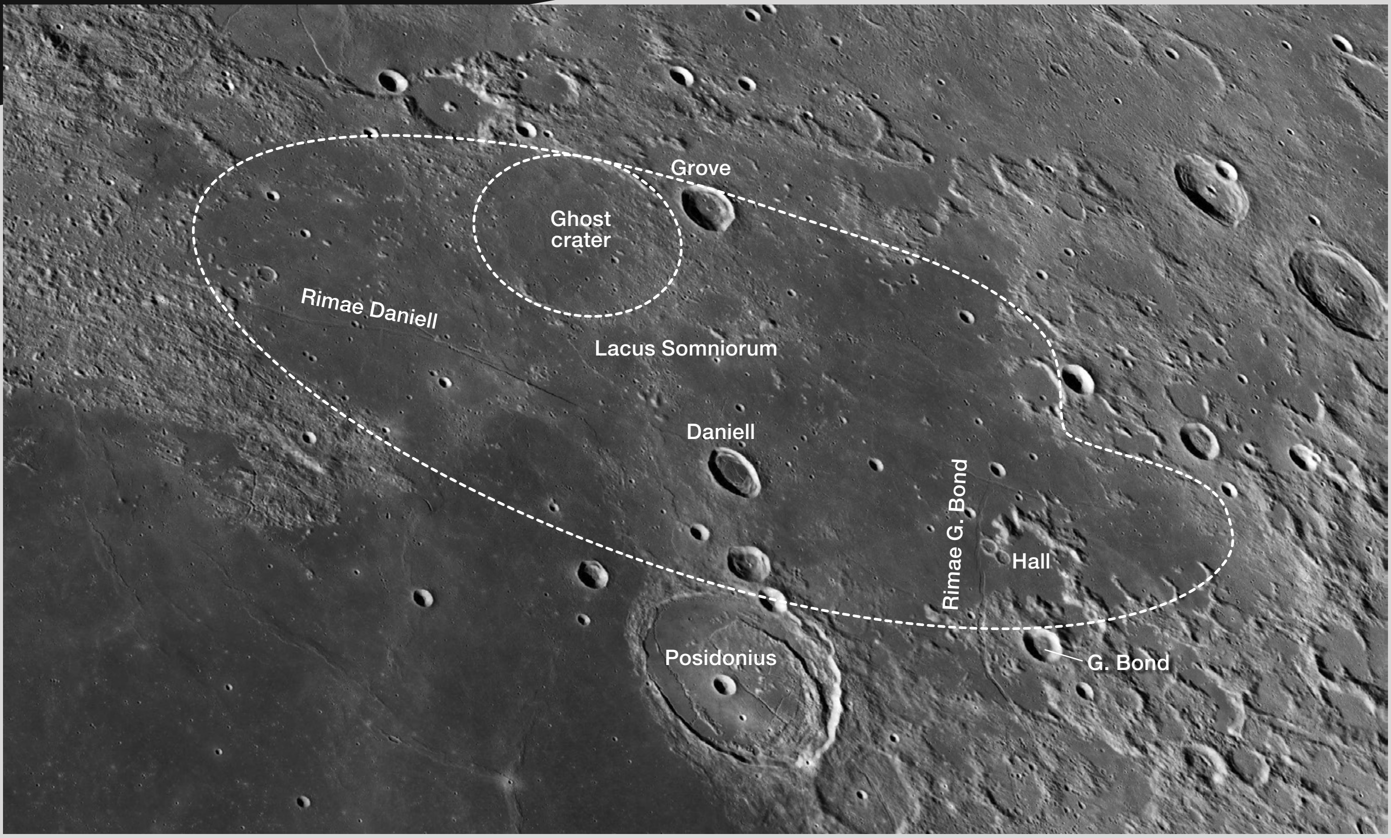
Feb. 1	0:01	II.Sh.E
	0:39	III.Oc.R
	4:13	III.Ec.D
	5:53	III.Ec.R
	14:44	I.Tr.I
	16:04	I.Sh.I
	16:54	I.Tr.E
	18:13	I.Sh.E
Feb. 2	11:55	I.Oc.D
	13:48	II.Oc.D
	15:26	I.Ec.R
	16:13	II.Oc.R
	16:34	II.Ec.D
	18:56	II.Ec.R
Feb. 3	9:13	I.Tr.I
	10:33	I.Sh.I
	11:23	I.Tr.E
	12:42	I.Sh.E
Feb. 4	6:24	I.Oc.D
	8:22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

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.



A Slumbering Lunar Lake

A neglected corner of the Moon contains interesting surprises under the right lighting.

You might say that lunar observers have been asleep when it comes to **Lacus Somniorum**, the Lake of Dreams. This poorly defined patch of mare lavas resides between the crater **Posidonius** and another lunar lake, **Lacus Mortis**. There have been very few reports about Lacus Somniorum. But it's worth disturbing your slumber on a cloudless night to visit its dark shores. Observers with an 8-inch or larger telescope can explore two fascinating rille systems, an unexpectedly complex rille-floored crater, and the ghost of a giant, ancient crater.

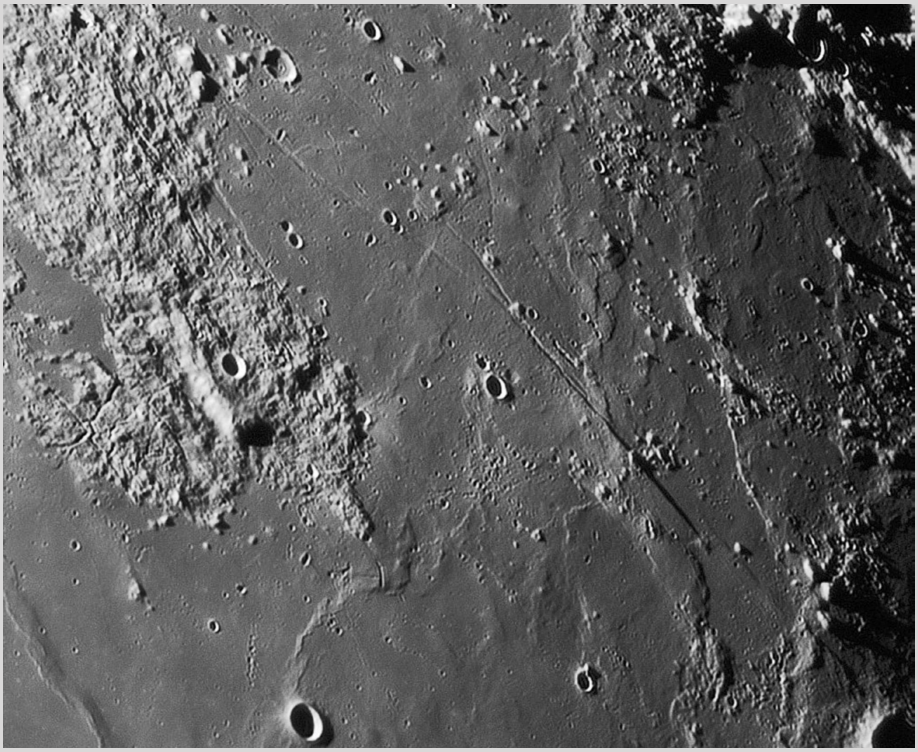
Lacus Somniorum is located in the Moon's northeastern quadrant and appears as a mostly flat and featureless oval area about 450 kilometers (280 miles) wide east to west, and half that dimension north to south. There's no evidence from topographic, morphologic, or gravitational data to indicate that its lavas fill a buried impact basin. The east-west edges are where the mare stops, meeting basin ejecta from the Imbrium basin on the west and tattered, old, eroded craters at the east. **Daniell** crater is near the middle of Somniorum and is a good starting point to explore this overlooked lava plain.

Daniell itself is a strange crater. This elliptical feature spans about 28 km north to south, but only 23 km east to west. A close examination shows the longer direction is due to massive rim slumps that expanded the crater's dimensions. But it's the floor of the crater that's most unusual. It's surfaced by smooth lava, and, like nearby Posidonius, Daniell's floor is tilted, with the southern side some 60 m higher than the northern section. Two rilles cross the floor parallel to the crater's long axis, and another rings the floor, concentric with the crater's walls. The area between the two parallel rilles is 100 m lower than the surfaces on either side of the parallel rilles, having subsided like a large graben between two rille-bounded, higher surfaces. Daniell is considered a *floor-fractured crater* — one whose floor is uplifted and fractured by an intrusion of magma entering from below. One wonders while examining the feature if the parallel rilles are also faults that accommodated the rise of the outer parts of the floor.

About two crater diameters to the west-northwest of Daniell is the most conspicuous section of **Rimae Daniell**. This very straight linear feature appears as a thin, bright line five days after new moon. A more dramatic view occurs near sunset in the region 14 days later,

NASA / GSFC / ARIZONA STATE UNIVERSITY

▶ Several sections of Rimae Daniell are visible in this photo taken as the Sun set over the western extent of Lacus Somniorum.



when a thin shadow is just visible. The southwest side of the mare rises 140 m over a 5-km span approaching the rille and then precipitously drops 220 m to the flat terrain on the northeast. This section of Rimae Daniell isn't actually a rille but rather a fault, spanning about half the height and 60% of the length of the better known Straight Wall in Mare Nubium.

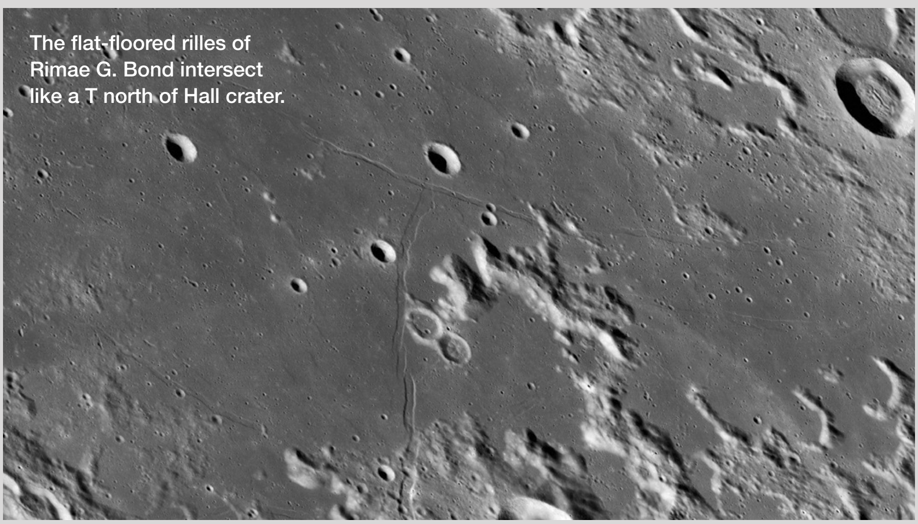
At about 70 km from its southern end, the fault forks and transforms into a thin, flat-floored rille segment that continues northwest. A second part bends west and cuts across mare lavas for nearly 100 km before continuing into hilly ejecta deposited during the formation of the Imbrium or Serenitatis basins. At least three similar rilles cut through the ejecta and curve around the Serenitatis basin, as do other rilles along the basin's north and east sides. These flat-floored rilles could be fractures created when the terrain surrounding Serenitatis bent downward as the mare-laden basin subsided. The best Earth-based image of the Daniell Rilles that I know of, shown above right, isn't from a spacecraft but rather taken by Oklahoma amateur Wes Higgins. He used his 18-inch Newtonian reflector to capture the entire rille system under the grazing light of a setting Sun.

Return to Daniell and then head east-southeast to the 20-km-diameter crater **G. Bond**. The flat-floored rille **Rimae G. Bond** curves from south of the crater and heads northward past the disintegrated crater **Hall** for about 80 km until it's truncated by another rille set at a right angle. This second section of the G. Bond Rilles extends east-northeast and west-southwest from the main rille, with the longest segment extending some 130 km to the east end of Lacus Somniorum, where it's barely visible as it crosses the region's rough and ancient cratered terrain. These details aren't well plotted in most lunar atlases but will reward careful observers using high power under low illumination angles.

Finally, north of the Daniell Rilles is a probable ancient crater immediately west of 28-km-wide **Grove** crater. A distinct rim fragment extends northwest from Grove and curves west, perhaps continuing as a short, curved mare ridge to the south, defining (with a little imagination) the incomplete outline of a roughly 100-km-wide crater. Rubbly terrain covers most of its southeast and west segments, but the interior is 400 m deep and has a hint of a central peak, adding evidence that it's a nearly-gone ghost crater.

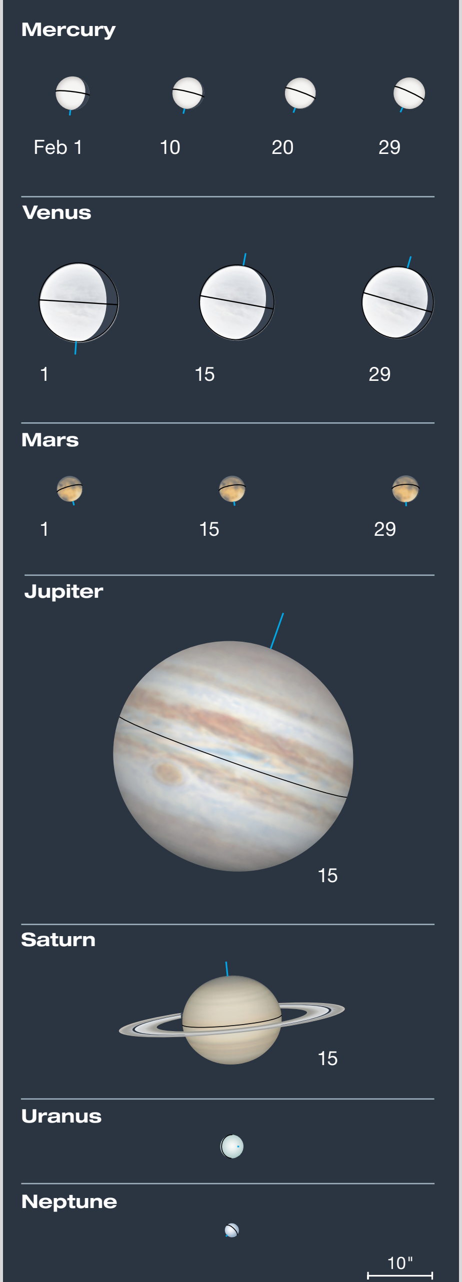
For nearly two daylong periods in the lunar morning and evening, Lacus Somniorum transforms from an easily overlooked plain of bland lavas into a fascinating region of subtle details to challenge the most seasoned lunar observers. The next time Posidonius reveals its fractured floor under a low Sun, be sure to cast your gaze to its north. You won't be disappointed.

■ Contributing Editor **CHUCK WOOD** never dozes when it comes to observing the Moon.



The flat-floored rilles of Rimae G. Bond intersect like a T north of Hall crater.

CLOSE-UP OF DANIELL RILLES: WES HIGGINS; BOND RILLES: NASA / GSFC / ARIZONA STATE UNIVERSITY



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

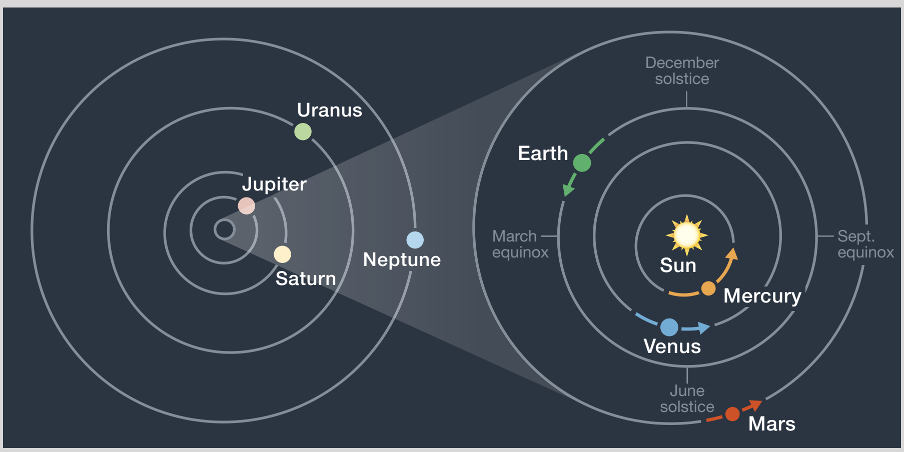
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during February. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** out of view all month • **Venus** visible at dawn all month • **Mars** is lost in the Sun's glare this month • **Jupiter** high in the southwest at dusk and sets at midnight • **Saturn** visible at dusk until the 13th.

February Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$20^h 54.9^m$	–17° 24′	—	–26.8	32′ 28″	—	0.985
	29	$22^h 44.5^m$	–7° 59′	—	–26.8	32′ 18″	—	0.991
Mercury	1	$19^h 41.4^m$	–22° 27′	18° Mo	–0.3	5.2″	88%	1.291
	10	$20^h 40.2^m$	–20° 13′	13° Mo	–0.5	4.9″	93%	1.359
	20	$21^h 47.5^m$	–15° 34′	7° Mo	–1.0	4.8″	98%	1.390
	29	$22^h 49.3^m$	–9° 26′	2° Ev	–1.8	4.9″	100%	1.368
Venus	1	$18^h 44.6^m$	–22° 24′	31° Mo	–3.9	12.2″	86%	1.362
	10	$19^h 32.5^m$	–21° 32′	29° Mo	–3.9	11.8″	88%	1.409
	20	$20^h 24.7^m$	–19° 35′	27° Mo	–3.9	11.4″	90%	1.458
	29	$21^h 10.4^m$	–17° 00′	25° Mo	–3.9	11.1″	91%	1.499
Mars	1	$19^h 28.3^m$	–22° 44′	21° Mo	+1.3	4.0″	98%	2.319
	15	$20^h 13.8^m$	–20° 52′	24° Mo	+1.3	4.1″	98%	2.267
	29	$20^h 58.3^m$	–18° 16′	28° Mo	+1.3	4.2″	97%	2.214
Jupiter	1	$2^h 19.8^m$	+12° 51′	86° Ev	–2.4	39.7″	99%	4.968
	29	$2^h 34.7^m$	+14° 12′	61° Ev	–2.2	36.5″	99%	5.397
Saturn	1	$22^h 34.0^m$	–10° 46′	25° Ev	+1.0	15.7″	100%	10.614
	29	$22^h 46.6^m$	–9° 31′	2° Ev	+1.0	15.5″	100%	10.711
Uranus	15	$3^h 06.1^m$	+17° 10′	83° Ev	+5.7	3.6″	100%	19.694
Neptune	15	$23^h 46.8^m$	–2° 45′	30° Ev	+7.9	2.2″	100%	30.750

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**.



Basic Image Editing

These simple processing tips can transform your astrophotos from bland to beautiful.

Unlike daytime snapshots, night-sky photos almost always require some amount of post-processing to bring out the very best each frame has to offer. Indeed, a working knowledge of basic image editing is as important as a detailed understanding of how to use your camera.

The following recipe offers some simple steps you can follow to transform your raw images from bland to beautiful. In this discussion I'll describe methods using *Adobe Photoshop Lightroom*, but you can obtain similar results with almost any photo-editing software.

Quality Ingredients

As with cooking a fine meal, you need to start with high-quality ingredients to ensure a successful photographic result. You can't fix trailed stars, camera shake, or poor focus with post-processing. Setting your camera to shoot in RAW mode (rather than JPEG) will provide the greatest latitude for making adjustments to your images.

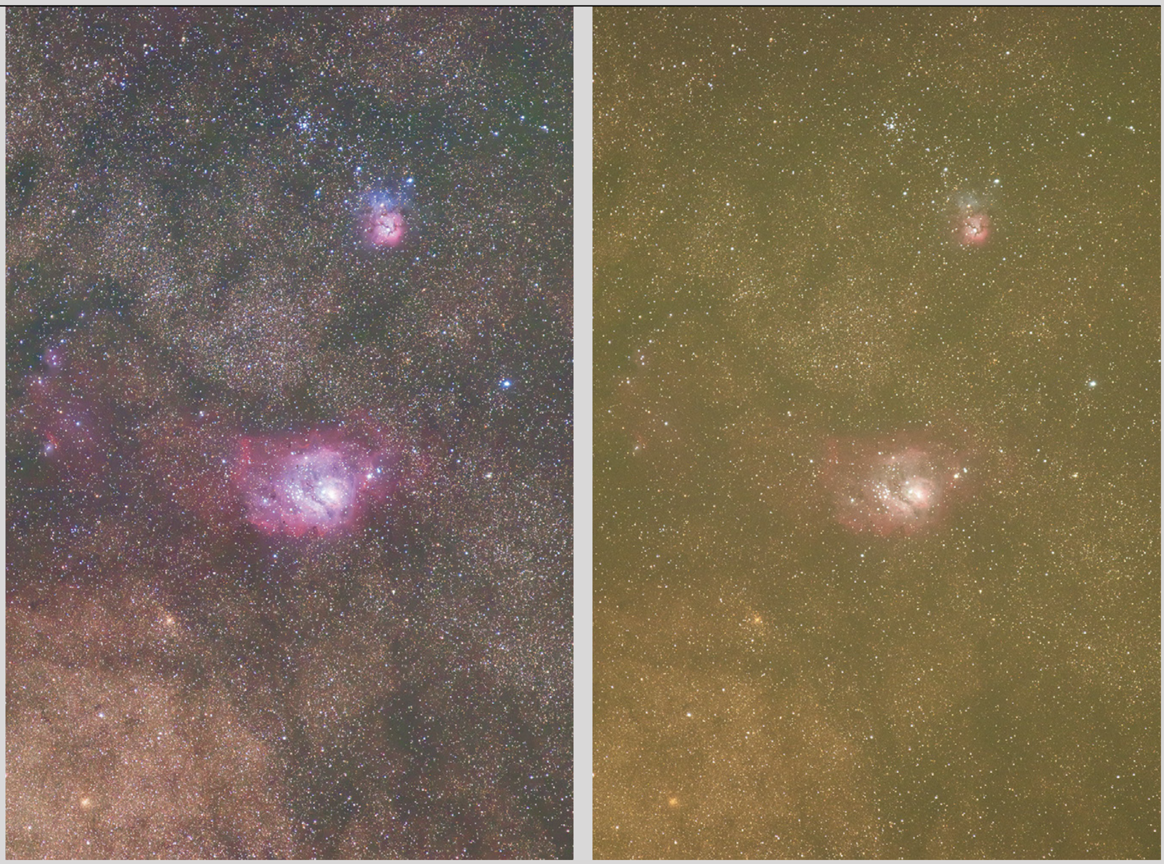
Even with post-processing magic, it's still crucial to get the exposure right "in camera." While you can recover some shadow detail in an underexposed image, it's impossible to rescue blown-out (or "clipped") highlights. Since stars are often the brightest objects in a night-sky photograph, it's important not to overexpose them as this tends to wash out their vivid colors.

The best way to ensure the correct exposure is to utilize your camera's histogram display. A well-exposed night-sky image will have a histogram hump fully separated from the left side of the graph, while not extending too much past the midway point.

Correcting Colors

As shot, all astronomical images have some sort of color cast straight out of the camera. When you drop your images into *Lightroom*, you could just set the ***White Balance*** setting in the Edit panel to Daylight (the Sun is just another star, after all), but this usually results in a brownish background sky — especially in light-polluted areas.

Since it's extremely hard to detect subtle color casts, one trick I use is to temporarily set the ***Saturation*** slider in



▶ **THE RAW AND THE COOKED** These two images portraying the Lagoon and Trifid nebulae in Sagittarius show the effects of the basic editing steps described in the text. All adjustments were made in *Adobe Lightroom*. Compare the modified version (left) to the original image (right) and note the pleasingly neutral background sky, higher contrast, reduced noise, and increased saturation. All this detail was present in the original RAW file and just required some adjustments to reveal. Since the alterations are non-destructive, they can be revisited later to obtain a different look.

▲ **ARTIFICIAL INTELLIGENCE AT WORK** In 2023, Adobe added an AI-powered feature called ***Denoise*** to *Photoshop* and *Lightroom*. The software uses machine learning to differentiate between fine details (including stars) and unwanted noise in high-ISO images. This before-and-after comparison of a cropped-in photo of the Andromeda Galaxy shows its benefits. The original 30-second exposure (left) was shot at ISO 16,000 and displays a large amount of digital noise, which appears as confetti-like colored speckles. A similar, standalone product called *Topaz DeNoise AI* is also available from Topaz Labs.

Lightroom to +100, which makes any color issues more obvious. Next, as you adjust the ***Temp*** and ***Tint*** sliders, watch the Histogram display and simply line up the colored humps to maximize the grey area in the middle of the graph. I find this to be an extremely sensitive way to color-balance my wide-field astro images.

Once you've eliminated the color cast, you can return the ***Saturation*** slider to a more reasonable value. The final setting is very much one of personal taste, but I usually leave it around +15 or so. The ***Vibrance*** slider offers a more subtle form of adjustment that increases the intensity of the less-saturated colors while leaving already-saturated colors alone. Again, adjust to personal taste.

At this point, you'll have a neutral white balance. This is fine, but you may want to circle back to make your photo a little warmer (more yellow) or cooler (bluer) for purely aesthetic reasons. A winter image may benefit from a cooler tone, while a desert landscape may work better with a warmer setting. Try some minor white balance tweaks and see what resonates with you.

Tone, Texture, Clarity, and Noise

Astro images are odd ducks that often have a whole bunch of information packed into a fairly narrow luminance range. You can use the sliders in *Lightroom*'s ***Edit*** panel to enhance the overall brightness and contrast in your image. This is where shooting in RAW format pays off, because you can make more aggressive adjustments than possible with a JPEG image.

Start with the ***Exposure*** slider to adjust the overall brightness of the image. If you've followed my recommendation to expose the original image to protect the highlights, then you may need to brighten the image a bit. If the stars start to blow out, you can recover some detail in them by reducing the ***Highlights*** slider. If your image lacks contrast, you can darken the sky background by reducing the ***Blacks*** slider level. (If you're old enough to remember graphic equalizers on component stereo systems, this set of sliders is the visual equivalent.)

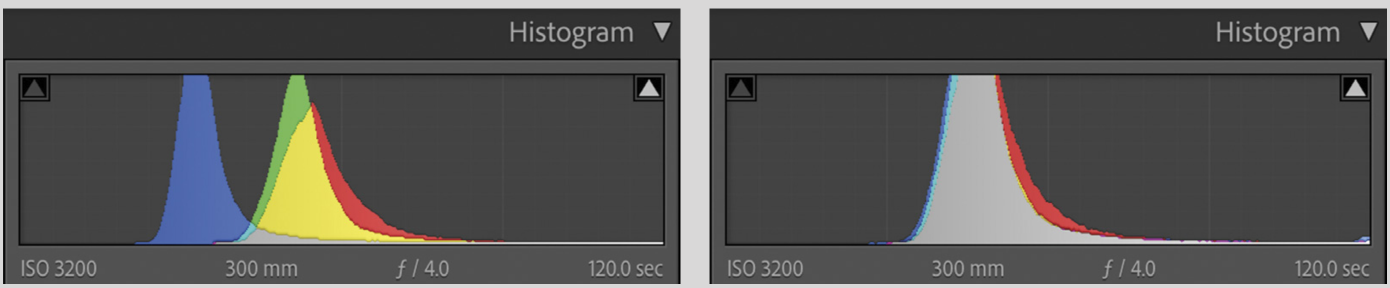
Use the ***Texture*** slider to increase the visibility of mid-level brightness features in your photo, without affecting the fine details. You may need to zoom in to 100% magnification to properly judge its effects.

The ***Clarity*** slider is one of my favorite tools for enhancing wide-field astro images. It adds midtone contrast, which helps bring out details in nebulae and galaxies without affecting the highlights or shadows in the photo. It's easy to overdo it, though, so use it sparingly — a little goes a long way.

If you're imaging from an urban area, your images will suffer from light pollution, which makes any atmospheric haze look worse. Dragging the ***Dehaze*** slider to the right can cut through the fog and help reveal more detail and color. It also helps add some punch to a moonlit nightscape.

Noise Reduction and Lens Correction

Quite often when imaging faint astronomical objects you'll have to resort to



▲ **GRAPHIC EXAMPLE** The screen at left shows the appearance of the Histogram in *Lightroom* when the image was initially imported. Note how the red, green, and blue humps in the display aren't lined up. A simple trick to neutralize the color cast of a wide-field image is to line up the three humps by adjusting the ***Temp*** and ***Tint*** sliders. And as the illustration on the facing page demonstrates, you can also use these sliders for creative purposes.

▲ **A MATTER OF (WHITE) BALANCE** This triptych illustrates the creative options available when setting the white balance for a night-sky image. The center panel is technically correct since it displays a neutral color with the ***Temp*** slider set to 4,000K. The frame on the left has the white balance set to a cooler 3,000K value, which gives a wintery appearance. The panel on the right has a white balance of 5,000K, giving it a warmer cast.

high-ISO settings. This can give images a grainy, sandpaper-like appearance. You can minimize this problem by utilizing *Lightroom*'s ***Luminance*** and ***Color*** noise-reduction sliders. Unfortunately, these adjustments can also eliminate some of the natural color variation among stars — and you may even start to lose faint stars.

Last year, Adobe introduced an AI-powered feature called ***Denoise***, which uses machine learning to differentiate between fine detail and unwanted noise in a high-ISO image. It works remarkably well on night-sky images — all with the press of a single button! The default setting seems to be effective, but if you want to manually adjust the amount of noise reduction there is a slider you can tweak. A similar, standalone product called *Topaz DeNoise AI* is also available from Topaz Labs (**topazlabs.com**).

One advantage of shooting with a standard camera lens is that you can use *Lightroom*'s built-in lens profiles to automatically correct issues like distortion, vignetting, and chromatic aberration. In the ***Optics*** subsection, simply click the ***Enable Lens Corrections*** box, then select the Make and Model of the optic you used for the photo. (If your lens isn't listed, check the Adobe Lens Profile Downloader.) The only time I don't enable the profile corrections is when I'm shooting with a fisheye lens.

Experiment and Tweak

At this point in the process, you should have an image that's dramatically different from what you started with. Since every photo is unique, you'll probably want to go back and revisit some of the adjustments you've made. The good news is that all the changes you make to RAW files are completely non-destructive and reversible. So, feel free to experiment!

After I do an initial edit of my image, I usually set it aside overnight to "let it simmer." I'll come back the next day and see if there are any revisions I want to make upon second viewing. Once I'm happy with how things look, I move on to cropping. It's the final step, and it should be done after all other post-processing is complete.

The specific aspect ratio you choose will largely be determined by how the image will be displayed. Different social media outlets have different requirements, and if your goal is to create a print you can hang on a wall, you'll make different choices. Of course, there's no reason why you can't create different versions for each application.

After cropping, export your final version in JPEG format. Before you do this, take a moment to scan around the perimeter of your image. This "border patrol" can turn up unwanted intrusions (such as a tree branch, or half a star) that poke into the frame and detract from the overall composition. Tightening your crop a bit to remove such distractions will instantly strengthen your image. Like cutting a diamond, it's often what you remove rather than what you keep that will ultimately make your photo sparkle.

Sharing and Feedback

It's worth remembering that there's no "correct" outcome when it comes to image processing — it's very subjective and depends on your particular taste. Regardless, make sure that all your editing choices are completely intentional rather than just accepting whatever comes out of your camera. Don't be afraid to experiment. If it makes for a better photo, then go for it!

Finally, to improve your editing skills, consider posting your final image on one of the many online astrophotography forums. You might get some helpful tips and suggestions. However, it's up to you to decide if the feedback you receive is worth considering or not. After all, the route you take on your creative journey is yours alone to choose.

■ **TONY PUERZER** is a retired professional photographer and an avid amateur astrophotographer. He loves discovering the details hidden in a properly exposed night-sky image.

◀ **COSMIC COMPANIONS** NGC 125, in southern Pisces, travels through space accompanied by multiple "friends." East of NGC 125 lies a grouping of galaxies centered on 12th-magnitude NGC 128. In addition, two stars south of the ringed galaxy handily point to your quarry.

ADAM BLOCK

Sampling Some Ring Galaxies

A duo teams up to observe and image a selection of interacting galaxies.

Galactic interactions can manifest in many shapes, forms, and classifications, details which Halton Arp's classic *Atlas of Peculiar Galaxies* distinctly illustrates. A subset of peculiar galaxies is the "ring galaxies." In an *S&T* article, Dave Tosteson covered four categories of ring galaxies: *polar*, *collisional*, *accretion*, and those resulting from *secular evolution* (*S&T:* May 2020, p. 57; the classifications are from a 2017 journal article authored by Burçin Mutlu-Pakdil of the University of Minnesota and her colleagues). Both amateur and professional images show the exquisite dynamism of these galactic interactions. However, for visual observers, these unique objects can be quite challenging. Nevertheless, we decided to take a whirl through a sampling of them.

Our starting point was *Observing Ring Galaxies* by renowned amateurs Alvin Huey and Jimi Lowrey (**https://is.gd/RingGalaxies**), from which we culled a selection of 51 ring galaxies brighter than magnitude 14.8 and farther north than –9° declination. We set those parameters so as to narrow our subset down to targets that we could snag visually as well as image advantageously from our observing sites in Pennsylvania.

My (Lamperti) primary telescope was a 22-inch f/4.2 Obsession Ultra Compact reflector, equipped with a Paracorr, Argo Navis, and ServoCAT. Unless otherwise noted, I used a magnification of 450×.

Of the targets I observed visually, I could only detect rings in half of them. For the most part, I observed the rings as an extended glow around the brighter core of the galaxy. Moreover, the average altitude of the object for my detections was 48.4°, and the average Sky Quality Meter reading was 20.6 magnitudes per square arcsecond.

Altitude turned out to be a decisive factor in my observations. I couldn't detect any evidence of a ring in five galaxies when they were at an average altitude of 29°. However, when I reobserved them at an altitude of around 57° (with the same telescope and magnification), I definitely noted haze around the bright core with direct vision.

Let's review a dozen of the more accessible ring galaxies visible in winter and spring skies.

Ring Galaxies for Winter Nights

Look for 13.2-magnitude **UGC 1840** near the Perseus–Andromeda border, about 3.7° east-southeast of Gamma (γ) Andromedae. To snag my quarry, I had to place the 5.8-magnitude star HD 14622 outside the field of view. This way, I could just tease out an arc of haze adjacent to a close pair of 13th-magnitude stars. I also detected the galaxy that together with UGC 1840 makes up Arp 145, one of hundreds of peculiar galaxies Halton Arp listed in his seminal 1966 catalog.

Now let's slide over to Pisces for our next four targets. Our first stop is **NGC 7428**, which is fairly bright at magnitude 12.5. You'll locate it in westernmost Pisces, about 6½° southwest of 3.7-magnitude Gamma Piscium and less than ½° northwest of 6.4-magnitude HD 217131. I could easily detect the galaxy's core at 337×, but its ring remained elusive. However, upping the magnification to 450× and using averted vision, I saw an oval glow (that I'm taking to be the ring) that was larger than the core.

Next, we'll visit **NGC 38**, a 13.3-magnitude spiral, which is in southern Pisces about ¾° north of the border with Cetus. The galaxy is a bit more than 1½° east of 4.6-magnitude 33 Piscium and ½° southeast of 5.8-magnitude HD 587. With my standard setup, I noted that NGC 38 has a brighter core with a misty patch surrounding it. This was one of the targets that — to detect the ring — I had to observe when it was at an altitude greater than 24°.

From NGC 38 slew a little less than 9½° north-northeast to arrive at 12.1-magnitude **NGC 125**. Four NGC galaxies lie east within 7′, and a close pair of 11th-magnitude stars point northward toward the galaxy. Adopting averted vision I could see haze around the fairly bright core of the galaxy, but I needed the full aperture of the 22-inch, as the ring remained elusive in my 18-inch and 20-inch telescopes.

Look for our last Pisces target, **IC 89**, some ¾° northwest of 5th-magnitude 89 Piscium. I found this 12.4-magnitude barred spiral galaxy to be a round, direct-vision glow that reminded me of a planetary nebula. Employing a magnification of 337×, I detected some mistiness surrounding a fairly bright, starlike core.

In the eastern reaches of Cetus, locate **NGC 985** a bit less than 1° due south of 5.7-magnitude 77 Ceti — this 13.4-magnitude galaxy is seemingly in the middle of nowhere! With my standard setup I noted a somewhat conspicuous core, and tapping the telescope (the jiggling motion helps makes threshold objects more readily visible) brought into view irregularity north of the core.

Into the Spring

If you think you are seeing double when searching for **UGC 4052**, you are! This 13.2-magnitude galaxy is located in Lynx and found by slewing a bit more than 1° east-southeast of the 5th-magnitude possible binary star HD 61931 (confusingly also known as 50 Camelopardalis). Once I landed at UGC 4052, I detected a 14th-magnitude galaxy immediately to the east of my target. Fuzziness enveloped both galaxies, and the duo reminded me of a double star.

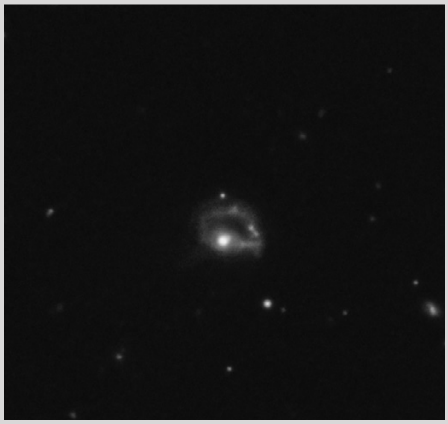
Just across the border in Leo Minor is **NGC 2859**, which you'll find 40′ east-northeast of 3rd-magnitude Alpha (α) Lyncis. With my standard setup, I found this barred lenticular to be bright, large, and easy to see at magnitude 10.9. I noted an elongated core a bit tilted from north-south as well as a glow in the east-west direction. The 7.1-magnitude star HD 80966 shines a mere 6′ to the galaxy's northwest.

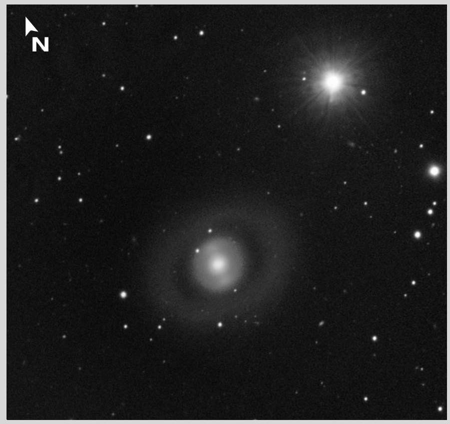
Moving on to Leo, you should find the 13.5-magnitude spiral **UGC 6614** some 3½° northwest of 2nd-magnitude Beta (β) Leonis (Denebola). Guide your way to the galaxy by slewing 6′ northeast of the 8.6-magnitude star HD 101195. By tapping my telescope, I detected a definite glow around a brighter center, but I couldn't make out a sharp demarcation between the glow and the galaxy's core.

Find Gamma Ursae Majoris and point your telescope a bit less than 1½° north-northwest to arrive at 12.4-magnitude **NGC 3921**. The spiral galaxy was obvious in my 22-inch, and I noted an oblong projection extending north from the core. The image on page 60 shows this nicely as well as 14th-magnitude NGC 3916 a mere 4′ north-northwest.

We'll complete our sampling of ring galaxies in Virgo. Locate **NGC 5534** around 1½° south-southeast of Iota (ι) Virginis. The 12.3-magnitude barred spiral shares a high-power eyepiece field with the 6.5-magnitude visual double star HD 125184. The galaxy presented a solid core, oblong in shape and oriented in the east-west direction. Careful examination revealed that the south-eastern side of my target showed a more concentrated misty patch.

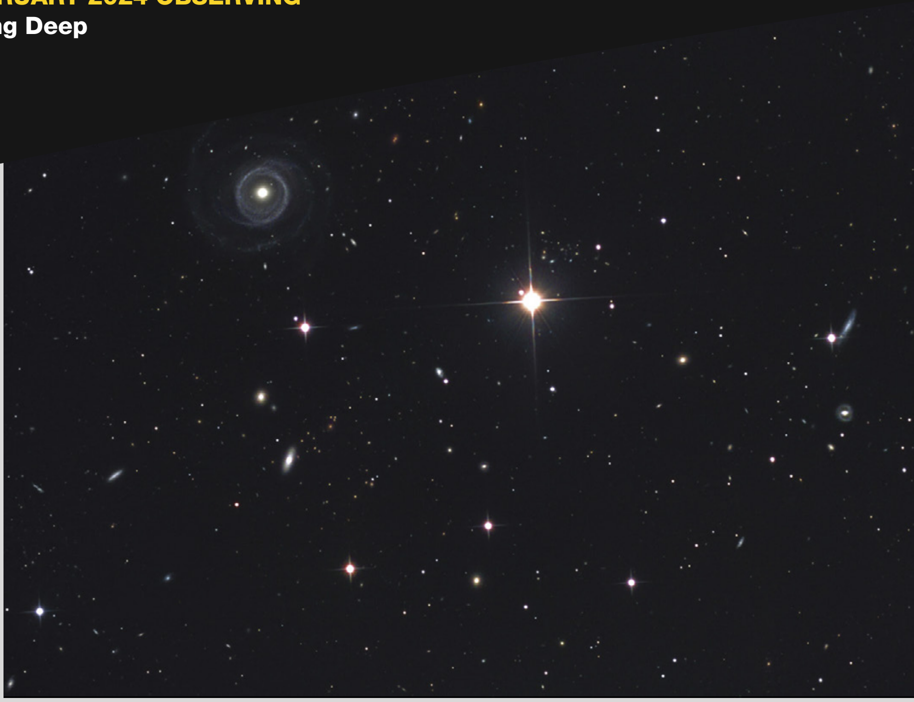
▲ **DUO OF RINGS** The barred galaxy NGC 7428 sports a lovely double ring and lies some 130 million light-years away. At that distance, it spans nearly 100,000 light-years.





▲ **PECULIAR TARGETS** *Left:* NGC 985 could be overlooked in the uncrowded reaches of eastern Cetus. It's the sole Seyfert — a type of active galaxy — in this sample and lies at a distance of more than 600 million light-years. *Right:* NGC 2859 is a fine example of a ringed galaxy — the bar is quite prominent and brightens toward the outer edges of the object. Use 7th-magnitude HD 80966 northwest of the galaxy to guide you to your target. To acquire this image, Frank Colosimo used a Starizona Hyperion 12.5-inch telescope and an Apogee U8300 camera.

GARY IMM (2); NGC 2859: FRANK COLOSIMO



◀ **ETHEREAL BEAUTY** Delicate face-on UGC 6614 by Leo's hindquarters is classified as a *giant low surface brightness* galaxy. The spiral arms extend much farther than what we can see in the image.

▲ **MERGING TANGLE** NGC 3921, in Ursa Major, is a pair of similar-size galaxies in the process of merging, following a collision some 700 million years ago. You can see the resulting tails and loops from the interaction. Colosimo's equipment was a Celestron EdgeHD 11-inch telescope with a ZWO ASI1600MM camera.

Our last ringed object is 15′ northeast of 7th-magnitude HD 127742. I detected 13th-magnitude **NGC 5674** marginally at 337× but pumping the power to 450× revealed more detail — with the increased magnification I noted a dense core with a hazy glow around it.

Final Thoughts

Detecting galaxy rings was definitely a visual challenge from the skies at the locations of our observatories. It's no surprise that I detected them best when they were favorably placed high in the sky and with the largest of my telescopes. In a similar vein to Ivan Maly's pursuit of the Hickson Catalog (*S&T:* Apr. 2023, p. 57), when we used the highest magnification I improved my chances of snagging the rings. What can you see from your location with your equipment?

■ **AL LAMPERTI** and **FRANK COLOSIMO** are members of the Delaware Valley Amateur Astronomers. The authors conducted most of their observations (Lamperti) and imaging (Colosimo) at the Blue Mountain Vista Observatory and field in New Ringgold, Pennsylvania.

A Sampling of Ring Galaxies

Object	Constellation	Surface Brightness	Mag(v)	Size	RA	Dec.
UGC 1840	Andromeda	14.1	13.2	1.7′ × 1.6′	$02^h\ 23.2^m$	+41° 22′
NGC 7428	Pisces	13.6	12.5	2.4′ × 1.3′	$22^h\ 57.3^m$	–01° 03′
NGC 38	Pisces	13.3	13.3	1.1′ × 1.1′	$00^h\ 11.8^m$	–05° 35′
NGC 125	Pisces	12.4	12.1	1.2′ × 1.2′	$00^h\ 28.8^m$	+02° 50′
IC 89	Pisces	13.5	12.4	2.0′ × 1.6′	$01^h\ 16.1^m$	+04° 18′
NGC 985	Cetus	13.1	13.4	1.0′ × 0.9′	$02^h\ 34.6^m$	–08° 47′
UGC 4052	Lynx	13.1	13.2	1.3′ × 0.8′	$07^h\ 51.3^m$	+50° 14′
NGC 2859	Leo Minor	14.0	10.9	4.6′ × 4.1′	$09^h\ 24.3^m$	+34° 31′
UGC 6614	Leo	14.1	13.5	1.6′ × 1.3′	$11^h\ 39.2^m$	+17° 09′
NGC 3921	Ursa Major	13.3	12.4	2.1′ × 1.3′	$11^h\ 51.1^m$	+55° 05′
NGC 5534	Virgo	13.1	12.3	1.7′ × 1.3′	$14^h\ 17.7^m$	–07° 25′
NGC 5674	Virgo	13.0	13.0	1.1′ × 1.0′	$14^h\ 33.9^m$	+05° 27′

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

UGC 6614: STEFAN BINNEWIES / JOSEF PÖPSEL / CAPELLA OBSERVATORY; NGC 3921: FRANK COLOSIMO

Tough Stuff

STARSTRUCK: *A Memoir of Astrophysics and Finding Light in the Dark*

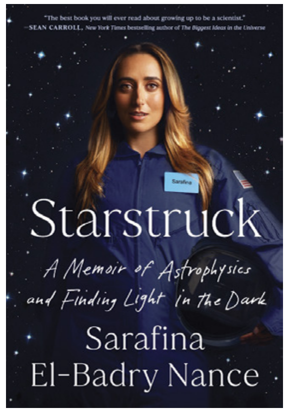
Sarafina El-Badry Nance
Dutton, 2023
325 pages, ISBN 978-0-593-18679-4
US$29.00, hardcover

DELVING INTO *Starstruck: A Memoir of Astrophysics and Finding Light in the Dark* is a bit like gazing at a stellar nursery. We can admire the Orion Nebula for what it is and yet know that the tendrils of gas we're observing will eventually give way to swirling masses as gravity pulls the material together. Atom by atom, a shimmering star will emerge from the maelstrom. It will be a long process, but because we understand astrophysics, we know what's coming, and we know it will be beautiful.

So it is with this tender and complicated story of an astrophysicist coming of age. Sarafina El-Badry Nance, a PhD candidate at the University of California, Berkeley, has penned a memoir of a young scientist-in-training challenged by struggles both internal and external.

El-Badry Nance's journey is by turns inspiring and harrowing. We root for her as she anchors her life in the sciences while the world around her offers both encouragement and hostility, sometimes with breathtaking whiplash. A gentle elementary-school teacher shows her how to observe the differences in trees, even as she has to lose herself in Harry Potter books to keep from focusing on her parents' loud arguments at night. A high-school teacher nurtures her budding love of the universe, while her family struggles so mightily with finances that at one point she's left to fend for herself while her parents pursue jobs in other cities.

As the world disappoints and even betrays her, El-Badry Nance stays on her feet. She pursues astrophysics as a profession even when the equations are endless and the concepts mentally exhausting. She keeps looking up at the sky. And we, her readers, cheer for her. We want this story to turn out well. We want to see the nebula transform into a star.



The book's cover places El-Badry Nance literally among the stars. You open the book expecting triumph after triumph, but this story goes to some dark places. I don't want to give too much away here. The narrative deserves an audience that stays with El-Badry Nance as she lurches from gazing at the heavens to navigating a world of troubles, to finding her way back again and again, the stars lighting the path that guides her.

The depths of the challenges this young investigator experiences as she matures make us cheer her on — and yet the reading can be infuriating, because the adults around her are often too mired in their own problems to safeguard her. The parent in me wants to protect her. The reader in me wants her to win every battle.

> At its core, *Starstruck* is a memoir of how scientific inquiry parallels life.

Still, El-Badry Nance perseveres, and the portrait that emerges is one of resilience. I want to recommend this book to your teenage, astronomy-loving kids, but with a caveat: Prepare for some tough conversations with them about experiencing racism, growing up with unhappy parents, leaving abusive romantic relationships, identifying and fighting back against sexual harassment in the workplace, and making life-changing decisions in the face of devastating medical diagnoses. Our greatest instinct as parents is to shield our children from the world's disappointments and disasters, but by giving them examples of resilience, we can help them light their own path. This book does just that.

At its core, *Starstruck* is a memoir of how scientific inquiry parallels life. El-Badry Nance finds meaning in the formation of black holes, the explosions of supernovae, and the reality of recognizing how tiny we all are in the vast universe. It is a story of hope bolstered by the promise of scientific exploration, for in the end it will be cutting-edge science that provides her with a lifeline.

When she discovers she carries a genetic mutation that all but guarantees a cancer diagnosis, she moves ahead with a medical intervention that no young person should ever have to decide upon. But here is the future El-Badry Nance becoming one of the adults that should have protected her as a child, embracing her scientific abilities, trusting the data, and moving forward into a life filled with promise. The author is at her best in these pages when she faces this most traumatic of moments. The star emerges. Science delivers its promise. This is a big and challenging book, and one worthy of your time.

■ **NICOLE NAZZARO** is a writer based in Edmonds, Washington.

EXPANDING the Field

Try this technique when photographing targets that don't fit in your telescope's field of view.

There is no "one size fits all" telescope, particularly when it comes to deep-sky astrophotography. Imagers typically build their photographic system with a certain type of target in mind: Some want to take high-resolution pictures of galaxies, star clusters, or planetary nebulae, while others prefer a wide-field system to record expansive swaths of nebulosity and star fields in the Milky Way. But it's almost inevitable that a seasoned astrophotographer will turn their attention to objects that are too large to fit in the field of their telescope. They could switch to a different telescope for such targets, but that isn't an option for everyone. Deep-sky imaging can be a fairly expensive hobby, and the cost of an additional telescope may not immediately be in the cards.

But there's another option for framing larger fields without having to raid the piggy bank, and it costs you nothing more than time. The key is to capture multiple, overlapping images to record the full extent of the chosen object. The result is technically known as a "panoramic image mosaic," though astrophotographers simply refer to it as a "mosaic."

Unlike a traditional mosaic, in which an image is made up of tiny pieces of glass, stone, or colored paper to form a single picture, astronomical mosaics more closely resemble *panoramas*. One important difference, though, is that an astronomical mosaic benefits from the typically higher resolution of a single-scope-and-camera combination yet produces a much wider view.

It takes some planning to produce an astro-image using

▲ **STITCHING PIECES** Assembling panoramic image mosaics is an affordable way to increase the field of view in your astrophotography setup that only costs you time. Ron Brecher describes how to create seamless mosaics using the equipment you already own. This two-panel mosaic of M45, the Pleiades, was taken with an ASA 10-inch f/3.6 Newtonian astrograph and Moravian G3-16200 CCD camera.

the mosaic approach, both in terms of acquisition and post-processing strategies. Here are some of the most important things to consider when executing one yourself.

It's All in the Planning

Mosaicking star fields is fairly straightforward: Consider the size of your target, then determine how many fields your particular scope and camera combination requires to cover it. But you can't simply shoot adjacent fields and assume they will snap together like pieces of a puzzle. Instead, you need to precisely aim for the fields to overlap enough that you'll have identifiable alignment stars common to each of the overlapping segments in order to accurately and seamlessly stitch them together.

While you can plan and execute an image mosaic manually, you'll have better luck if you use control software to point your telescope to record the necessary frames. Most imaging-control software includes mosaic scripting. Some popular examples are *Sequence Generator Pro* (**sequencegeneratorpro.com**), *TheSkyX Imaging Edition* (**bisque.com**), and *Voyager* (**software.starkeeper.it**). I find that the free software *N.I.N.A.*, short for Nighttime Imaging 'N' Astronomy (**nighttime-imaging.eu**), works very well for automating all my image-acquisition tasks, including capturing mosaics (*S&T:* Sept. 2023, p. 28).

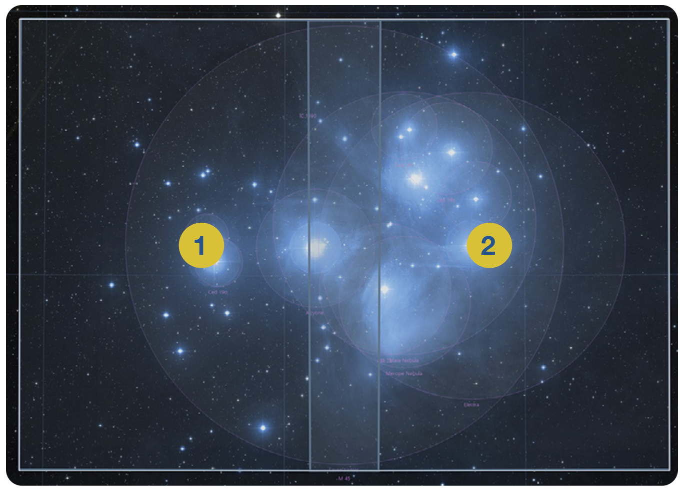
Let's consider a two-panel image for your first mosaic project. Once you've learned the ropes, you can increase the size of the mosaic almost without limit.

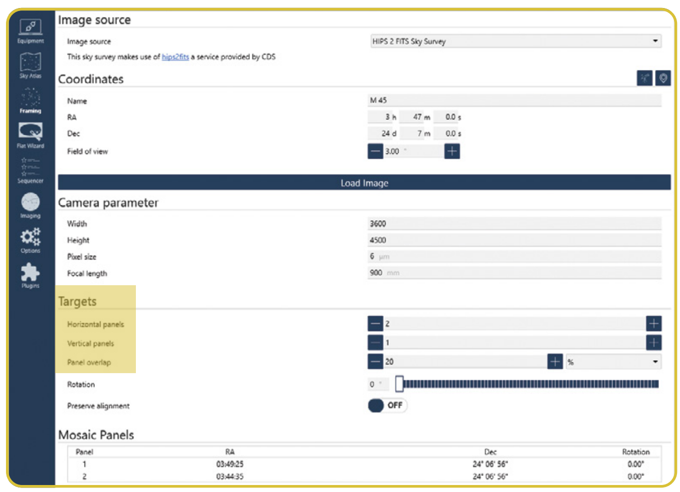
Perhaps the most important consideration when planning a mosaic is determining how much overlap between panels is sufficient to produce a seamless result. You need to consider having enough stars in the overlapping area to use as alignment points, as well as adequate space to ensure gradients or other inconsistencies between the overlapping frames won't create a visible seam in the final product. A 20% overlap should be adequate for most purposes, though you may need to increase this if your telescope produces noticeable field distortions, as is common particularly in wide-field instruments.

The ***Framing Assistant*** in *N.I.N.A.* makes mosaic planning easy. For it to work correctly, you'll need to input information about the imaging system's focal length and sensor size. Start by searching for your target in the ***Sky Atlas*** located in the main menu along the left side of the screen. Then click on ***Send to Framing Assistant*** in the top right of the window. In a few moments, the Framing Assistant opens with an image of your target taken from one of the all-sky surveys that the software utilizes for this purpose. Verify that the information about your camera and telescope focal length is correct. Next, increase the number of vertical or horizontal panels you'd like to shoot using the ***Horizontal panels*** and ***Vertical panels*** sliders until the simulated frames cover the entire target. You can adjust the ***Panel overlap*** setting if needed, though I find the default 20% works well with my equipment. When you're satisfied with the framing and panel overlap, click ***Add target to sequence*** and choose the options ***Add target to sequence > Sequencer > Deep Sky Object Instruction Set***.

The program then opens the ***Advanced Sequence*** tab. Here you'll need to decide whether to shoot data for both panels each night or concentrate on one field at a time. There are good arguments for both approaches, but I find I get more consistent results by recording data for both panels each night until they are all complete. This ensures that the exposures across the two fields are subject to the same transparency and seeing conditions, making them slightly easier to assemble.

A related question for monochrome-camera users making color composites is whether to shoot through all the necessary filters during each session, or just one or two per night. I recommend the latter so I can tailor the filter choice to the observing conditions. For example, I tend to image with color filters on the best nights, using the luminance filter in particular on the very best nights. Narrowband images are a bit more forgiving of seeing and sky brightness and so are desirable on most nights, including when the Moon is up.

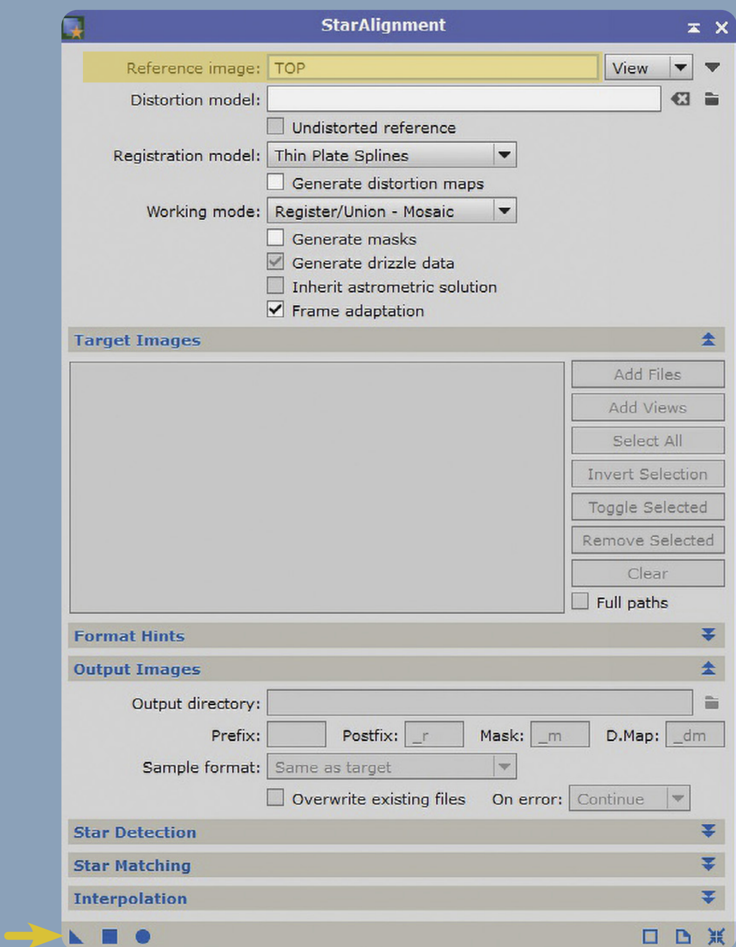


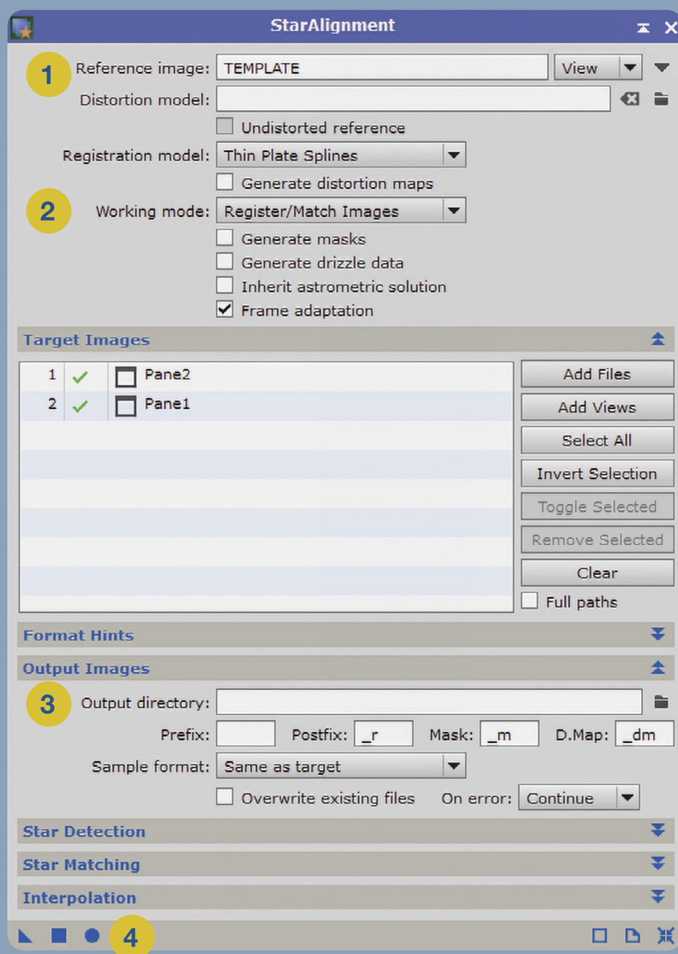


▲ **A GOOD PLAN** The ***Framing Assistant*** in *N.I.N.A.* makes it easy to plan your mosaic. After entering the specifics about your camera and telescope, set the number of horizontal and vertical panels in the Targets section. Then simply drag and rotate the field-of-view simulation to compose your shot.

▼**ALIGNMENT STEP 1** *Bottom left:* The ***StarAlignment*** process in *PixInsight* requires two passes in order to register one panel to the other. The first step is to make a template by selecting one of the panels as the reference image and then dragging the New Instance triangle (arrowed) onto the other panel. In a moment, the program generates a composite of the two panels stitched together though not perfectly blended together (right). This template is used in the next step.

▼**STEP 2** *Bottom right:* Next, select your template image as the Reference image (1) and change the Working mode to Register/Match Images (2). Choose a directory where the registered images will be saved (3) and then run the process by clicking the blue circle at bottom left of the screen (4).





Once you've made these choices and input the exposures and sessions for each panel, save the sequence and start it on the next clear night.

Some Assembly Required

Once you've captured all the data for each panel, there are four main processing stages necessary for assembling the mosaic: Cleanup, registration, mosaic assembly, and processing. While there are several image-processing programs that have good mosaicking routines, I prefer the tools available in *PixInsight* (**pixinsight.com**). Begin by calibrating and combining your individual exposures to make master frames for each filter, treating each of the two panels as individual images.

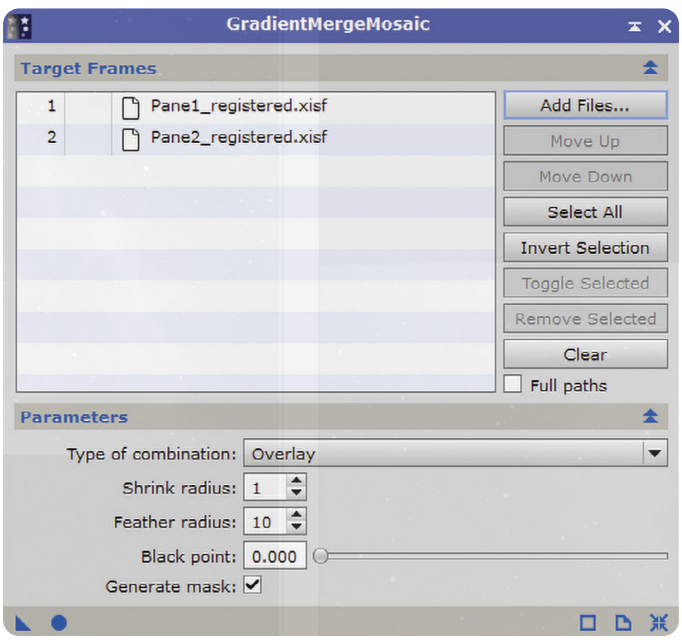
To make a seamless mosaic, it's important that the brightness and contrast be consistent between panels. If you're imaging in color, then the hue between the overlapping areas becomes extremely important. To achieve a good match, crop all the panels to eliminate any black edges that come from dithering fields while retaining as much of the field as possible. Next, you'll need to address gradients in the images using the ***DynamicBackgroundExtraction*** process found in the pulldown menu ***Process*** > ***BackgroundModelization*** > ***DynamicBackgroundExtraction***. You can find tips for using this and other general *PixInsight* tools mentioned here in *S&T:* June 2023, p. 60.

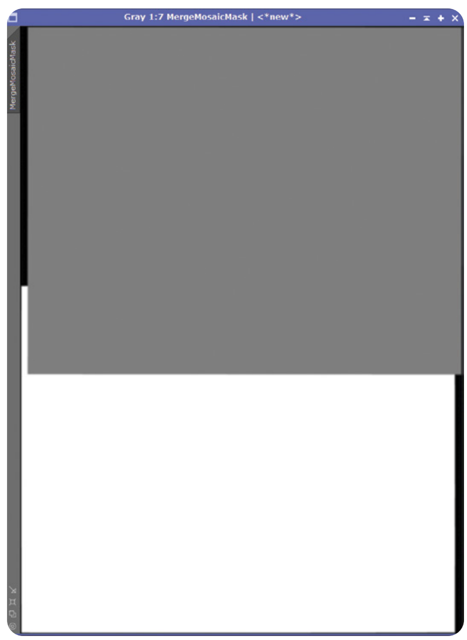
If you're assembling a color mosaic imaged through individual color filters, you should decide at this point whether to combine color channels before or after stitching the panels together. Each approach has its pros and cons. Working up each color- or narrowband-filtered image separately provides the most control but is also the most time-consuming. In practice, good results can be achieved either way, so experiment to see which approach you prefer.

If you choose to work on color data, start by balancing the color of each panel as you would for any deep-sky photo. I usually use ***Process*** > ***ColorCalibration*** > ***SpectrophotometricColorCalibration*** for images taken with my color camera or through RGB filters with a monochrome camera. When assembling pictures made from individual narrowband filters, I prefer to use ***Process*** > ***ColorCalibration*** > ***BackgroundNeutralization***.

After you've addressed gradients and color-balanced the two panels so that they appear similar, open both panels and use the ***StarAlignment*** tool (***Process*** > ***ImageRegistration*** > ***StarAlignment***) to align the fields in two steps. The first step involves making a template from the two panels, while the second aligns each panel to that template. Start by assigning one of the panels as the reference image at the top of the window by clicking the arrow to the far right of the line and navigate to one of your two panels (it shouldn't matter which one you choose). Now change the ***Registration model*** to Thin Plate Splines. Select Register/Union – Mosaic in the ***Working mode*** line and check the Frame Adaptation box.

The next step is to drag the New Instance triangle (located at the very bottom left) onto the other panel. In a few moments the process generates a larger image from the two panels. Change the name of this resulting *View* (what *PixInsight* calls an open image) to *template*. With the StarAlignment process still open, change the Reference image to your template view and switch the Working mode to Register/Match Images. In the ***Target Images*** section, click the Add Views button on the right and select your two open panels. If you're working on each monochrome color-filtered image separately, simply add all the individual master views or saved master files here. A final detail is to choose the directory where you'll save the registered panels in the ***Output***





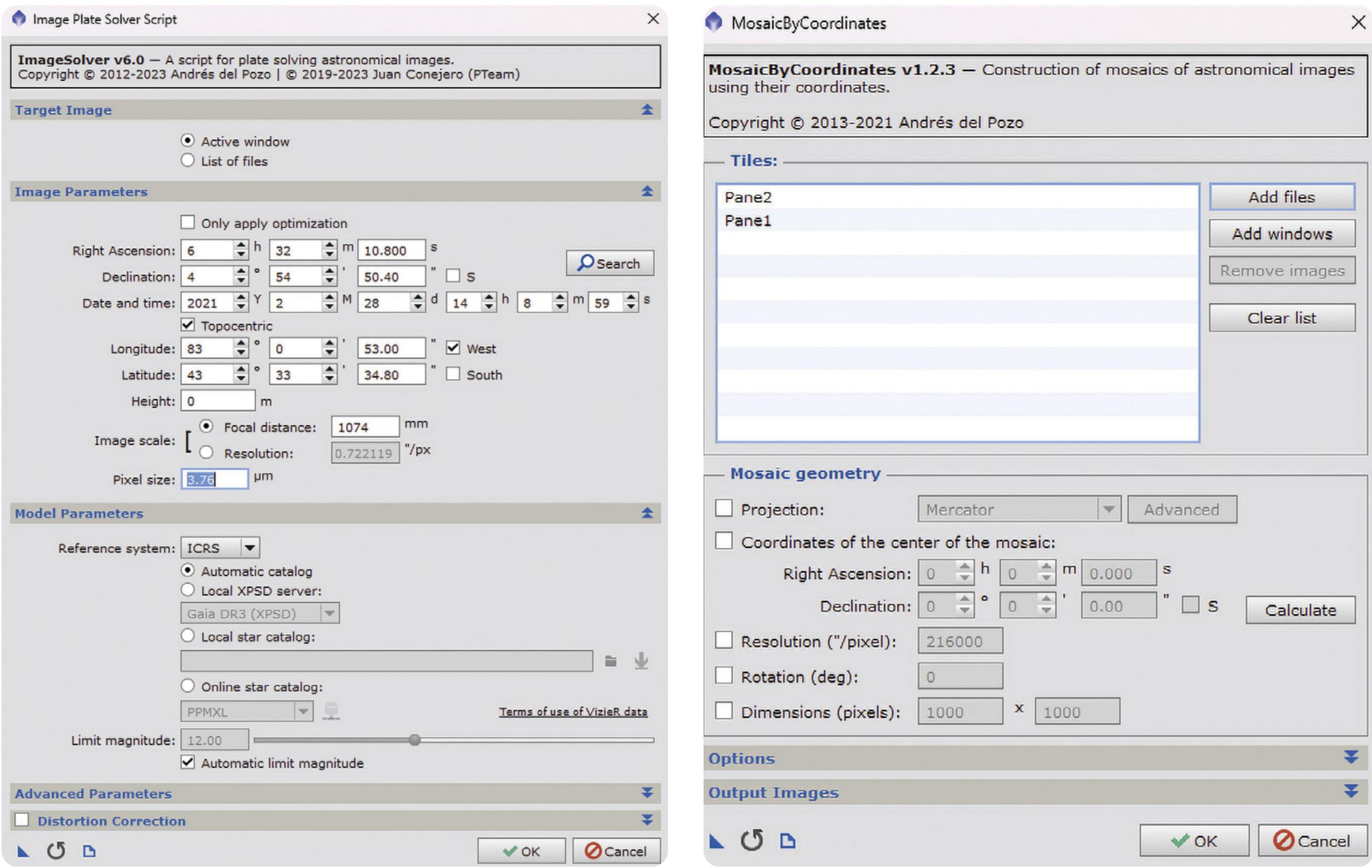
▶ PUTTING IT ALL TOGETHER Use the ***GradientMergeMosaic*** process (left) to assemble and blend the registered sections of your mosaic. The process also generates a mask image (right) you'll use to examine the seams to identify any areas that still require cleanup before assembly.

Images section. Now you're ready to run the tool by clicking the circular Apply Global button at bottom left of the process window. The process creates and saves the two registered files that are ready to assemble to the assigned directory.

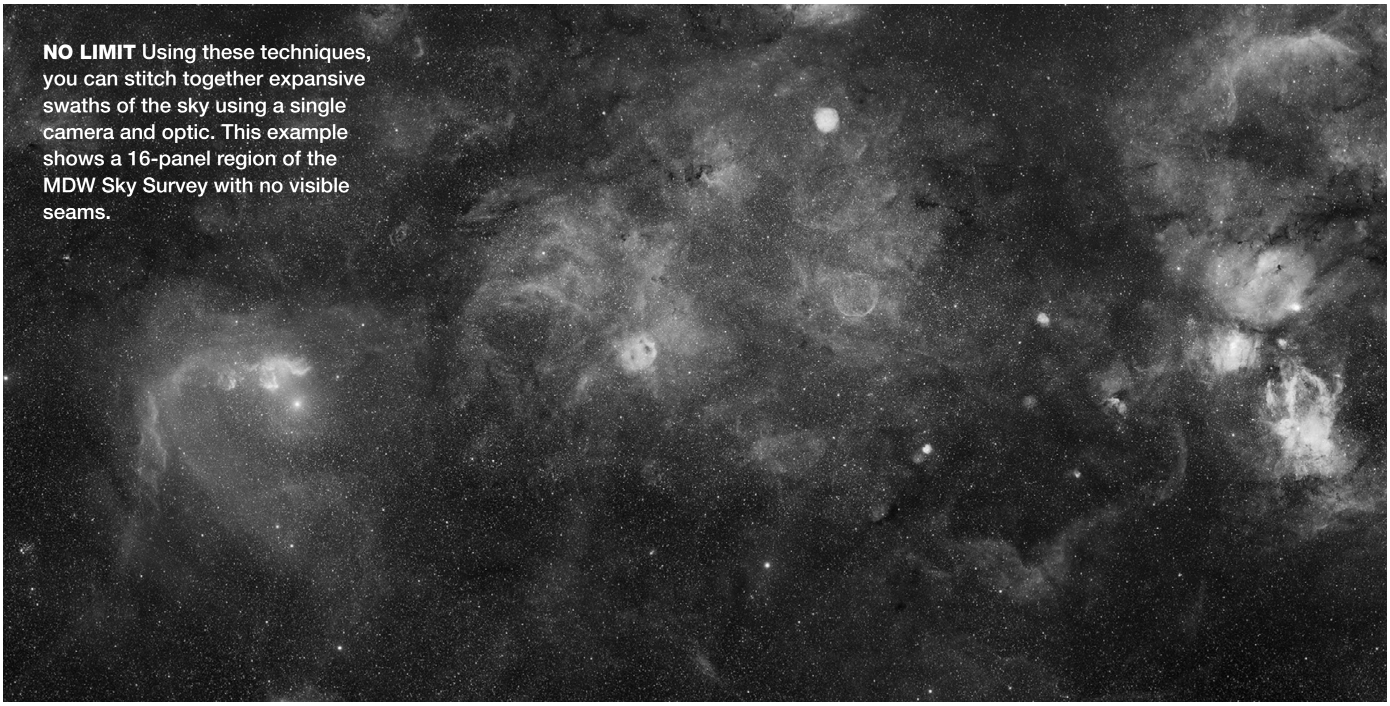
Open the registered panels and give them a screen stretch so you can properly see the data using ***Image > STF Autostretch***. You'll note the large black areas where no data are present on each panel — much of it corresponding to the area that will be filled in with the other panel. Now it's time to blend the two frames into a single, seamless image using the GradientMergeMosaic (GMM) process (***Processes > GradientDomain > GradientMergeMosaic***). Click Add Files to import the two images registered to the template. Change the ***Type of combination*** to Overlay and then check the Generate Mask box. Finally, click the Apply Global button to generate the final mosaic. Ideally, it will be difficult or impossible to see any seams.

You can use the mask generated by the GMM process to closely inspect the mosaic. It works by dragging the mosaic image title bar so it's directly over the mask with both displayed at the same zoom level. Now click and hold on the mosaic image's title bar, and the image becomes translucent so you can see the mask underneath. This helps you find and inspect overlapping locations. If you still see some visible seams, try increasing the ***Feather Radius*** value in GMM and reapply the tool until the problem areas disappear. If star artifacts (often appearing as black areas around stars along the seam) are visible, try increasing the ***Shrink Radius*** value until they disappear. Another option is to change the order in which panels are combined by selecting one of the images in the GMM process window and clicking the Move Up or Move Down buttons to the right. If neither option is satisfactory, try changing the GMM ***Type of combination*** setting to Average and see if you get a better result. If seams or other problems persist, go back to the clean-up stage and ensure that gradients are eliminated and that color is consistent between the two panels — just a slight difference in hue can be obvious after mosaicking. You can correct smooth gradients that don't show seams with another pass of the ***DynamicBackgroundExtraction*** process.

Repeat the GMM process as necessary until all your panels are aligned. The precise number depends on whether you are aligning two color images or individual monochrome images that will then be combined into a final color com-



▲ **PLATE-SOLVING REGISTRATION** Two scripts within *PixInsight* can make short work of registering multi-panel mosaics. *Left:* The ***ImageSolver*** script examines your panels, identifies their exact celestial coordinates, and saves this information to the images. The full-size registered panels, containing black regions, are then created using the ***MosaicByCoordinates*** script (right). The ***GradientMergeMosaic*** process is then used to produce the final assembled image in the same way as for a two-panel mosaic.



NO LIMIT Using these techniques, you can stitch together expansive swaths of the sky using a single camera and optic. This example shows a 16-panel region of the MDW Sky Survey with no visible seams.

posite. Once assembled, the mosaic is processed just like a single-panel image.

What if you have more than two panels? You can repeat the ***StarAlignment*** process as many times as necessary to make the template, but it requires several templates and quite a bit of additional work.

Fortunately, there is an alternative for larger mosaics. Run the ***ImageSolver*** script (***Scripts > Image Analysis > ImageSolver***) on each of the cleaned-up panels. This script updates the FITS headers with precise celestial coordinates to use in the next step — a process known as *plate solving*. You can apply this script to a single open image or to multiple files on disk. Once you've plate-solved all the panels, activate the ***MosaicByCoordinates*** script (***Script > Mosaic > MosaicByCoordinates***) to generate four ready-to-combine panels for the final mosaic. Again, these files are all larger than any single panel, have the same geometry, and contain some black regions.

Room for Expansion

Many astro-imagers have one imaging system, and its focal length and sensor size together determine the field of view and therefore the optimal target size for deep-sky objects. Rather than investing in a smaller, shorter focal-length telescope or a bigger sensor, mosaicking can open up a lot of new imaging opportunities you may not have considered before. You'll expand your target list while still retaining the resolution and fine detail that your bigger scope provides.

■ Contributing Editor **RON BRECHER** hosts *PixInsight* image-processing workshops at **mastersofpixinsight.com**, often while *N.I.N.A.* runs his observatory.

▲ **HYBRID MOSAIC** The ***StarAlignment*** process is also useful when combining images with differing plate scales. This image of the Rosette Nebula uses a single, wide-angle color image and a two-part Hα mosaic shot at more than twice the focal length. They were combined after first creating a high-resolution mosaic of the Hα data and then registering the color image to the stitched result.

WIDE-FIELD MOSAIC: MDW SKY SURVEY / SEAN WALKER

The Astro-Tech AT115EDT Refractor

This 4½-inch apochromat provides high-quality views at an affordable price.

◀ The Astro-Tech AT115EDT scope comes with two mounting rings and a 20-cm (8-inch) Vixen-style mounting bar. A medium-capacity equatorial mount, such as the author's Losmandy G11 mount (shown here), is ideal for the scope's focal length and 5.9-kg (13-lb) weight.

Astro-Tech AT115EDT 4.53″ f/7 ED triplet apochromatic refractor

U.S. Price: $1,399
Astronomics.com

What We Like

Solid build quality

Sharp views

What We Don't Like

Compression ring may tip certain star diagonals

Case lacks space for additional accessories

IF YOU'VE EVER USED a fine refractor, you know about the breed's sharp, well-corrected star images, excellent contrast, and freedom from the collimation adjustments that other optical designs often require. You also know how deep your pockets have to be in order to purchase one.

Entering "refractor" into the search field on the Astronomics website (**astronomics.com**) returns 87 hits from several manufacturers. That's way more than any other type of telescope offered by the longtime, family-owned business in Norman, Oklahoma, which owns and operates Astro-Tech as their in-house product line of telescopes.

Among those 87 refractors, there are just five whose purchase prices made me do a double-take. All five Astro-Tech EDT series refractors (ranging in aperture from 60 mm to 152 mm (2 to 6 inches) seem out of whack because they're unusually affordable compared to similar instruments from other manufacturers. The Astro-Tech AT115EDT is one of those surprisingly affordable instruments. This 4.53-inch, f/7 triplet apochromatic refractor is priced at $1,399, very similar to several much smaller apos.

Given that difference, we arranged to borrow one to see how well one of these budget apochromats performed under the stars.

Fit and Finish

The AT115EDT has an attractive, flat-white finish with a high-gloss, silver-gray trim. Its focuser is painted with the same trim finish and has a black drawtube with a graduated scale that's helpful for noting the focus position for different eyepieces or cameras. The tube measures 68 centimeters long with its dew shield and focuser fully retracted — not quite airline carry-on-compatible, though still very portable.

The objective has an extra-low-dispersion (ED) element sandwiched between two other elements to reduce color fringing on bright targets to vanishingly low levels. The manufacturer says each optical surface is "slow-polished," claiming extremely smooth surfaces that scatter less light than with other machine-polishing techniques. Astro-Tech also notes every air-to-glass surface is coated with state-of-the-art antireflection multicoatings. These seemed to work quite well — it was hard

▲ The AT115EDT's triplet f/7 objective is hard to see when viewed straight on — a testament to the effectiveness of its antireflection coatings.

for me to see reflections when looking directly at the objective lens. The lens cell is nonadjustable, though I didn't see any need to tweak its collimation.

The dew shield has no locking screw to secure its position, but it takes a rather strong pull to extend it, and it remains firmly in place in all positions. An aluminum lens cap protects the objective when not in use.

The telescope includes a pair of 114-mm hinged tube rings with large, knurled knobs and attached to a 20-cm-long, Vixen-style dovetail mounting bar. The rings are lined with white felt, and each has three M6-threaded holes on its flat top surfaces, allowing users to add a second dovetail bar for additional accessories such as a guidescope or a ride-along imaging computer.

The scope comes in a lockable, hard-sided case with form-fitting high-density foam inside. The case accommodates the tube assembly very well, though there isn't much additional space for accessories.

Weighing in at 5.9 kilograms (13 pounds) including rings and dovetail bar, the AT115EDT is predictably heftier than the smaller 4-inch apo I've owned for several years. A medium-capacity mount should be the rule for this scope. It worked well on my Losmandy G11 mount as well as on an iOptron HAE29EC strain-wave mount. It was a bit undermounted on my iOptron CEM25P mount but was okay for visual use. Like many triplet refractors, the objective contributes much of the telescope's weight, making the tube slightly front-heavy. I found its balance point to be about 25 cm from the front of the objective cell.

While a finder isn't included with the AT115EDT, a universal mounting base comes affixed to the scope's focuser. The focuser can be rotated 360° to orient a diagonal or camera to any desired position and is locked in place with a single thumbscrew. Likewise, no star diagonal is included.

While many budget refractors

▶ This Astro-Tech optional dedicated 0.8× Photo Reducer/Flattener screws onto the 63-mm male threads on the focuser drawtube.

come with a barely adequate focuser that owners often replace with a better model, the AT115EDT's stock focuser is particularly good for both visual observing and imaging needs. The 2.5-inch, dual-speed unit's drawtube has 90 mm of travel driven by a helical rack-and-pinion gear. Two hex-head screws allow adjusting the tension, though it didn't require any finessing on my part. It easily supported my 2 kg of imaging gear consisting of a ZWO ASI2600M camera, a filter wheel, the scope's dedicated focal reducer, and an off-axis guider, even when the scope was aimed near the zenith. A threaded, 2-inch adapter is also provided with three locking thumbscrews set 120° apart pressing on an internal compression ring.

With the focuser of the AT115EDT racked all the way in, the focal plane lies 24 cm beyond the flange of the 2-inch adapter, leaving plenty of space for accessories such as an off-axis guider, filter wheels, field flatteners, and focal reducers.

▲ The focuser has a 2.5-inch-aperture drawtube with 90 mm of travel and a printed scale on the outside. Its dual-speed focuser includes two course-adjustment knobs and one gold anodized, 10× reduction fine-focus knob. A 2-inch adapter threads into the end of the drawtube with 63-mm threads. Although a finder isn't included, the scope has a mounting base that accepts universal finder brackets. The entire focuser is rotated by loosening the silver thumbscrew and turning the unit.

▲ Helical rack-and-pinion gears drive the focus movement and could support all the author's heavy imaging gear even when aimed toward the zenith. The 2-inch adapter uses a compression ring to ensure a solid purchase on accessories, though it may inadvertently tip some in the optical path (see the accompanying text for details). Threaded holes on the underside of the focuser allowed for easy installation of a ZWO EAF focus motor bracket.

◀ The Astro-Tech AT115EDT tube assembly is well protected, nestled in a cradle of high-density foam inside its included case. Unfortunately, there is little room for additional accessories.

Visual Impressions

As soon as I turned the scope to the sky, there was never any doubt I was looking through a fine refractor. Stars snapped tightly into focus, and I had no problems getting any of my eyepieces to reach focus, with plenty of travel to spare when using my own 2-inch diagonals. A look at Saturn on the meridian showed the Cassini Division well on both ansae of the increasingly edge-on rings, while several bands were easily visible on the planet's butterscotch globe.

Color correction in this relatively inexpensive refractor was the visual test I most eagerly anticipated. I slewed over to the Moon and carefully examined the bright lunar limb with a 12-mm Tele Vue Nagler eyepiece. I didn't detect any hint of color fringing when my target area was centered in the field but saw a very slight green fringe when I moved the lunar limb to the top of the field. Moving the limb to the bottom of the field produced an equally slight purple fringe. This puzzling effect also was present with other eyepieces as well as with different star diagonals and when adding a 2× Tele Vue Powermate. A closer examination of the connection between the accessories revealed the culprit. The 2-inch adapter's compression ring is set at a depth that just catches the edge of the undercut on the 2-inch barrels of my diagonals, cocking them at a slight angle in the focuser when locked down. Pulling the diagonal out slightly before tightening the compression ring eliminated this odd fringing. It's something owners should be aware of with these undercut barrels often found on diagonals and eyepieces.

After that, objects were always crisp and tight, with no hint of false color. Star tints were particularly pleasing. The famed Cygnus double star Albireo showed dramatic color contrast, with its vivid blue and yellow components both surrounded by distinct diffraction rings. When checking out Epsilon Lyrae, the Double Double, both pairs were an easy split with the scope using a 10.5-mm Plössl eyepiece paired with the 2× Powermate.

Photographic Performance

I found the Astro-Tech AT115EDT also makes a very nice astrograph. By itself, the scope's f/7 focal ratio and 805-mm focal length are well suited for photographing a wide range of deep-sky objects, including large nebulae, star clusters, bright comets, and some of the larger galaxies in the local group. The scope includes internal knife-edge baffles to prevent bright objects just outside the field of view from scattering light.

I used the AT115EDT to shoot several deep-sky objects as well as the Sun and Moon. All of the deep-sky images showed good star images across the field when the appropriate flatteners were used. Focusing the images was quite easy manually thanks to the fine-focus adjustment knob. It was even more convenient after attaching a ZWO EAF focus motor, which didn't require any modification to mount it on the scope.

Like most short-focus refractors, the AT115EDT needs some help to produce round stars across a full-frame detector. Using my Nikon D850 DSLR camera without a field flattener shows good stellar images across about ⅔ of the 24 × 36-mm sensor, with stars radially elongated beyond that point, and increasing distortion towards the corners of the frame.

Imaging results were much better but still showed slightly elongated stars in the corners when using a ZWO ASI2600MC Pro camera with its APS-C-size sensor. The 2.5-inch focuser helps make vignetting practically non-

▲ Using the optional 0.8× flattener/reducer on the AT115EDT produces some vignetting and mirror-box shadowing when used with the author's Nikon D850 full-frame DSLR camera. Stars are corrected nearly to the corners of the frame.

▲ Both M8 and M20 in Sagittarius fit comfortably within the field produced by using the AT115EDT with its optional 0.8× reducer/flattener and a ZWO ASI2600MC Pro color camera.

▲ The last-quarter Moon showed no color fringing when imaged using the AT115EDT and a 2× Tele Vue Powermate with an ASI294MC-Pro camera.

existent on smaller detectors such as this. Even better was the performance with my ZWO ASI294MC Pro camera. Images with this camera yielded round star images in the corners across the 23.3-mm diagonal of the chip even without a flattener.

Astro-imagers looking for a bit more photographic speed should consider purchasing Astronomics' optional 0.8× Photo Reducer/Flattener ($199.95), designed specifically for use with the AT115EDT. (I tested it as well for this review.) It screws on to the focuser drawtube, replacing the thread-on 2.5-to-2-inch adapter. The reducer shortens the focal length of the instrument to 644 mm with a focal ratio of f/5.6. The reducer adds some vignetting but corrects star images completely across APS detectors.

Using my Nikon D850 with the reducer/flattener, only the very corners of the field still showed slight elongation. For best correction across your camera's detector, the reducer requires a distance of 55 mm from its 48-mm male threads to the imaging chip.

The Bottom Line

After a few months observing and imaging with the Astro-Tech AT115EDT, I can confidently say it's an excellent performer for its price. You'll need to supply your own star diagonal and a finder, but these are minor considerations, and chances are you'll probably have these on hand already. The AT115EDT offers generous aperture, excellent mechanics, and color-free views. For the money, it's a combination that's tough to beat.

■ Contributing Editor **JOHNNY HORNE** has been reviewing equipment for *Sky & Telescope* for 36 years.

A Sturdy Scope Dolly

Third time's a charm.

I'VE WRITTEN ABOUT wheeled telescope carriers before (most recently in the August 2023 issue, p. 74). You'd think there's not much more to say on the subject, but you'd be missing at least one more cool build from Illinois amateur Peter Ponzio.

Peter has an astrophotography setup centered around an 80-mm refractor on an equatorial mount. Anyone who's set up and torn down an astro-imaging rig more than a few times begins to dream about how to move the scope and all the ancillary equipment around without having to disconnect everything and carry it all back and forth and reconnect it again, often in the dark. A dolly of some sort is the ideal solution, but some dollies are more perfect than others.

Peter had already purchased a commercial one for his 8-inch SCT, but even with its 10″ wheels, that dolly didn't have enough clearance to move the scope into his backyard. (The dolly was purposefully built as a low-rider to keep the center of gravity close to the ground, but it shared the same problem as a low-rider car: It high-centered easily.) So Peter decided to build a dolly that would hopefully overcome the deficiencies of the commercial one.

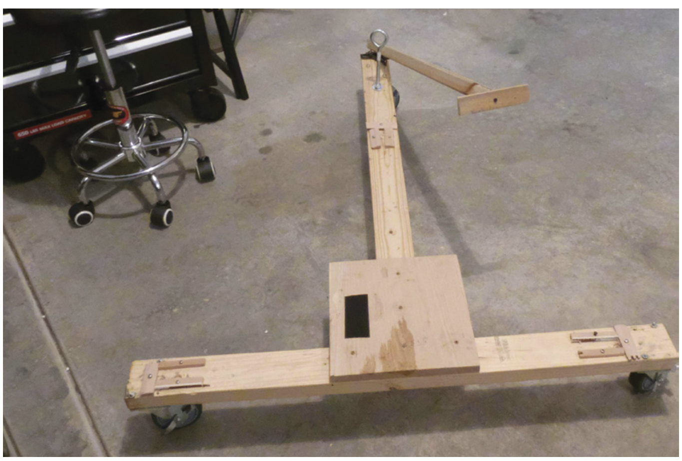
▶ *Right:* Third time's a charm. Peter can roll out his scope, mount, and all his astrophotography gear into the backyard and be ready for observing within minutes. *Far right:* The final iteration has four wheels in back for stability and an equipment rack at a convenient height.

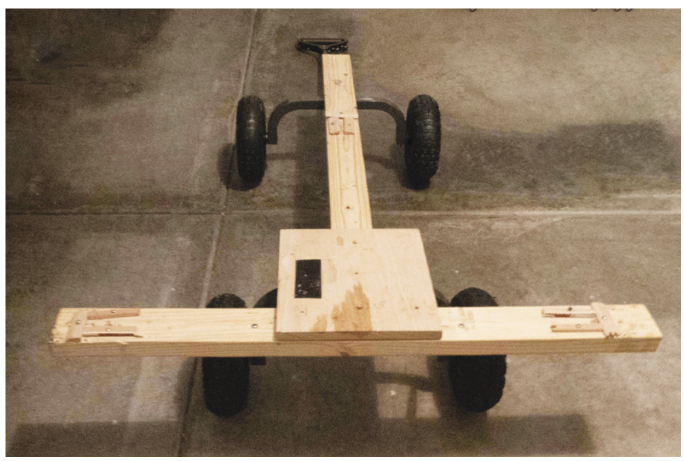
He used the basic template of the commercial unit, which utilized a "T" framework with the equatorial mount's tripod legs reaching out to the three extremities of the "T." But Peter added 5-inch, hard rubber wheels and put them beneath the frame rather than alongside it in order to give the framework the needed clearance to roll the entire scope and mount over obstacles and across the grass to his observing location in his backyard. The frame itself was composed of 2″-by-4″ pine lumber, with a single wheel in front and two wheels in back.

The extra height helped, but the frame wasn't as sturdy as Peter wanted, especially for astrophotography. Also, the dolly still wasn't as maneuverable over grass as he'd have liked. The 5″ wheels were too small for a lawn. So Peter went back to 10″ wheels, which helped with the grass but still didn't solve the stability problem.

At that point, Peter did a major rethink of the entire setup and decided on a complete rebuild. This time he used 2″-by-6″ lumber for the frame and added two more 10″ wheels to the wide end of the T, which spread out the load and provided a wider stance. In front he added a pivoting crossbar to allow the two front wheels to move more freely, as in a child's wagon.

The new dolly worked much better, but Peter added one more feature that helped even more: Because there is so much extra gear with an imaging setup,





▲ *Left:* Peter's first attempt at a scope dolly was shaky and too low to the ground. *Right:* The second iteration with larger wheels was an improvement, but still not ideal.

ALL IMAGES COURTESY OF PETER PONZIO

he added a tall platform above the wide end of the T that let him place the power bricks, an ASIair control box, and a tablet computer at a convenient height while at the same time permitting him to keep all the various cables in order.

This third-iteration dolly lets Peter roll his scope and camera equipment out to the backyard, polar-align, and perform his initial focusing and guiding routines in a matter of minutes. The dolly itself weighs 80 pounds (36 kilograms) and, combined with the scope and mount, it comes to about 120 lbs. Far from being a hindrance, that weight is an asset in that the dolly needs no braces or jacks to stabilize it once it's parked. Sheer mass and its wide stance do the job. Peter reports that the setup produces round stars in exposures of 10 minutes or more.

For proof of this platform's success, visit Peter's website, where he displays the excellent astrophotos taken with this setup. And for more information about this build, contact Peter via that same website at **peterjponziophotography.com**.

Contributing Editor **JERRY OLTION** hauls his equipment in a collapsible wagon, but he has to set it up when he gets to his observing site.

What Is a Finder?

▲ **FINDING YOUR WAY** Every telescope used for visual observing needs some way to accurately aim it. Here are several common designs of finders, including two reflex sight finders and a straight-through 8 × 50-mm refractor finderscope.

NAVIGATING THE NIGHT SKY with a telescope in the digital age is much easier than in the past. Go To technology makes it simple enough to plug the object you want to see into your controller, then off your scope goes until it centers your target. When you look into the eyepiece, it's right in the field. What this scenario doesn't mention is that almost without exception, you'll need to align the telescope first before it can find all these wonderful objects. That's where a finder comes in.

Most every telescope needs a finder of some sort to help you accurately aim the main optics, with or without Go To. That's because your telescope magnifies the view, often much more than, say, a pair of binoculars will (in fact, large binoculars also need their own finder). The narrow field that an 8-inch f/10 Schmidt-Cassegrain (SCT) telescope sees makes it the equivalent of looking through a soda straw while trying to find your car keys. Unless you fortuitously happen to point directly at the keys, you likely won't find them without seeing a wider area to put the straw's aim into context with its surroundings. It might sound odd, but even a solar telescope needs a finder because you can't simply sight along the side of the tube to point at your target.

Finders can be anything that helps you aim the main scope accurately. They can be the most basic approach, such as using two screw eyes lined up on the side of your telescope tube. A step up from this is a *reflex sight* or *red-dot finder* that projects a bullseye target or a point of light (typically red) onto a piece of glass, making it appear at the same focus as the stars. Another common finder is a miniature telescope (called a *finderscope*) mounted alongside the main telescope that has a crosshair that pinpoints the center of the field.

▲ **BULLSEYE** Reflex sight finders project a red dot or bullseye target on glass, showing the sky without additional magnification.

The advantage of a finderscope over a reflex sight is that it gathers more light than your eye, revealing fainter stars and often the object you're hunting down directly. The reflex sight relies on your eye's visual acuity to see the stars you're aiming at. Finderscopes are particularly useful for aiming long-focal-length instruments, such as that SCT mentioned earlier. They're

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also better suited for finding your way under light-polluted skies. Some observers mount several progressively larger finders on their telescopes to make hunting down faint objects easier.

There are several types of finderscopes, including straight-through, right-angle, and even corrected-image finders. Some finders are even built directly into the telescope using the main optic as the finder, but those are rare these days (see page 84). Straight-through finderscopes used to be the default aimer that came with a new telescope, but their view often doesn't exactly match the orientation you are seeing the sky, which led to a lot of confusion for beginners. A typical straight-through refractor finderscope produces an inverted image of the sky, making it appear upside down.

You can even mount a laser pointer to function as a finder, though some observers consider these to be inconsiderate to others on the stargazing field.

No matter the design, the key to a good finder is that it includes the capability to adjust its pointing in order to be accurately aligned with the optical axis of the main telescope. Most reflex sights and finderscopes come with a mounting bracket that permits adjustments in two axes for this purpose. Larger finderscopes often include brackets with a pair of rings having three screws mounted at 120° intervals to adjust the pointing.

Aligning your finder should be done in daylight, at a place where you can readily see a distant target in your main telescope as well as the crosshairs, red dot, or projected bullseye in the finder. Start by locating a distinct, far-away object to focus on. Most telescopes are designed to come to focus on objects far in the distance, so a hilltop cell tower or antenna on a faraway building should suffice. Put your alignment target in the field of your telescope using the lowest-power eyepiece you own — most commercial scopes include a 25-mm or another wide-angle equivalent. The lower power you use, the easier this part will be. It may take some slewing around until you land that recognizable target in the field of the eyepiece.

Once you've found and centered the target, tighten any clutches if needed, ensuring the scope's pointing doesn't slip, and then move on to adjusting the finder. Without moving the scope, use the adjustment screws on the finder (or its bracket) until your target is centered.

Here's a useful tip for observers with an optical finderscope: Turn the device in its bracket so that the crosshairs are lined up with the directions that your telescope moves. For example, if you are aligning a finder on a Dobsonian telescope or any alt-azimuth mount, make the crosshairs point left/right, up/down. If your scope is mounted on an equatorial mount, be sure the finder's crosshairs are oriented to the right ascension and declination axes. You can determine these directions by nudging the scope slightly.

After you've aligned the finder with your lowest-power eyepiece, switch to a high-power ocular and fine-tune the pointing again. It will be off slightly, but not nearly as much as when you began the process.

With your finder set to your main telescope, it then becomes easy to track down objects in your main telescope, or simply to align your Go To system at the start of the night to do the work for you. The best type of finder is really whatever is most comfortable for you. ■

▲ **SCOPES AND SIGHTS** *Top:* Not so long ago, every telescope came with a finderscope, like the Meade ETX125 seen at top, with a 24-mm right-angle finder conveniently located to the right of the main scope's eyepiece. *Above:* Most commercial telescopes today come equipped with a reflex sight.

▲ **MULTIPLE FINDERS** Some observers mount additional finders for different uses. The author keeps a solar finder (top) on his favorite refractor in addition to a reflex sight, so his scope is always ready for both day and night use.

CRESCENT SUN

Jacques Guertin

The silhouetted lunar limb reveals the peaks and valleys of craters during the annular eclipse as seen from Newark, California, on October 14, 2023. Two sunspots are visible in the photosphere at top right.

DETAILS: *Six-inch Maksutov-Cassegrain telescope and Nikon D800E camera. Total exposure: 1/750 second through Baader Planetarium AstroSolar Safety film.*

△ OCTOBER'S ANNULAR ECLIPSE

Philippe Moussette

This sequence captures multiple phases of the October 14th annular eclipse, as seen from the middle of the shadow's path above Sevier, Utah.

DETAILS: *Canon EOS R3 camera and 600-mm lens. Composite of nine images, each 1⁄2,000 second at f/10, ISO 100.*

△ RING OF FIRE

Allen Mitchell

Several large prominences adorn the solar limb in this picture of the chromosphere, making an image that truly aspires to be a "Ring of Fire."

DETAILS: *Lunt Solar Systems LHT 100-mm solar telescope and ZWO ASI432MM video camera. Stack of 500 frames.*

△ BAILY'S BEADS

Damien Cannane

From Kerrville, Texas, Baily's Beads are seen along the eastern limb of the Moon during third contact on October 14th. A large, bright active region is visible to the upper left. North is at top right.

DETAILS: *Coronado SolarMax II 60 RichView solar telescope and ZWO ASI178MC video camera. Stack of roughly 350 frames.*

△ LUNAR SEED

Jordi Coy

On the night of the full Harvest Moon, these amateurs used the opportunity to create a playful narrative. The pair appear to plant the ripe, lunar "seed" in a field outside of Morón de la Frontera in Seville province, Spain, on September 28, 2023.

DETAILS: *Canon 5D Mark IV camera and 150-to-600-mm zoom lens. Total exposure: each 1⁄250 second at f/6.3, ISO 2500.*

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Becoming an Amateur Astronomer

A lifelong fascination with the heavens leads to an impromptu office star party, launching a hobby of outreach.

WHEN I WAS young, I had several encounters that helped lead me towards a lifetime of interest in astronomy. I grew up in a housing project in Brooklyn, New York, and one of my earliest memories as a child was of my father taking me up to the roof of our building and handing me a solar filter. He told me to hold the filter up before my eyes and look at the Sun. As I did so, he explained that what I was seeing was a partial solar eclipse.

My next experience occurred when I was walking with him one moonlit evening. He pointed up and asked if I could see the Man in the Moon. Well, I know now that there are other things there, too — a woman, for instance!

Later, in school, I remember a field trip my class took to the American Museum of Natural History. I was fascinated with everything, especially the planetarium. The star show was, literally and figuratively, out of this world.

When I was somewhat older, poking around on my father's shelves, I found an old telescope. We lived on the top floor of our 14-story building and enjoyed views of Manhattan to the west and the Atlantic to the east. Gazing east through the telescope, I saw a bright object in the sky. That turned out to be my first telescopic view of Jupiter.

I went to college in Santa Barbara, where, in addition to walking out to the cliffs to watch sunsets and occasionally seeing Mercury or Venus, I had my first memorable encounter with Saturn. On the roof of the physics building, amateurs would sometimes set up telescopes, and during one of these events, I observed Saturn for the first time, through a Questar scope. As everyone agrees, it was stunningly beautiful.

Still later, my wife, whom I had met at college, surprised me one Christmas with a 6-inch reflector. When my mother came to visit us right after the birth of our first child, I was delighted to show her the Ringed Planet through that telescope.

> My boss directed my co-workers to come out. I had my very own star party!

Years on, while living in the San Francisco Bay Area, I purchased a Sears 60-mm refractor. I used to load the scope into the car and record sunspots during lunch at my job working for AT&T. I'd set up the scope outside, look at the Sun, and take notes, sketch, and sometimes photograph.

I was out one morning on a break while a partial eclipse was in progress. My boss happened to be outside at the time and was captivated by what she saw through my scope. She told me to stay put, then directed my co-workers to come out to see the eclipse. I had my very own star party!

That was the beginning of my outreach hobby. Soon I picked up a 90-mm refractor, and from then on I'd sit out in my front yard every Halloween and show trick-or-treaters and their parents some celestial object of interest. I treated my own kids to such sights as well, of course, including Halley's Comet on its return in 1986.

As you can see, becoming an amateur astronomer was a natural progression for me. Over the years, I've read many books and magazines about astronomy. I joined the Eastbay Astronomical Society in Oakland, California, and have attended lectures, done outreach, and even published astronomy-related poems in *The Refractor*, the society's newsletter. The journey has certainly been very interesting.

■ **CLARENCE UNDERWOOD** is a recently retired substitute teacher who lives with his wife, Regina, and their dog Chewy in Northern California.

▶ Clarence Underwood prepares his 60-mm refractor for projecting the Sun.

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