CECILIA PAYNE: Her Stellar Revolution PAGE 22

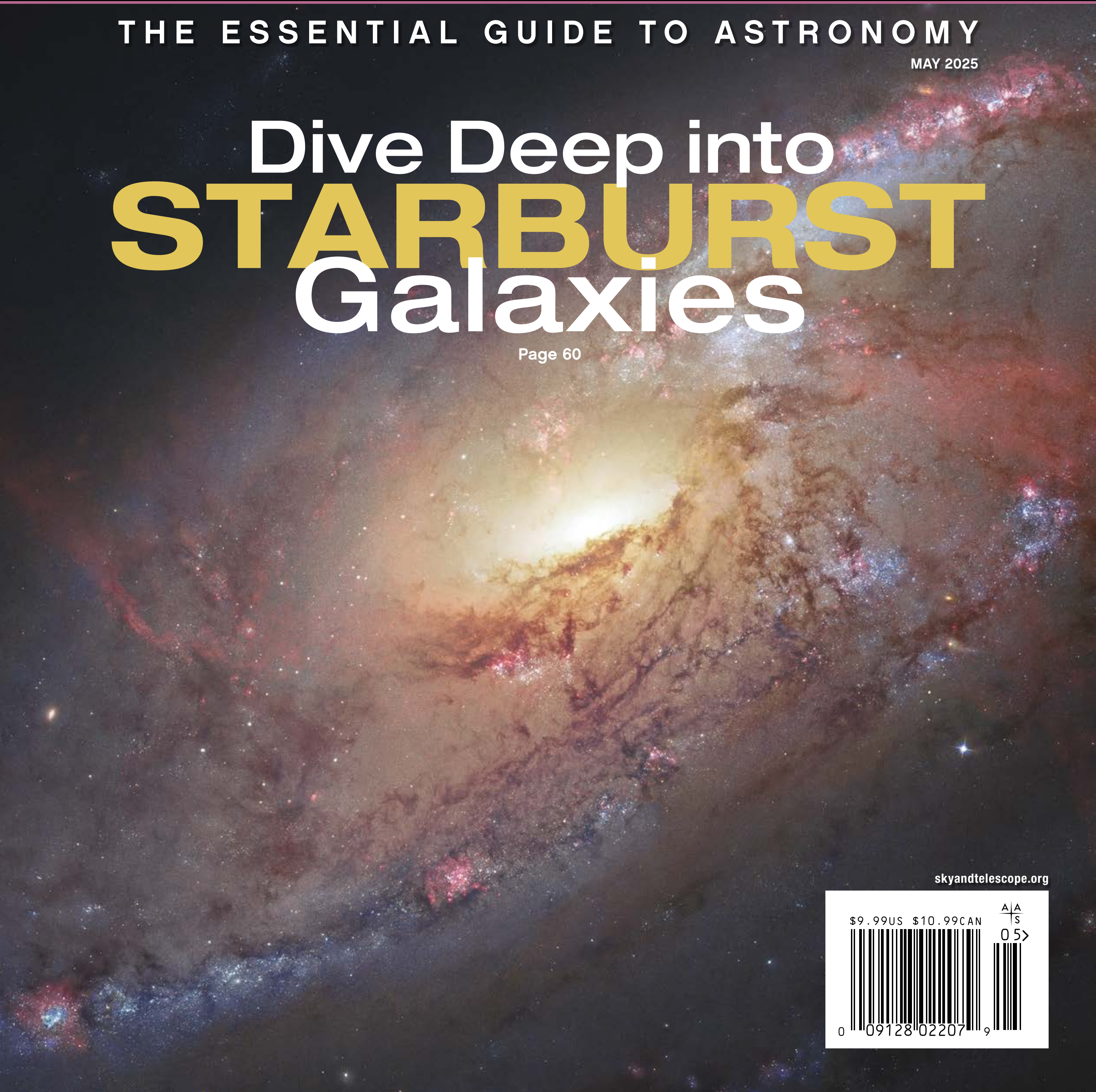
WORKBENCH: A New Way to Balance Your Dob PAGE 74

INTRODUCING: O'Meara's Enchanted Skies PAGE 12

SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

MAY 2025



Dive Deep into STARBURST Galaxies

Page 60

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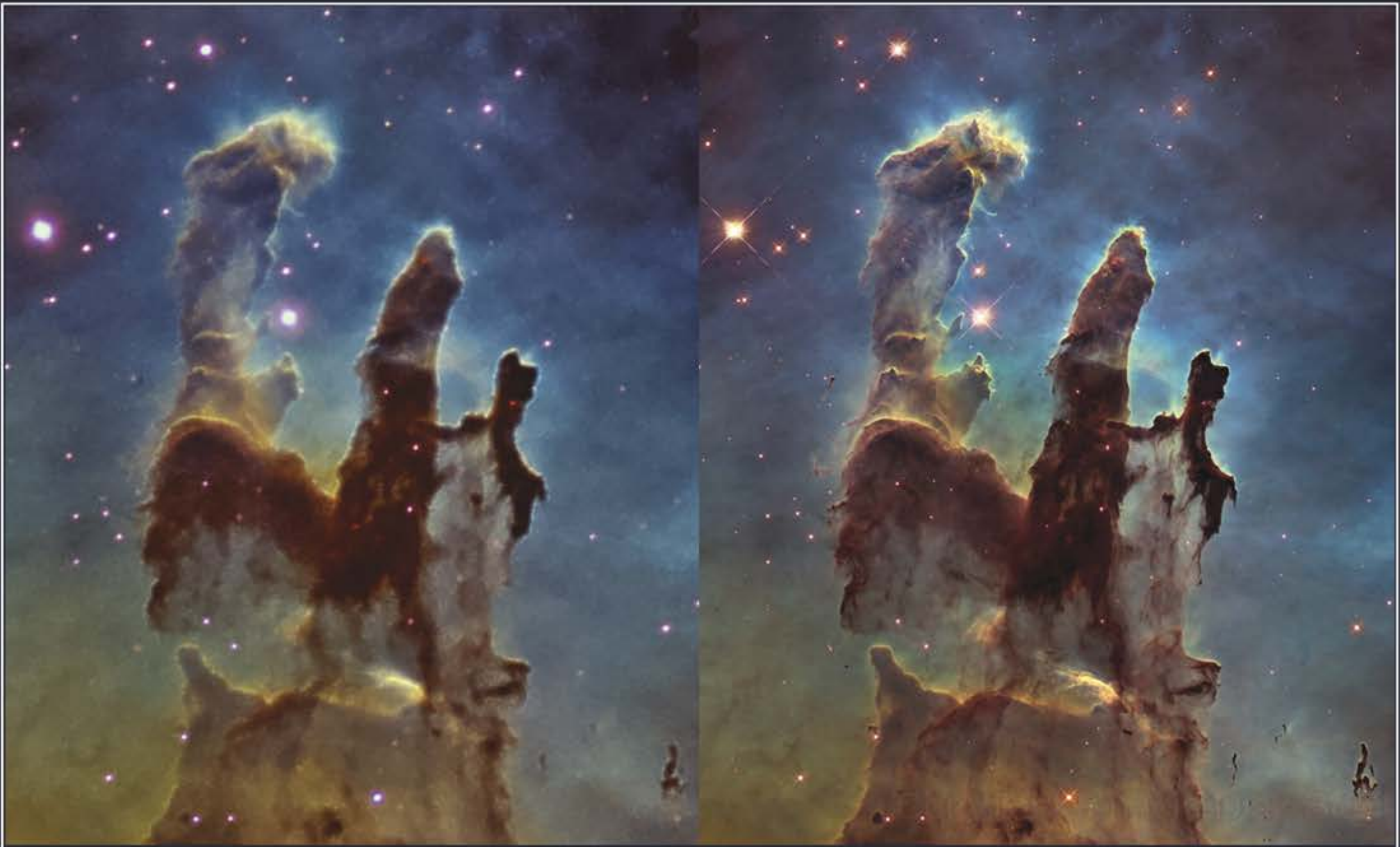

CONTENTS

SKY&TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

May 2025 VOL. 149, NO. 5

NSF / AUI / NSF NRAO / B. FOOT

FEATURES

S&T TEST REPORT

OBSERVING

COLUMNS / DEPARTMENTS

ON THE COVER

Spiral galaxy M106 in Canes Venatici, as seen by the Hubble
NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA)

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Bravura

IT WAS BUT FOUR YEARS AGO that I shepherded the debut article of a certain young observer through our publication process. That article was vibrant and refreshing, reflecting the enthusiasm of its author. The writer, Scott Harrington, has consistently submitted articles of high caliber during these intervening years. And this month, as we did four years ago, we're featuring his article on the cover. Turn to page 60 to enjoy Scott's second foray into the wonderful world of star-forming regions in galaxies far, far away.

Reading this month's articles has made me muse on how we come by success. For the most part, talented and driven as we may be, we often do not reach our pinnacles without mentors. This is as true for young observers as young scientists. But sometimes we need more than "just" mentors: We need recognition and acceptance. That's why it's all the more remarkable that Cecilia Payne persevered despite the misogyny that she endured while studying at Cambridge and later working as an astronomer at Harvard College Observatory. (See Douglas MacDougal's account on page 22.) She had her champions, though, in Arthur Eddington and Harlow Shapley. Ultimately, she published the "best doctoral thesis I ever read," as Henry Norris Russell, her teacher at Princeton, eventually conceded.

I wonder what loftier heights she might have reached, had she had that kind of support from the very start. As a woman who studied astronomy in the latter quarter of the 20th century, I'm sad to say things hadn't changed very much — at least for me — since Cecilia's time. I was extremely lucky, though, that as I embarked on my PhD studies a pair of guardian-angel mentors swooped in.

While we're on the subject of debuts and legends, I'm thrilled to announce that Stephen James O'Meara's brand-new column, Enchanted Skies, makes its first appearance on page 12. Veteran readers know Stephen's work well; his fame as a top-notch observer is well earned. By happenstance, two other authors this month independently make references to Stephen's observing prowess: Tom Dobbins notes that it took NASA's Voyager *spacecraft* to confirm Stephen's ground-based observations of Saturn's "spokes" (page 53), while Ken Hewitt-White features Stephen's fabulously detailed sketch of the globular cluster M5 (page 55).

One last thing: Before I started at *S&T*, I worked in radio astronomy. But even while elbow-deep reducing reams of data, the subtler details of interferometric techniques eluded me. If only I had had Govert Schilling's article (page 14) to hand when I was analyzing those data! Rarely have I come across such a crystal-clear representation of interferometry's intricacies. If you're a teacher of radio astronomy, here's a tip: Avail yourself of Govert's article, including the informative diagrams, for your classes. Your students will be inspired.

Diana

Editor in Chief

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Subscription Rates:
U.S. and possessions: $59.46 per year
Canada: $75.38 (including GST)
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All prices are in U.S. dollars.

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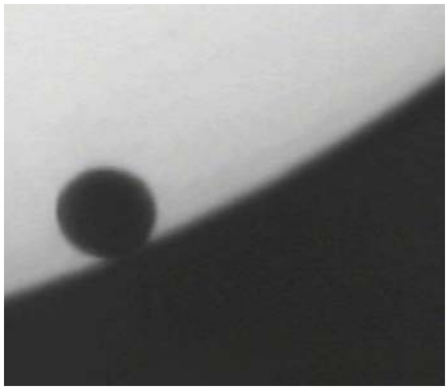
Venus in the Spotlight

I just wanted to let you know that I really enjoyed reading "The 150th Anniversary of a Transit of Venus" by William Sheehan (*S&T:* Dec. 2024, p. 18). I always look forward to articles that have a historical slant.

This story in particular brought back memories of my successful personal observations of both the 2004 and 2012 Venus transits using analog video equipment. Like the astronomers of the 18th and 19th centuries, I experienced the black-drop effect.

While it was Edmund Halley's urging that initiated the worldwide scramble to observe the transits, the very first recorded transit was actually observed by two other men: a young 20-year-old British amateur astronomer and minister named Jeremiah Horrocks and his fellow astronomer and friend William Crabtree, on December 4, 1639. After the transit, the two men exchanged letters about their observations. It was a good thing that they did, as before Horrocks could publish his official report of the transit, he died suddenly in 1641. Crabtree also passed away a few years later in 1644.



▲ Larry McHenry captured this image of the Venus transit on June 8, 2004, with his 8-inch Celestron Ultima 2000 Schmidt-Cassegrain, paired with a Lumicon solar filter and Astro-Vid StellaCam EX CCD camera.

Crabtree's letters and records from Horrocks were nearly destroyed in the following decades. But fortunately, enough were saved that we know of Horrocks and Crabtree's historic first observation of a Venus transit!

Larry McHenry • Pittsburgh, Pennsylvania

Youthful Outreach

I am writing to thank you for "Young Astronomer Wins Stellafane Award" by Diana Hannikainen (*S&T:* Dec. 2024, p. 10). So exciting! We were very pleased to present Kaitlynn Goulette with our first Raymond Fairbanks Youth Outreach Award at this year's Stellafane Convention. And the article made this award even sweeter!

Kaitlynn set the bar high for this new award with her many accomplishments in astronomy outreach. We hope that the award will inspire other young people to engage with their communities and bring astronomy to the next generation. I am looking forward to discovering the next recipient of this award, maybe next year or a few years in the future. Please keep us informed of possible candidates as you interact with people in the astronomy community.

Cecilia Detrich
President of Springfield Telescope Makers
Nahant, Massachusetts

Congratulations, Diana!

Congratulations to Diana Hannikainen on her promotion to Editor in Chief of *Sky & Telescope* magazine. I had the pleasure of hearing her speak at the 2022 Nebraska Star Party about her research on microquasars. The following year, I got to meet and chat with her over pizza lunch in Valentine, Nebraska. I realized then and there that she has an unwavering passion and a special place in her heart for the astronomical community. From professional astronomers doing cutting-edge research, all the way down to the casual stargazer, her enthusiasm for the universe is addictive. I sincerely wish her success in her new position and for the continued success of *Sky & Telescope* magazine.

Bob Wilshusen
Waterloo, Iowa

Galactic Smashup

I read "Life in a Galaxy Cluster" by Chris Mihos (*S&T:* Jan. 2025, p. 12) and thought the overall process was perhaps an explanation of the large black holes seen way in the past by the James Webb Space Telescope. Given that the universe was considerably denser 13 billion years ago, it seems reasonable that the process discussed in the article could have moved faster then, forcing the galaxy clusters back then into situations that could have produced the large black holes.

I enjoy and look forward to *Sky & Telescope*'s great articles each month.

Jim Smith
Albany, Oregon

Camille Carlisle replies: *Galaxy mergers probably helped, but we still have a bit of a pickle. Supermassive black holes grow by a combination of mergers and gas accretion, but in the early universe the primary method was accretion. Galaxy mergers can funnel gas to the galaxies' central black holes, and we've seen protoclusters of galaxies in the first few billion years of cosmic history (back to about 13 billion years ago). So yes, forming galaxies were swirling around then in close proximity to one another. But we already see billion-solar-mass black holes by that time. So just how early did the black hole seeds form, and how big did they have to be to grow by accretion and mergers to become the leviathans we see 13 billion years ago? Those remain open questions.*

Rebuilding Exoplanets

"Under Construction": a sign we encounter all too frequently in our lives, and which we have come to loathe, a foreboding signal of unexpected delays. But as we see a flock of hardhats parade, we philosophize that it is for the common good, and the finished project will garner our praise and justify the aggravation. Shannon Hall could not have chosen a better title for her report on the interpretation of the James Webb Space Telescope's data on exoplanet transmission spectra (*S&T:* Dec. 2024, p. 34).

Hall's overview, Beatriz Inglessis' graphics, and especially SayoStudio's illustrations have made this article one of *Sky & Telescope*'s most enjoyable reads this year. This week at CopernicusClub, we hastened to tack it on to the conclusion of this semester's course on exoplanet observation and light curves.

Your exegesis on the formation of sulfur dioxide in exoplanet atmospheres for all of us who have delved into the simplest forms of low-resolution spectroscopy, and the tie-in with the High-resolution Transmission Molecular Absorption Database, was a genuine touch of genius.

Bravo for a job well done!

Patrick Kavanagh
CopernicusClub
Huixquilucan, Mexico

Ruby Galaxies

In "Early Galaxies Test Ideas About Cosmic Evolution" (*S&T:* Nov. 2024, p. 10), Monica Young reports on early compact galaxies appearing as "ruby-colored smudges" detected in the infrared by the James Webb Space Telescope. Could radiation from these very distant sources be sufficiently redshifted to contribute to the cosmic microwave background?

Guy S. M. Moore
Sandown, United Kingdom

Monica Young replies: *The short answer is no, but that answer is not very interesting. Here's some more detail:*

The light of distant galaxies is redshifted according to this equation:

$$\lambda_{obs} = \lambda_{em} \times (1 + z)$$

Here, λ_{obs} is the wavelength of the light we observe, and λ_{em} is the wavelength of the light when it was emitted.

The wavelength of the cosmic microwave background that we observe is around 2 millimeters.

Meanwhile, galaxies emit most of their light at visible and ultraviolet wavelengths, so let's just take 550 nanometers (green light) as an example. For the light from galaxies to shift all the way to the CMB's wavelength, that light would have to be coming from redshifts of about 3,600. That corresponds to a time so early, the CMB photons hadn't even been released! No galaxies existed at that time.

JWST, which sees infrared rather than microwaves, has so far seen galaxies out to redshifts around 10, maybe even up to 14. These are some of the earliest that existed in the universe. Before then is what astronomers call the "Dark Ages," when matter was too jumbled to settle down into stars and galaxies.

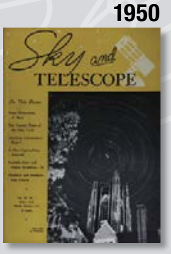
FOR THE RECORD

- The spiral galaxy M65 is 40 million light-years from Earth, not 40 light-years as stated in "The Legs of the Lion" (*S&T:* Mar. 2025, p. 55).

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

1950



1975

2000

May 1950

Pioneering Photometry "Dr. Gerald E. Kron, of Lick Observatory, described detailed observations made with a photoelectric photometer [of] Ross 248, an emission-line subdwarf of very low luminosity . . . Although it is a single star, it has a light variation of 0.06 magnitude in a period of 115 days. Possibly the variation is caused by axial rotation of the star combined with a patchy or spotted surface. If such proves correct, this will be the first time the rotation of a slowly rotating star other than the sun has been determined."

Ross 248 is a nearby star, 10.3 light-years away in Andromeda. Moving due south and approaching us, it will brighten as it nears and passes our solar system 36,400 years hence.

May 1975

Space Hazard "The word 'lethal' has often been loosely used to describe the roughly doughnut-shaped belt of trapped high-energy particles that surrounds Jupiter. But now three biophysicists at the University of Rochester's school of medicine have calculated the radiation dose that would have been encountered by any organisms on board Pioneer 10 when it flew by Jupiter in December 1973. . . .

"Inside the spacecraft, the radiation dose . . . would have resulted in a spore survival rate of about 0.05 to 0.01. . . . 'For man and other mammals the interior dose far exceeded the lethal level. Thus, Jupiter's radiation belts pose an extreme hazard to any manned mission passing through them,' [M. W. Miller and colleagues] note."

May 2000

Meeting Up "After a four-year journey, on February 14th the Near Earth Asteroid Rendezvous spacecraft successfully eased into [a] polar orbit around the asteroid 433 Eros. By then the spacecraft had already recorded thousands of images and spectra of its target, and mission scientists happily reported that Eros is not just a boring rock. 'We're on an adventure that will last for a year,' exulted NEAR project scientist Andrew E. Cheng . . .

"The misshapen, smoothly rounded body measures 33 by 13 km and is peppered with so many craters that much of its surface must be quite old. This suggests that it was not ejected toward Earth's general vicinity by a relatively recent collision within the asteroid belt, because such an impact would likely have erased most surface detail. Many giant boulders also dot the surface, presumably pieces blasted from the interior by impacts. . . . Cheng also notes that there are tantalizing hints of widespread layering."

Renamed NEAR Shoemaker in honor of planetary scientist Eugene Shoemaker (1928–1997), the craft capped off its mission with a soft landing on Eros in early 2001.

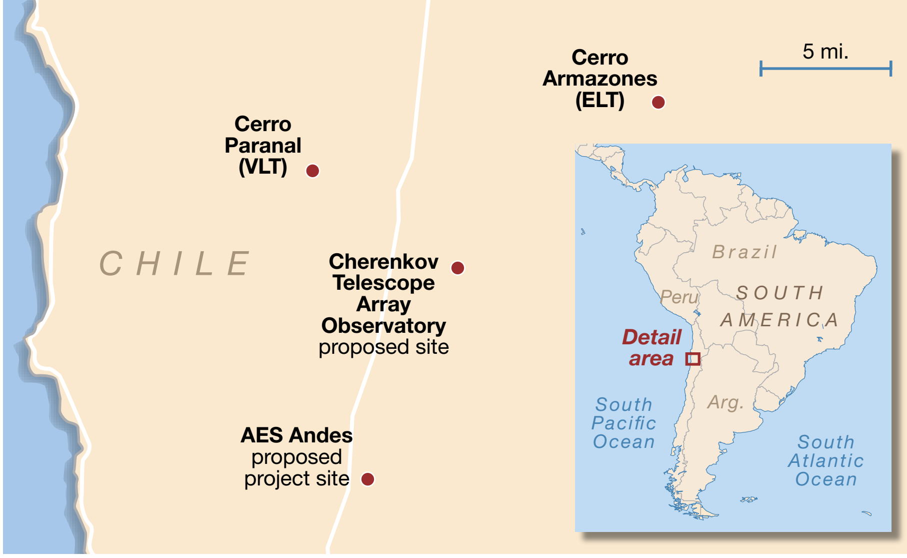
DARK SKIES

Industrial Project Proposed Near Chilean Telescopes

CERRO PARANAL, a 2,635-meter (8,645-foot) mountain in Chile's Atacama Desert, is the darkest observatory site in the world. And for more than 25 years, it has been home to the European Southern Observatory's (ESO) Very Large Telescope.

Now, a company named AES Andes (a subsidiary of the U.S. power company AES Corporation) is proposing an industrial project that threatens the unspoiled skies over this observatory.

The news comes as ESO is building its Extremely Large Telescope (ELT) on a site 22 kilometers (14 miles) to the east of Paranal. When that telescope sees first light before the end of this decade, it will become the world's largest visible-light observatory.



▲ The AES Andes proposed project site would cover nearly 12 square miles just south of three world-class observatories: the Paranal Observatory, which includes the Very Large Telescope (VLT); the Cerro Armazones Observatory that hosts the Extremely Large Telescope (ELT), currently under construction; and the proposed southern site of the Cherenkov Telescope Array Observatory (CTAO).

In addition, an international consortium plans to operate a new site of the Cherenkov Telescope Array Observatory to the southeast of Paranal. It will detect high-energy gamma rays by the visible light they generate when they interact with our atmosphere.

Based on information provided to ESO, the closest parts of the AES Andes facilities will sit just 5 km from the CTAO site and about 11 km and 20 km from the VLT and ELT sites, respectively. "The biggest issue is light pollution, not only during construction but during

EXOCOMETS

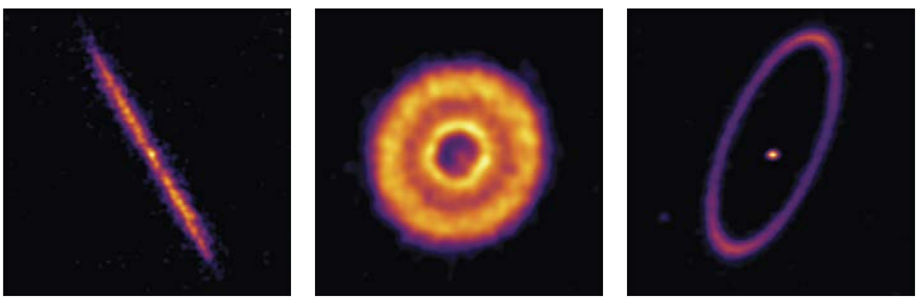
New Images Reveal Exocomet Belts in Nearby Systems

ASTRONOMERS HAVE TAKEN sharp new images of *exocomet belts* encircling 74 stars within 500 light-years of the Sun. These belts are a type of *debris disk* — appearing around newborn stars following the formation of planets — but they are distinguished by abundant volatile molecules, such as water and carbon monoxide.

While individual exocomets are too small to observe directly, collisions between bodies create smaller pieces, which spread into rings large enough for telescopes to image. Using the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile and the Submillimeter Array (SMA) in Hawai'i, astronomers observed a host of exocomet belts as part of the Resolved ALMA and SMA Observations of Nearby Stars (REASONS) survey. The team, led by Luca Matrà (Trinity College, Dublin), has published the survey's first results in the January *Astronomy and Astrophysics.*

Astronomers have confirmed the presence of hundreds of exocometary systems, but only a few have been resolved in detail. "This [survey] is the first time we can make a statistical analysis of what's going on in these disks," says Isabel Rebollido (European Space Astronomy Centre, Spain), who wasn't involved in the new study.

▼ Three exocomet belt examples highlight the variety seen in the survey.



The belts in the REASONS survey range from 20 million years old, after the planet-forming phase has just ended, to 2 billion years old. The images reveal surprising variety in the belts' structures: Some are narrow like our system's Kuiper Belt, but many are significantly wider and more massive — more akin to disks than belts. A few systems have multiple rings, perhaps shaped by undetected planets.

Preliminary results also confirm that the belts lose both mass and surface area over time, as expected if collisions are the mechanism producing the disk particles; however, the disks' heights don't necessarily thin with age.

"Knowing these other systems," says team member Carlos del Burgo (University of La Laguna, Spain), "we can arrive at a more complete interpretation of the solar system's formation."

■ JAVIER BARBUZANO

MAP: LEAH TISCIONE / *S&T*; EXOCOMETS: LUCA MATRÀ operation," says ESO Director General Xavier Barcons.

The project is supposed to generate green hydrogen and ammonia from sea water, using power generated from solar and wind energy. The project includes solar panel and wind turbine arrays as well as a production plant, power lines, pipelines for sea water and processed products, and a port at the coast for exporting the final products. The plans cite an investment of $10 billion and call for 11.7 square miles of land.

As soon as ESO learned of the project plans in August 2024, the organization reached out to AES, as Barcons recounts: "We showed them that the impact, based on sophisticated models of light pollution, is going to be very serious on the observatory sites. And we told them that if they moved away to 50 kilometers, according to the simulations, we will be safe." Nonetheless, AES submitted the original plans to the environmental agency without changes.

While AES did not reply to *S&T*'s questions regarding the possibility of relocating the facilities, the company did respond to dark-sky concerns in an email: "This proposed project specifically incorporates the highest standards in lighting in its design, complying with the Ministry of the Environment's new regulatory requirements."

ESO has brought its concerns to Chilean authorities. "They're taking this very seriously," Barcons says. "But we're at a point now where the project has been submitted and we're very concerned that, if approved, it might compromise our business and our investments."

Barcons adds that ESO supports the production of clean energy. "I don't see why Chile has to choose between the best astronomical observing sites in the world and green energy production," he says. "It can have both — just not in the same place!"

■ **JAN HATTENBACH**

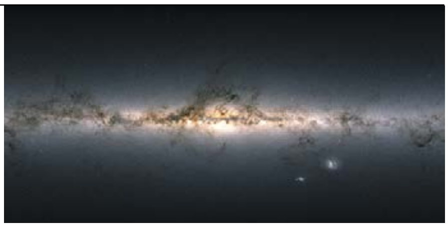
SPACE MISSIONS

Galaxy-mapping Gaia Ends Science Operations

AFTER MORE THAN a decade in space, the European Space Agency's Gaia observatory ended its science observations on January 15th. The last of the satellite's supply of nitrogen gas, used to adjust its spin and maintain its position in space, was reserved for technical observations at the close of the mission. Meanwhile, astronomers are still preparing final data blasts.

Seeing the mission come to an end is hard, admits Carme Jordi (Barcelona University), who has been on the project since the 1990s: "Gaia is a bit like our scientific child," she says. From concept to launch to science, she adds, "takes decades, a life!"

The effort has paid off: Gaia's legacy will be a catalog of the positions, movements, brightness, color, and distances for about 2 billion stars. The positions will be known down to microarcsecond precision — a gold standard for the next generation of astronomers.



▲ This map of the Milky Way shows the total brightness and color of 1.8 billion stars, as measured by the Gaia satellite.

"New results based on Gaia [data] are pouring in at a rate of more than five peer-reviewed scientific publications per calendar day," says Gaia project scientist Johannes Sahlmann (European Space Astronomy Centre, Spain). Among other things, Gaia has revealed 9 million variable stars, 2 million eclipsing binary systems, 355,000 white dwarfs, some 700 new open clusters, and more than 150,000 asteroids.

These results rely on only the first 33 months of the mission. In 2026, the Gaia team will release a new data set covering 5½ years. That release will also include an exoplanet candidate catalog. Around 2030, all 10½ years of data will be published in Gaia's final data release.

■ **JAN HATTENBACH**

IN BRIEF

Fate of Megatelescopes Undecided

A National Science Foundation report from an external panel has hedged on how to proceed with the two U.S.-led extremely large telescopes, both of which would have primary mirrors 25 to 30 meters across. The Giant Magellan Telescope and Thirty Meter Telescope have vied for funding and support for years, but now astronomers have called for a joint program that incorporates both telescopes, with NSF support. However, each project needs $1.6 billion from NSF to proceed — an amount once considered enough to construct both telescopes. Even funding one project could "have a significant negative impact on the NSF budget," unless Congress were to substantially increase NSF's budget, the report concludes. Without more money, the NSF would not be able to adequately support other telescopes and astronomy research alongside an ELT. The committee did not pick a project to prioritize.

■ **CAMILLE M. CARLISLE**

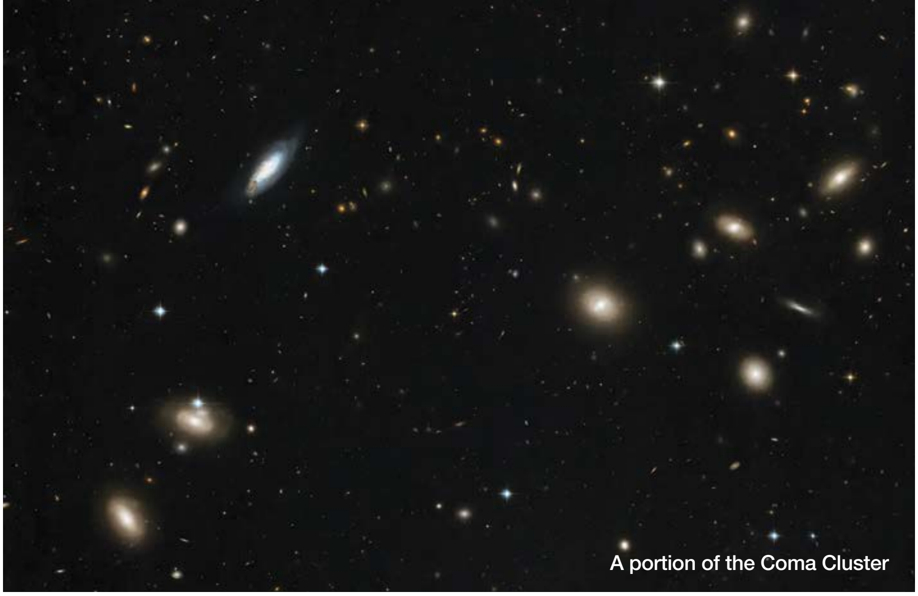
"Little Red Dots" and Early Black Holes

When the James Webb Space Telescope (JWST) first allowed astronomers to peer at our universe's infancy, curious red pinpricks stared back. Astronomers dubbed these compact galaxies "little red dots." New research presented at the 245th meeting of the American Astronomical Society, and to be published in the *Astrophysical Journal*, shows that most of these galaxies may in fact host unexpectedly massive black holes. Sifting through images taken as part of JWST surveys, Dale Kocevski (Colby College) and his team found 341 little red dots — one of the largest samples yet compiled. The addition of spectra showed the researchers that more than 80% of the little red dots contain gas spiraling at more than 1,000 km/s (2 million mph): solid evidence that the galaxies host active central black holes. The finding supports the idea that the first supermassive black holes formed by the direct collapse of giant gas clouds rather than from the collapse of individual stars. The little red dots appear to be far more abundant than astronomers expected such active galaxies to be; in fact, they represent some 3% of all galaxies in the early universe.

■ **HANNAH RICHTER**

COSMOLOGY

New Distance Measurement Highlights Hubble Tension


A portion of the Coma Cluster

A NEW ESTIMATE of the distance to the Coma galaxy cluster highlights a discrepancy between different measurements of the universe's current expansion rate, known as the *Hubble constant*.

Astronomers have measured the distance to the rich Coma Cluster many times in different ways. At the 245th meeting of the American Astronomical Society, Daniel Scolnic (Duke University) presented a new estimate, also published in the January 20th *Astrophysical Journal Letters*.

Measurements of the Hubble constant from observations of the early universe align with the value predicted by the standard cosmological model. But observations of nearby objects tend to obtain a slightly faster expansion rate — a phenomenon known as the *Hubble tension*. Scolnic's team began with the latter type of object: 13 Type Ia supernovae. These white dwarfs in the cluster exploded with a characteristic brightness that can in turn be linked to their distance. Combining those observations with distant galaxy data from the Dark Energy Spectroscopic Instrument, the team arrived at a distance to the Coma Cluster of 321 million light-years. In that case, the universe must currently be expanding at between 74.3 and 78.7 kms/s/Mpc. The standard model of cosmology, however, predicts a Hubble constant of 67.4 km/s/Mpc, with an associated Coma Cluster distance of 365 million light-years.

Scolnic noted that previous distance measurements to the Coma Cluster, some computed "blind" to the Hubble tension, are likewise smaller than the standard cosmological model predicts.

Taken together, the findings underscore the importance of consistent distance measures. "The problem comes from the disagreement between two very different classes of calibrators," says Daniel Eisenstein (Harvard), who was not involved in the study. But whether the problem is one of calibration or physics is still unclear, he adds: "The jury is still out!"

■ **ARIELLE FROMMER**

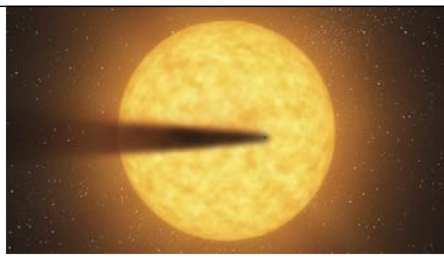
EXOPLANETS

Disintegrating World Sheds Comet-like Tail

TWO DISINTEGRATING WORLDS provide a unique window into the end of planets' lives.

One of these is BD+05 4868 Ab, a planet in a 30.5-hour orbit around its orange star 144 light-years away. The team determined key properties of this world from 29 of its transits in front of its host star. At the 245th American Astronomical Society (AAS) meeting, Marc Hon (MIT) presented the discovery, seen in data from the Transiting Exoplanet Satellite Survey. With every transit, the star dims suddenly and only gradually returns to full brightness.

Analyzing the light curve's shape, the team concluded that the planet has two dusty tails — a trailing tail 9 million kilometers (5.5 million miles) long, which partially encircles the star, and a shorter leading tail. Simulating the star's radiation as it scatters off the dust, the team found that the leading tail has larger particles, around the size of desert sand, while smaller, soot-size grains make up the trailing tail. The team estimated the planet's mass loss, at about a Moon's worth of material every million years. Planets lose material more quickly as they shrink, so due to the amount of mass in the tails, the planet itself is probably of lunar mass.


▲ This artist's illustration shows a disintegrating exoplanet shedding a tail of debris.

"The planet will completely evaporate, or disintegrate, within the next 1 or 2 million years," Hon said.

However, the planet's original size remains unknown. That may change with observations of the tails, which should shed light on the planet's interior. As the star's light filters through the tails, the material will absorb certain wavelengths of light.

Also at the AAS meeting, Nick Tusay (Penn State) presented James Webb Space Telescope observations of another disintegrating planet, the Neptune-size K2-22b. The spectrum of K2-22b reveals hints of nitric oxide and carbon dioxide ices, which suggest that the planet may have formed far from its star before migrating closer. (Incidentally, both parent stars K2-22 and BD+05 4868 A are binaries, which might have played a role in their planets' demise.)

The extensive tails around BD+05 4868 Ab, as well as its proximity to Earth, make that system ideal for similar follow-up observations.

■ **ARIELLE FROMMER**

COMA CLUSTER: NASA / ESA / THE HUBBLE HERITAGE TEAM (STSCI / AURA); ACKNOWLEDGMENT: D. CARTER (LIVERPOOL JOHN MOORES UNIVERSITY) AND THE COMA HST ACS TREASURY TEAM; DISINTEGRATING EXOPLANET: JPL-CALTECH / NASA

BLACK HOLES

Black Hole Sprouts Jet Amid Periodic X-ray Signal

WHEN THE SUPERMASSIVE black hole at the center of a galaxy some 270 million light-years away ate a quick meal, that act kicked off a series of events that may have changed its appearance for hundreds of years. A team of astronomers reported new observations at the 245th meeting of the American Astronomical Society.

First, over the course of a few months back in 2018, the galaxy 1ES 1927+654 brightened by 100 times at visible wavelengths as a glut of gas whirled around the galaxy's black hole. Then that same year, the *corona* (an X-ray-emitting region normally associated with feeding black holes) suddenly disappeared. And even when the X-rays returned, they'd changed: Whereas before they had twinkled in a random way, now the brightness varied periodically. In 2022 that period was roughly 18 minutes; by 2024, it had dropped to 7 minutes.

◀ In one scenario explaining the X-ray oscillations, a white dwarf (lower right) orbits just outside the supermassive black hole's event horizon.

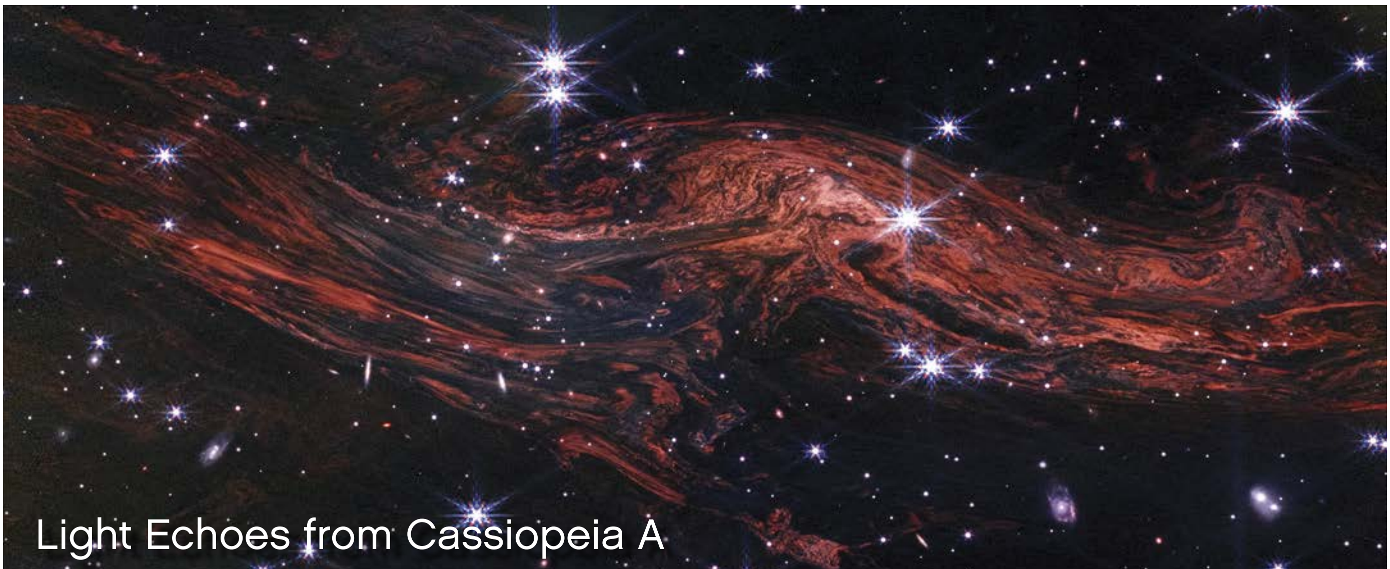
If that signal came from something compact that's still orbiting the black hole, such as a white dwarf, then it would be circling the black hole just outside the event horizon. That's close enough that the Laser Interferometer Space Antenna (LISA) mission, due to launch in the mid-2030s, could detect it by its gravitational waves.

And the surprises weren't over yet: In early 2023, radio waves from near the black hole suddenly shot up from nothing, revealing a pair of jets shooting away from the black hole at a third the speed of light. Because the black hole probably quaffed a single meal rather an ongoing feast, these jets are still stubby and will likely be short-lived, lasting at most 1,000 years.

The jets' presence offers another possibility for the X-ray signal: The base of the jet itself could be what's oscillating, eliminating any need for a white dwarf. However, there's no obvious explanation for why the base of a jet should behave in this way, and there's no ready test for the scenario.

"The fun thing is," Meyers says, "we really don't know what [this system] is going to do."

■ MONICA YOUNG



Light Echoes from Cassiopeia A

When the progenitor star of the Cassiopeia A supernova remnant exploded 350 years ago, it sent a pulse of X-rays and ultraviolet light into its surroundings. As that energetic light expands through space, it encounters dusty interstellar clouds, warming them and causing them to glow at infrared wavelengths. These "light echoes" of the original blast are shown in the image above. At the 245th meeting of the American Astronomical Society, Jacob Jencson (Caltech/IPAC) and Joshua Peek (Space Telescope Science Institute) presented new images from the James Webb Space Telescope that show infrared echoes from two small clouds southwest of Cas A. The clouds light up in a way that suggests that the pulse of high-energy radiation from the supernova lasted mere days. The light echoes also reveal details in the rarefied clouds of neutral gas and dust that fill the space between stars. Using images and spectra, the astronomers traced the clouds' 3D structures, which appear like crumpled ribbons. Further study of these fine-scale structures — which are comparable in size to typical star-forming clouds — could help answer questions about the nature of star birth.

■ RICHARD TRESCH FIENBERG

To watch these light echoes traverse the two interstellar clouds, visit https://is.gd/CasAvideo.

ARTIST'S CONCEPT OF WHITE DWARF AND BLACK HOLE: NASA / AURORE SIMONNET, SONOMA STATE UNIVERSITY; LIGHT ECHOES: NASA / ESA / CSA / STSCI / J. JENCSON (IPAC-CALTECH)

Webb's Wreath

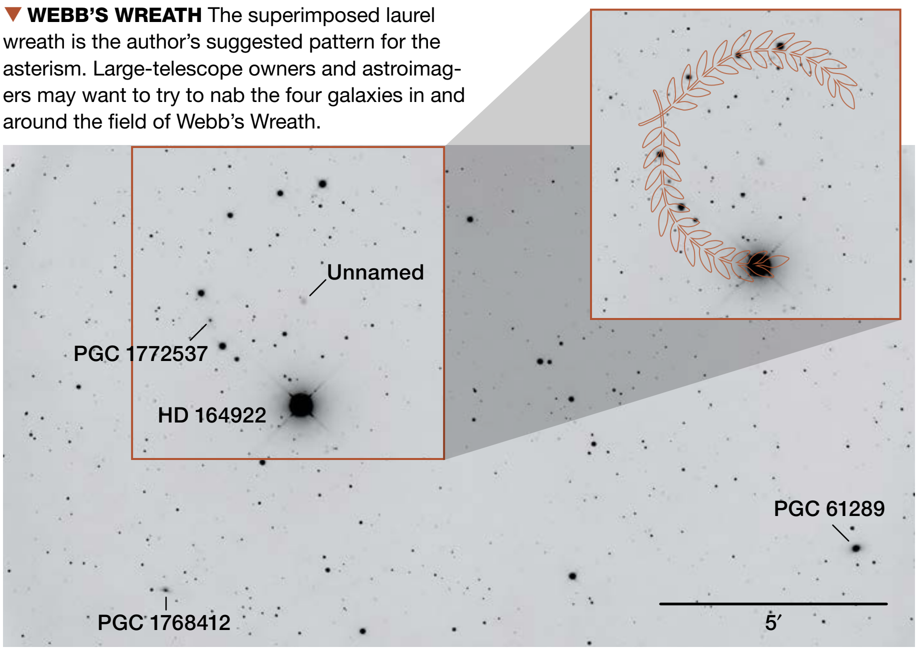
Hercules hosts a curious asterism fit for small and large telescopes.

WHEN IT COMES TO the deep sky, one thing is certain: Observers have pushed their limits over time. Today, it's common for objects once suitable for small telescopes to be proving grounds for deeper explorations with larger telescopes. **Webb's Wreath**, a little-known asterism in Hercules, is a perfect example. While the smallest of telescopes will show its stars, the field around it presents an extreme challenge for those using larger telescopes while working at the limits of perception. Before we dive into the deep end, let's explore a mystery involving the asterism itself.

After reading about the Wreath in former Contributing Editor Sue French's delightful book *Deep-Sky Wonders,* Roger Ivester of Boiling Springs, North Carolina, brought the asterism to my attention. It first appears in Rev. Thomas W. Webb's 1894 edition of *Celestial Objects for Common Telescopes*, where he describes the object simply as a "wreath" of 11th-magnitude stars attached to an 8.5-magnitude star. Webb does not record the wreath's dimensions, nor the number of stars in it. Most likely, Webb used his Tulley 3.7-inch f/18 refractor, though he provides no magnification. Note also that his "8.5-magnitude star" is actually 7th-magnitude HD 164922, which you'll find 2.7° south-southwest of Omicron (ο) Herculis.

The problem appears to be one of identity — namely the Wreath's shape. Commonly, a wreath conjures up a vision of a circular arrangement of foliage. So, when searching for the asterism, one might expect to seek out a circular arrangement of stars. But that's simply not the case. For instance, through her 4-inch refractor at 68×, French describes the pattern as an "11′ × 7′ oval" that "leans northeast and is dented inwards at the bright star." Ivester noted a similar view through his 10-inch f/4.5 reflector at 104×. Both recorded about two dozen stars in the asterism. But how many actually belong to the Wreath?

To be clear, not all wreaths are round. A laurel wreath, for example, can be curved like a tiara. In fact, Webb occasionally described curved, spiral structures in deep-sky objects as "wreaths." Indeed, through my 3-inch refractor at 72×, I found five roughly 11th-magnitude stars forming a 5′-wide laurel-wreath pattern, which spirals northeast from HD 164922. Based on this immediate impression, I suspect that these five stars comprise Webb's true Wreath, especially as Webb says that the asterism is "attached" to the bright star.



▼ **WEBB'S WREATH** The superimposed laurel wreath is the author's suggested pattern for the asterism. Large-telescope owners and astroimagers may want to try to nab the four galaxies in and around the field of Webb's Wreath.

Up for a Challenge? The image, taken by Mario Motta of Gloucester, Massachusetts, with his homemade 32-inch reflector, shows four dim galaxies in and around Webb's Wreath. Keith Rivich and Larry Mitchell of Houston, Texas, searched for them using a 25-inch f/5 Newtonian telescope while observing about 16 kilometers (10 miles) southeast of Leakey, Texas. They succeeded in sighting two of the four. The 14.1-magnitude elliptical galaxy PGC 61289, was "quite easy to see," they said, "appearing as a very small oval glow." Given the ease of the observation, the galaxy is likely to be within range of smaller telescopes, but just how small is the challenge.

On the other hand, they found the 16th-magnitude edge-on spiral PGC 1768412 "tough and fun." At 650×, the observers could, during moments of good seeing, distinctly see the galaxy's western ansa; a 15th-magnitude field star 20″ to the east interfered with the view of the galaxy's eastern side. The fun part came when Mitchell put his night-vision device into the telescope, which showed the galaxy as a "complete edge-on spiral." The remaining two galaxies most likely require even larger apertures to detect.

Whether you're using a small or a large telescope, I hope you enjoy the mystique of Webb's Wreath, one of the Reverend's "peculiarly interesting, but hitherto little noticed, class of objects to which the persevering student may make large and very curious additions."

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

IMAGE: MARIO MOTTA; LAUREL WREATH ILLO: KICHIKIMI / SHUTTERSTOCK.COM

Sharp Vision

The power of interferometry has enabled astronomers to see far beyond the resolution limit of any single telescope.

It was front page news back in April 2019. For the first time, astronomers revealed the image of a black hole — a circular, dark silhouette surrounded by an eerie, glowing ring (*S&T:* Sept. 2019, p. 18). As newspaper reports and magazine articles explained, astronomers reconstructed the image using data from a network of radio telescopes scattered across the globe, working together as one single, virtual dish almost as large as Earth: the Event Horizon Telescope (EHT).

This impressive technology, known as interferometry, is an essential part of today's astronomical toolbox. "Interferometry provides the highest resolution" for these kinds of objects, says EHT director Huib van Langevelde (Leiden University, The Netherlands).

Of course, the EHT isn't the first project to use interferometry, although it spans some of the largest distances thus far. The technique is a mature and established technology, particularly in radio astronomy. Big observatories like the Karl G. Jansky Very Large Array (VLA) in New Mexico — a Y-shaped array of 27 dishes — use it all the time. Without interferometry, future facilities such as the Square Kilometre Array (SKA; *S&T:* June 2017, p. 24) would be rendered all but useless.

At much shorter optical (visible and near-infrared) wavelengths, astronomers also link telescopes together to obtain unprecedented angular resolution; two prime examples are the Very Large Telescope Interferometer (VLTI) of the European Southern Observatory (ESO) in Chile, and the Center for High Angular Resolution Astronomy (CHARA) array in

◀ **THE SHADOW** This is the first image of the black hole at the center of the galaxy M87, called M87*.

TELESCOPES: NSF / AUI / NSF NRAO / B. FOOTT; M87* SHADOW: EVENT HORIZON TELESCOPE COLLABORATION

California. Such interferometers have enabled astronomers to image the surfaces of relatively nearby stars (*S&T:* Nov. 2019, p. 24).

Let's delve into how this technology works.

▲ **ALMA** This mosaic panorama shows the central portion of the Milky Way arching over the Atacama Large Millimeter/submillimeter Array in Chile. The Large and Small Magellanic Clouds lie at far left (the LMC is the lower object).

Fringe Science

As the name implies, interferometry works through the *interference* of electromagnetic waves. British physicist Thomas Young demonstrated this effect in the early 1800s by shining light from a single source through two side-by-side vertical slits. On a screen behind the slits, a distinct pattern of bright and dark vertical bands (so-called *fringes*) became visible. The bands appeared because the two slits acted as individual light sources, the light waves spreading out from each slit after they passed through. When the two sets of waves met on the screen, they had traveled slightly different distances to each point on the screen, such that the waves' crests and troughs no longer perfectly overlapped. Instead, they either amplified or nullified each other, creating a comb-like pattern.

In the 1880s, Albert Michelson (the first American to win a Nobel Prize in physics) realized that interferometry enabled precision metrology. In the Michelson interferometer he developed together with Edward Morley — originally devised to study the *luminiferous aether* that was supposed to fill "empty" space — a beam of light was split in two and then brought together again with the help of mirrors. If the path length (or light-travel time) changed for one or both of the beams, then these changes would be evident in the resulting fringe pattern. The same principle lies at the basis of gravitational-wave observatories like LIGO in the U.S. and Virgo in Europe.

In 1920, Michelson and astronomer Francis Pease constructed the first *stellar interferometer* on the 100-inch Hooker Telescope at Mount Wilson. Two mirrors at the end points of a stiff 6-meter (20-foot) steel beam captured the light of the red supergiant star Betelgeuse. The two images of the star, each with a distinctive *diffraction pattern* (caused by light bending at the edges of the mirrors and also known as the *Airy pattern*) were then brought together in the prime focus of the telescope. By studying the changing interference of the two diffraction patterns as the distance between the two mirrors was slowly varied, Michelson and Pease were able to measure Betelgeuse's tiny apparent diameter on the sky: 0.047 arcsecond.

"Plans to build a larger, 50-foot interferometer were never realized," says Gail Schaefer (Georgia State University), director of the CHARA array, also located at Mount Wilson. "Optical interferometry went dormant for a long time." Indeed, it wasn't until the 1960s and 1970s that optical interferometry experienced a reawakening, with instruments built in Narrabri, Australia, and again at Mount Wilson.

The delay was partly due to the birth and early development of radio astronomy between the 1930s and 1950s, which jump-started astronomical interferometry at these longer wavelengths. "Right from the start, astronomers realized that interferometry would be much easier at radio wavelengths," says van Langevelde.

Paint It Black

To understand how a collection of small telescopes can work together as a single, much larger one, it helps to work backwards and start with imagining that you really do have access to a telescope with a 100-meter-wide parabolic mirror. Because of its large aperture, this monster instrument would have not only high sensitivity (it collects a lot of light, enabling the detection of extremely faint objects) but also high angular resolution, giving it the ability to see fine detail.

Now what happens if you paint the huge mirror black, except for two circular 1-meter patches on opposite sides? Obviously, you lose a lot of sensitivity, but because the two patches are 100 meters apart, in principle the angular resolution doesn't change.

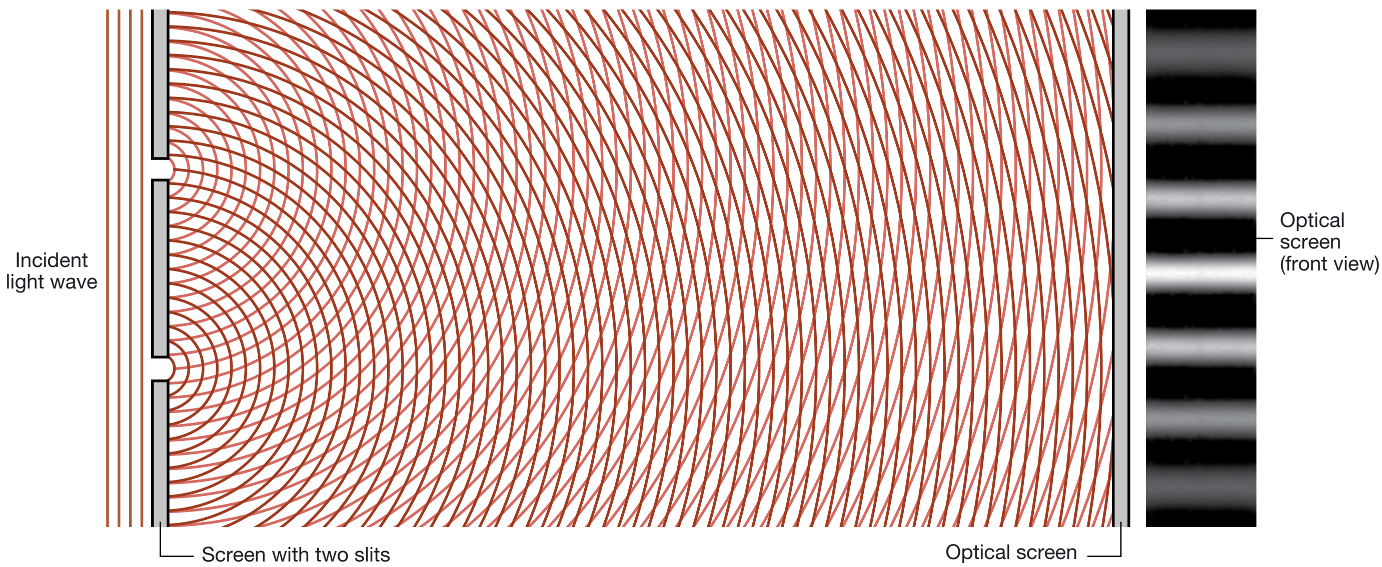
The same would be true for a pair of individual 1-meter telescopes separated by 100 meters — that is, provided you can trick the light into "believing" that it has been reflected by two parts of a single giant, parabolic mirror.

To that end, the signals from the two small telescopes need to be brought together in a single focal plane. Moreover, you have to make sure that the signals remain *coherent*, with the two light waves arriving at the same time, so that the same original *wavefront* is being observed, independent of the route the light waves have taken. In most cases, there *will* be a small time difference: The light from a star arrives a tiny bit earlier at telescope 1 than it does at telescope 2, depending on the position of the star with respect to the two telescopes. But as soon as you take care of this *geometric time delay* — for instance by using moving mirrors to vary the path length of the signals — you're in business.

So why is this called interferometry — where does interference come into play? Well, as van Langevelde explains, interference happens all the time, including in the focal plane of your imaginary monster telescope. Each and every single point on the mirror receives light waves from each and every point in the telescope's field of view. It is only through mutual interference of all the reflected light waves that this convoluted information is "transformed" into a crisp picture, with the interference process still evident in the diffraction patterns (the Airy patterns) of the individual stars.

However, if most of the mirror is painted black, this transformation (technically known as a *Fourier transform*) is incomplete, so you won't see a sharp image at all. Instead, you end up with a pattern of fringes, comparable to the fringes in Young's double-slit experiment. Moreover, the single *baseline* formed by the two non-painted patches (or by the two individual 1-meter telescopes!) yields a fringe pattern that only contains information on angular resolution in one direction and at one scale across the field of view.

Adding more elements to the interferometric array, with



▲ **DOUBLE-SLIT INTEFERENCE** When light from one source passes through two slits (left), the single wavefront splits into two (overlapping semicircles). These two wavefronts then overlap and interfere with each other as they travel, which we can see when they hit a blank surface and create a pattern of bright and dark bands. Bright fringes mark where the waves from the two slits interfered *constructively* — that is, the waves' peaks and troughs line up and augment each other. Conversely, when the waves are out of phase with each other, they cancel each other out, creating dark bands. (If you defocus your eyes, you can see the banding pattern in the overlapping waves filling the diagram's center.)

● Low-frequency radio	● VLBI
● Radio	● Optical (visible/near-infrared)
● (Sub)millimeter	

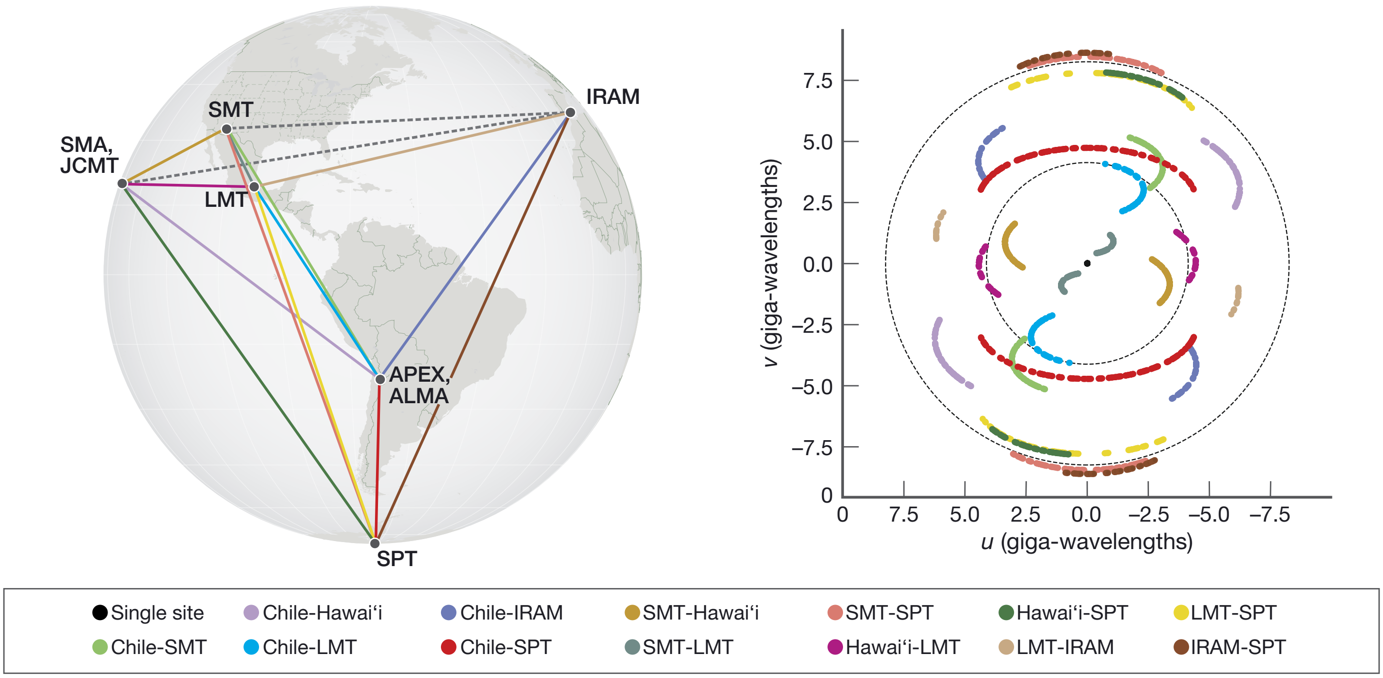
Notable Interferometers

Listed in chronological order, although some dates are ambiguous (for example, the start of operations might not include all elements of an array). Note that comparison of the various arrays can be difficult, because they work in different wavelength bands.

	Acronym	Full name	Location	Number and diameter of elements	Longest baseline	Start of operations
Radio		One-Mile Telescope	United Kingdom	3 × 18 m	1.6 km	1964
Radio	WSRT	Westerbork Synthesis Radio Telescope	The Netherlands	14 × 25 m	2.7 km	1970
Radio	MERLIN	Multi-Element Radio Linked Interferometer Network	United Kingdom	7 (5 × 25 m, 1 × 32 m, 1 × 76 m)	217 km	1980
Radio	VLA	Karl G. Jansky Very Large Array	New Mexico, USA	27 × 25 m	36 km	1980
(Sub)millimeter	PdBI[1]	Plateau de Bure Interferometer	France	6 × 15 m	400 m	1988–2014
Radio	ATCA	Australia Telescope Compact Array	New South Wales, Australia	6 × 22 m	6 km	1988
VLBI	VLBA	Very Long Baseline Array	USA	10 × 25 m	8,611 km	1993
Optical	NPOI	Navy Precision Optical Interferometer	Arizona, USA	6 (4 × 1.8 m, 2 × 0.5 m)	500 m	1994
Radio	GMRT	Giant Metrewave Radio Telescope	India	30 × 45 m	25 km	1995
Optical	CHARA	Center for High-Angular Resolution Astronomy	California, USA	6 × 1 m	330 m	1999[2]
Optical	VLTI	Very Large Telescope Interferometer	Chile	8 (4 × 8.2 m, 4 × 1.8 m)	200 m	2001[3]
(Sub)millimeter	SMA	Submillimeter Array	Hawai‘i, USA	8 × 6 m	508 m	2003
Optical		Keck Interferometer	Hawai‘i, USA	2 × 10 m	85 m	2003–2012
VLBI	EVN	European VLBI Network	Europe, Asia, South Africa	21 (14 – 100 m)	~10,000 km	2004
(Sub)millimeter	CARMA[4]	Combined Array for Research in Millimeter-wave Astronomy	California, USA	23 (6 × 10.4 m, 9 × 6.1 m, 8 × 3.5 m)	2 km	2006–2015
Radio	ATA	Allen Telescope Array	California, USA	42 × 6.1 m	300 m	2007
Optical	LBT	Large Binocular Telescope	Arizona, USA	2 × 8.4 m	22.8 m	2008
VLBI	EHT	Event Horizon Telescope	World	11 (various diameters)	12,000 km	2009[5]
(Sub)millimeter	ALMA	Atacama Large Millimeter/submillimeter Array	Chile	66 (54 × 12 m, 12 × 7 m)	16 km	2009[6]
Low-frequency radio	LOFAR	Low-Frequency Array	Europe (core in the Netherlands)	~20,000 dipole antennas	1,300 km	2010
Radio	ASKAP	Australian Square Kilometre Array Pathfinder	Western Australia	36 × 12 m	6 km	2012
(Sub)millimeter	NOEMA	Northern Extended Millimetre Array	France	12 × 15 m	1.7 km	2014[7]
VLBI	CHIME	Canadian Hydrogen Intensity Mapping Experiment	British Columbia, Canada (outriggers in Canada and USA)	4 half-pipe-shaped antennas (100 × 20 m each) + 3 smaller outrigger telescopes	3,300 km	2018 (outriggers: 2024/2025)
Radio	MeerKAT	Meer (“more”) Karoo Array Telescope	South Africa	64 × 13.5 m	7.7 km	2018
Radio	DSA-2000	Deep Synoptic Array 2000	Nevada, USA	2,000 × 5 m	19 km	2027?
Radio	SKA-Mid	Square Kilometre Array Mid-frequency	South Africa	197 (64 × 13.5 m, 133 × 15 m)	150 km	2028?
Low-frequency radio	SKA-Low	Square Kilometre Array Low-frequency	Western Australia	~130,000 dipole antennas	74 km	2028?
Optical	MROI	Magdalena Ridge Observatory Interferometer	New Mexico, USA	10 × 1.4 m	340 m	2030?
VLBI	ngVLA	Next-Generation Very Large Array	USA/Mexico (core in New Mexico)	263 (244 × 18 m, 19 × 6 m)	8,860 km	2037?[8]

Notes

[1]Expanded and renamed NOEMA in 2014; [2]First fringes with limited number of telescopes (array completed in 2002); [3]First fringes with two 1.8-meter telescopes (completed in 2011); [4]Expanded from the older Owens Valley Radio Observatory (OVRO) array and the relocated Berkeley-Illinois-Maryland Association (BIMA) array; [5]First observations with limited number of antennas (ALMA joined in 2017); [6]First fringes with two antennas (first science observations in 2011; array completed in 2013); [7]Start of NOEMA project (array completed in 2022); [8]First science observations expected in 2031



▲ **VLBI** For its 2017 campaign, the Event Horizon Telescope combined eight observatories at six sites to create a planet-size interferometer. *Left:* The stations, with baselines color-coded. Solid lines connect those that observed our galaxy's central black hole; M87* observations excluded SPT and added the dashed baselines. *Right:* Station pairs create baselines of different lengths (axes are multiples of the observed wavelength, 1.3 mm). As the world turns, each baseline changes, tracing out curves in the *u*,*v*-plane. The circles mark resolutions of 50 (inner circle) and 25 (outer) microarcseconds.

LEAH TISCIONE & BEATRIZ INGLESSIS / *S&T*, SOURCE: EHT COLLABORATION / *ASTROPHYSICAL JOURNAL LETTERS* 2022, 930:L12 (2)

a variety of separations and orientations, fills in the imaginary mirror — also known as the *u,v-plane*, where *u* and *v* are just two orthogonal coordinates — and provides information in various directions and at multiple scales. But in order to reconstruct the image (a computationally intensive process), the fringe pattern from each and every possible baseline has to be pulled out of the noise, and the amplitude of the signal at every location in the fringe pattern needs to be precisely measured — a process known as *correlation*.

Two to Tango

The Large Binocular Telescope (LBT) on Mount Graham in Arizona is a two-element optical interferometer on a single mount. The telescope has two large primary mirrors, each 8.4 meters in diameter. Together they provide the same light-gathering power as a single 11.8-meter mirror and the same angular resolution as a 22.8-meter telescope. Since the two mirrors share the same mount, there is no need to compensate for geometric time delay.

Another two-element optical interferometer was the Keck Interferometer, which combined the light from the two 10-meter Keck telescopes on Mauna Kea, Hawaiʻi, providing the same angular resolution as an 85-meter telescope. Funded by NASA, it began operations in 2003 but was decommissioned in 2012. Since then, the two Keck telescopes have only operated individually.

Radio Advantage

Every part of this process is much easier to accomplish at long radio wavelengths than at short optical wavelengths. Granted, to reach a certain angular resolution, a radio telescope needs to be much larger than an optical instrument, as resolution is inversely proportional to wavelength. But longer wavelengths also loosen the constraints on the surface accuracy of the reflecting surface: While telescope mirrors need to be smoothly polished to a fraction of a micrometer, the dish of a radio telescope often consists of wire mesh.

The same holds for the separation between the elements of an interferometer and the path-length corrections: the necessary precision is tens of nanometers for optical interferometry, versus centimeters for traditional radio interferometry.

Furthermore, in an optical interferometer, the light collected by the various telescopes needs to be transported by means of mirrors (or fiber optics) to a complicated instrument that correlates the signals optically, using the photons themselves. But a radio telescope's receiver converts radio waves into electrical signals at the focal point of the dish, enabling astronomers to amplify the signals, transport them through cables, and carry out the correlation process electronically with a dedicated computer. "For instance, the Gravity interferometric instrument on the VLTI is enormously complex and expensive," says Heino Falcke (Radboud University, The Netherlands), one of the founders of the Event

Horizon Telescope consortium, "while in radio astronomy, we just need a fast computer and good algorithms."

Little wonder then that radio interferometry took off so fast in the late 1950s and 1960s, in particular in the United Kingdom, Australia, the United States, and the Netherlands. These developments led to large interferometric arrays, such as the Westerbork Synthesis Radio Telescope (WSRT) in the Netherlands and the VLA in New Mexico, with fourteen and twenty-seven 25-meter dishes, respectively. (For a list of notable interferometers, see the table on page 17.)

As the individual telescope dishes observe together over many hours, Earth turns, changing the orientations of the various baselines with respect to the sky. Utilizing this effect, a method known as *Earth rotation aperture synthesis* and pioneered by British radio astronomer Martin Ryle in 1962, results in more complete coverage of the *u*,*v*-plane and a corresponding improvement in image quality. (Ryle shared the 1974 Nobel physics prize for this invention.)

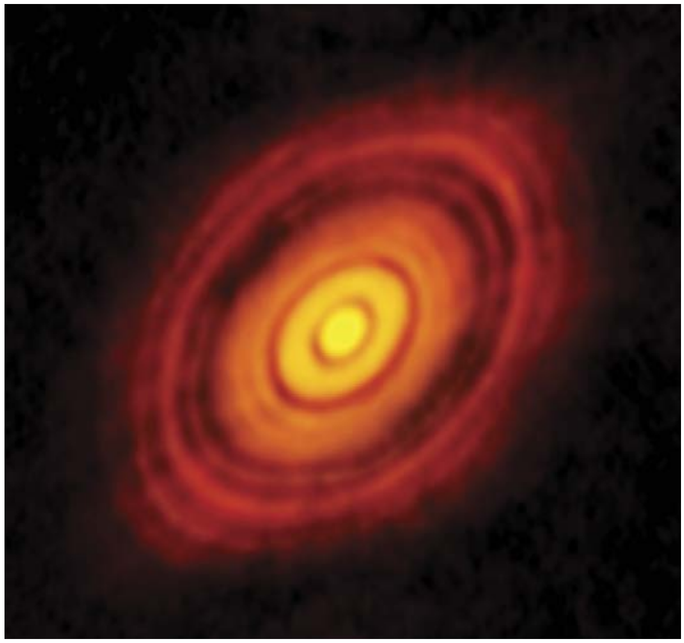
In the case of the VLA, operators can also move the array's dishes on railroad tracks, changing the baselines depending on an observing program's goals. This makes it possible to use the facility as a makeshift zoom lens: In the "large" configuration, with the antennas spread across tens of kilometers, the array has higher angular resolution but can only observe small-scale structures, while in the "small" configuration, with all antennas close together, larger-scale structures can be observed, albeit at lower resolution.

Worldwide Telescopes

Using the first radio interferometers, astronomers mapped the distribution of cold hydrogen gas in galaxies beyond our own Milky Way, discovered the narrow jets spewed into space in two opposite directions by radio galaxies, and pinpointed the precise sky locations of enigmatic radio sources like pulsars and quasars. But reaching even higher angular resolution required baselines of many hundreds or even thousands of kilometers. So how do you "connect" radio telescopes on different continents?

The straightforward answer: You don't, since you don't have to. Remember that the radio waves observed by a single dish are converted into electrical signals. You can store these signals on magnetic tape or giant hard drives for later processing. If they all have precise, synchronized time stamps, provided by atomic clocks, the time-delay corrections, the correlation, and the image reconstruction can take place at a later stage, anywhere on the globe (and usually in a supercomputer). Thus emerged the technology known as VLBI — very long baseline interferometry.

VLBI easily reaches resolutions on the order of milliarcseconds, but it has its own logistical problems. For instance, the European VLBI Network (EVN) works with data from 21 radio telescopes (or arrays) in Europe, eastern Asia, and South Africa. But all these facilities have their own designs, frequency limitations, and receiver characteristics. Moreover, they carry out their own observing programs, so planning a



▲ **HL TAURI** This now-iconic ALMA image shows the protoplanetary disk around the young star HL Tauri. Astronomers suspect that forming planets carve out the gaps between the rings in the disk.

ALMA (ESO / NAOJ / NRAO)

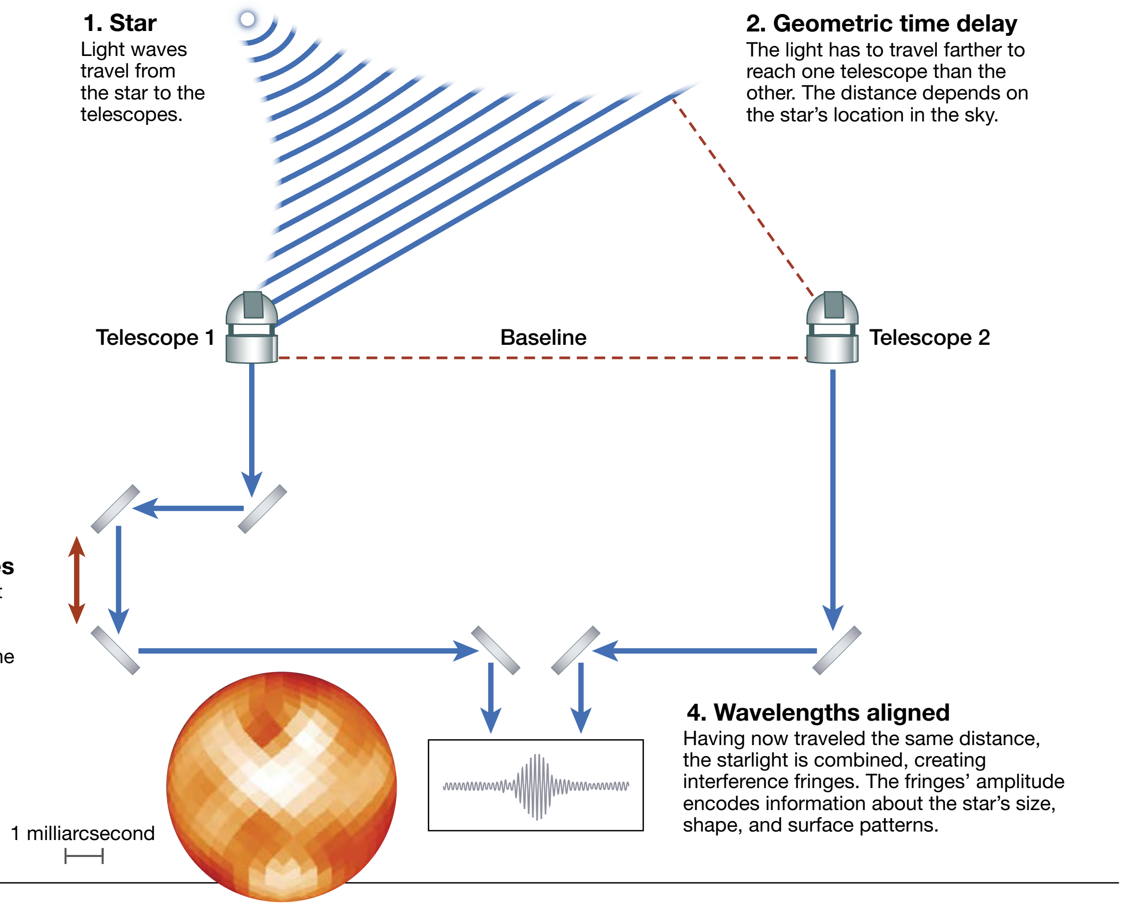
VLBI run requires a lot of organization and fine-tuning, says van Langevelde, who is also chief scientist of JIVE (Joint Institute for VLBI ERIC, where ERIC stands for European Research Infrastructure Consortium). In contrast, the American Very Long Baseline Array (VLBA) consists of 10 identical and dedicated 25-meter dishes, spread out between Hawai'i and the Virgin Islands, so it doesn't suffer from these issues as much.

Among many other achievements, VLBI enabled the discovery of superluminal (apparently faster-than-light) motion of plasma blobs in radio jets and the ultra-precise localization of fast radio bursts. In addition, by turning the technology around, so to say, VLBI observations of distant quasars yield the most accurate measurements of continental drift. And in 2020, astronomers for the first time used VLBI to discover an exoplanet, by measuring the induced wobble of a radio-loud red dwarf star as the planet orbited around it. According to van Langevelde, VLBI astrometry is even more precise than what's possible with the European Space Agency's (ESA's) Gaia space observatory.

Black Holes and Microwaves

VLBI technology is the bread and butter of the Event Horizon Telescope, which produced the first-ever image of a black hole. The main difference is that observations are carried out at shorter submillimeter wavelengths, at the high end of radio frequencies. "We experience all the problems of VLBI, but worse," says Falcke. "Everything is getting more complicated."

In particular, turbulence in the atmosphere has a much stronger disturbing effect at submillimeter wavelengths than it does for longer radio waves. That's because atmospheric water vapor absorbs submillimeter waves (which is why



▶ **IMAGING A STAR'S SURFACE** Optical interferometers use an elaborate system of mirrors to combine the light received from a source by two or more telescopes. The resulting interference pattern enables them to resolve details that would otherwise be inaccessible and to create images of stellar surfaces, such as that of Polaris (inset).

submillimeter telescopes need to be located at high and dry sites). According to Falcke, the amount of absorbing water vapor in the troposphere above a submillimeter telescope varies on a time scale of 10 seconds or so.

As a result, the detailed structure of a distant source (like the ring of light around the supermassive black hole in the galaxy M87) can only be inferred through a complicated process, involving not only the "regular" correlation of the interference patterns of many baselines but also precise calibrations to correct for subtle effects like the minuscule drifts of the atomic clocks, as well as the development of image-processing algorithms. "The devil is in the details," says Falcke. Indeed, the EHT black hole images are not "real" photos, but elaborate image *reconstructions* that best fit the observations.

Then again, says Falcke, "What is a 'real' photo these days? It's all about processed light. We do everything a camera with a highly scratched lens would also do, and then remove the artifacts [caused by the scratches]. Raw Hubble images don't look quite so nice, either, when they come out of the telescope and before they go into the analysis pipeline. Of course, we have the worst 'lens' of all, but then it is also the biggest."

The same of course holds for all other interferometric images, including those from the international Atacama Large Millimeter/submillimeter Array (ALMA) in northern Chile, which also takes part in EHT observing runs. ALMA is an interferometer itself, consisting of 66 radio dishes that can be moved around an area 16 kilometers (nearly 10 miles) across. According to Wouter Vlemmings (Onsala Space Observatory, Sweden), it is by far the most powerful instrument for millimeter and submillimeter observations, building on earlier experiences with smaller interferometers at Plateau de Bure in France and on Mauna Kea in Hawai'i that operated in the same wavelength range.

With 66 antennas, as opposed to the VLA's 27, ALMA is much better at producing nice images: There are fewer "holes" in the *u*,*v*-plane, because the number of correlated baselines grows with the square of the number of antennas. "Probably the most iconic ALMA result was the image of the protoplanetary disk surrounding the young star HL Tauri," says Vlemmings. "When that image came in, many of us first thought it was a model simulation."

Despite the many difficulties and intricacies of performing interferometry at submillimeter wavelengths, ALMA has produced many impressive results, including the detection of bubbles on the surface of the star R Doradus; detailed images of distant, dusty star-forming regions; and information on the disk-like morphologies of extremely remote galaxies in the early universe — all thanks to interferometry.

Optical Challenges

Compared to submillimeter interferometry, optical interferometry is even more complicated. That's partly because of

POLARIS: NANCY REMAGE EVANS ET AL. / *ASTROPHYSICAL JOURNAL* 2024, 971:190; INTERFEROMETER: LEAH TISCIONE / *S&T*

the shorter wavelengths, but also because everything has to happen in real time, using the photons themselves instead of electrical signals. "Our frequencies are too high," says CHARA's Schaefer, "so we can't record and combine the observations after the fact, as radio astronomers do."

CHARA saw "first fringes" in 1999 and started full operations in 2002. The data from six identical 1-meter telescopes, with a maximum separation of 330 meters, are brought together through vacuum tubes into a central interferometry lab, where time delays are taken care of by mirrors on continuously moving carts on rails. A 2019 upgrade of the facility included the deployment of adaptive optics to eliminate atmospheric turbulence. In the near future, the array will be expanded with a movable telescope, connected through fiber optics, and eventually, all of the 1-meter telescopes may be replaced by larger 2-meter ones.

"We do optical interferometry almost every night," says Schaefer, "using one visible-light and two near-infrared instruments in the lab." Among the results are high-precision measurements of stellar diameters and pulsations; determinations of the orbits and masses of close binary stars; images of starspots (for instance on Zeta Andromedae and, more recently, on Polaris); and observations of the inner regions of protoplanetary disks.

According to Schaefer, CHARA's main "competitors" are the Navy Precision Optical Interferometer (NPOI) at Anderson Mesa in Arizona, the Magdalena Ridge Observatory Interferometer (MROI) under construction by British and American astronomers in New Mexico, and the European VLTI at Cerro Paranal in northern Chile.

The VLTI is arguably the most powerful optical interferometer in the world: Using optical delay lines, it can combine signals not only from the observatory's four 8.2-meter Unit Telescopes, but also from four movable 1.8-meter Auxiliary Telescopes. This makes it possible, for example, to map the motions of individual stars orbiting the galactic center — providing definitive, Nobel Prize–winning proof of the existence of the supermassive black hole that was later imaged by the Event Horizon Telescope (*S&T:* Dec. 2022, p. 12).

Bright Future

Interferometry has become an indispensable part of astronomical research, especially in the field of radio astronomy. Future large facilities like the next-generation VLA (ngVLA), the Square Kilometre Array, and the Deep Synoptic Array 2000 (*S&T:* Sept. 2023, p. 14) will exploit the technology to the fullest extent. Submillimeter, near-infrared, and visible-light applications are expected to become ever more commonplace, thanks to new developments in signal processing and computer technology. Physicists are also exploring ways of using quantum technology to realize a form of optical VLBI.

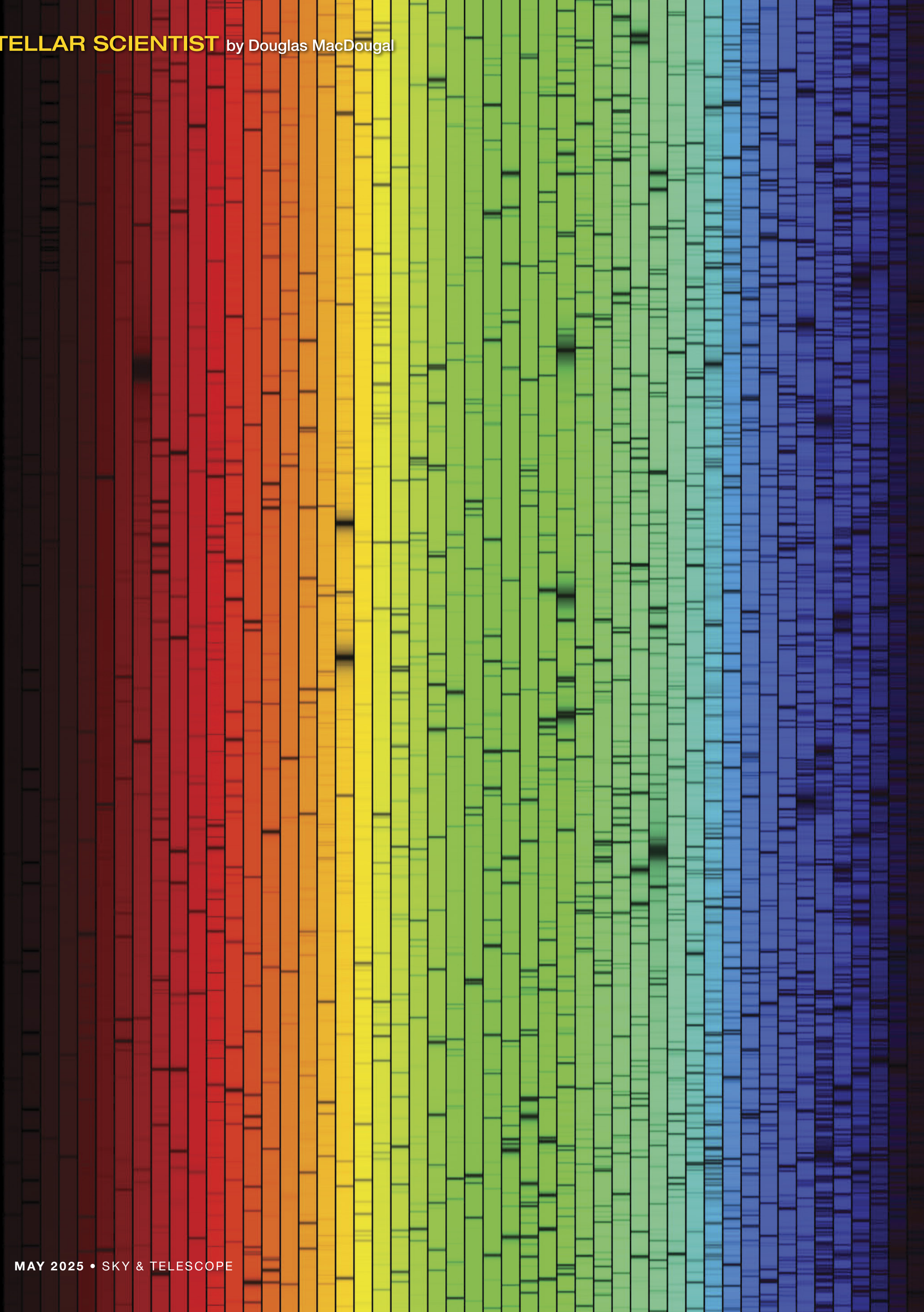
These advances will also see us putting interferometers in space. There have already been experiments with space-based radio interferometry, and astronomers are now thinking of extending the Event Horizon Telescope to Earth orbit. Space interferometry with baselines of 2.5 million kilometers lies at the heart of the Laser Interferometer Space Antenna (LISA), a Sun-orbiting gravitational-wave detector to be launched by ESA in 2035. If astronomers could combine similar technology with optical space telescopes, we might one day be able to map oceans and continents on distant exoplanets.

It's impossible to predict the new discoveries interferometry may bring, but one thing's for sure: Astronomers will never refrain from further sharpening their vision.

■ Contributing Editor **GOVERT SCHILLING** hates it when something interferes with his writing process, especially when the deadline is near and there's no hope for time delay.

INFRARED INTERFEROMETER The Very Large Telescope complex in Chile includes four 8.2-meter telescopes and four 1.8-meter movable telescopes (small domes). The smaller scopes can be relocated to 30 different positions.

J. L. DAUVERGNE & G. HÜDEPOHL (ATACAMAPHOTO.COM) / ESO



NIGEL SHARP / FTS / NSO / KPNO / AURA / NSF

A Stellar Revolution Turns 100

In 1925, pioneering astronomer Cecilia Payne found hydrogen in stars and disbelievers on Earth.

A century ago, astronomy had a momentous year. Two discoveries in 1925 were to reshape cosmology and astrophysics. On New Year's Day, Edwin Hubble announced the discovery of Cepheid variable stars in the Andromeda "nebula" at a meeting of the American Astronomical Society in Washington, DC. This finding, involving stars whose periodic pulsations depend on their inherent brightness, proved that the galaxy was much farther away than previously thought. It also triggered Hubble's all-out search for Cepheids in other galaxies that, by 1929, provided evidence of an expanding universe.

A second, paradigm-changing revelation in 1925 did not come from an established scientist at a well-known observatory, but from page 184 of a 210-page PhD thesis written by a little-known student at Harvard named Cecilia Payne. She found that stars consist mainly of hydrogen and helium. Her finding spelled trouble: It flew in the face of renowned Princeton astronomer Henry Norris Russell's firm opinion that the elements in stellar atmospheres closely mirror terrestrial abundances — a fact Payne largely confirmed but for the glaring exceptions of hydrogen and helium.

In particular, she found hydrogen to be a *million times* more abundant in stars than on Earth. The stage was thus set for conflict: A female graduate student was prepared to publish a thesis contradicting a venerable giant in American astronomy whose approval she needed for her degree. To get a sense of the issues at stake, let's look back to the events of that era, a time when the science of astrophysics was a new and incredibly promising field.

◀ **NOT JUST A RAINBOW** When seen in high resolution, the Sun's visible-light spectrum shows hundreds of dark lines. At these wavelengths, light emitted by the photosphere is being absorbed by specific atoms and ions higher up in the solar atmosphere.

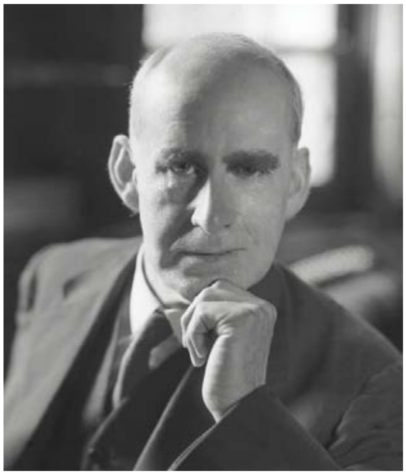
▶ **EYES TO THE STARS** Cecilia Payne-Gaposchkin (1900–79), as captured by American portraitist Patricia Watwood in 2001.

Stars, Earth, and Atoms

In the 1860s, Englishman William Huggins wanted to know what stars are made of. Like a forensic detective, Huggins compared the spectra of stars with those of terrestrial metals and gases, looking for spectral-fingerprint matches. Betelgeuse and Aldebaran revealed the presence of iron, sodium, calcium, magnesium, and hydrogen. Other spectroscopists joined in, and by 1914 Russell noted a resemblance between the chemical composition of Earth's crust and the elements found in the Sun's spectrum.

But determining actual abundances of these elements in the atmospheres of stars — even the Sun's — was tricky business, pushing at the cutting edge of unfamiliar new physics. It turned out that the most powerful tool for investigating stars lay within the innards of the atoms themselves.

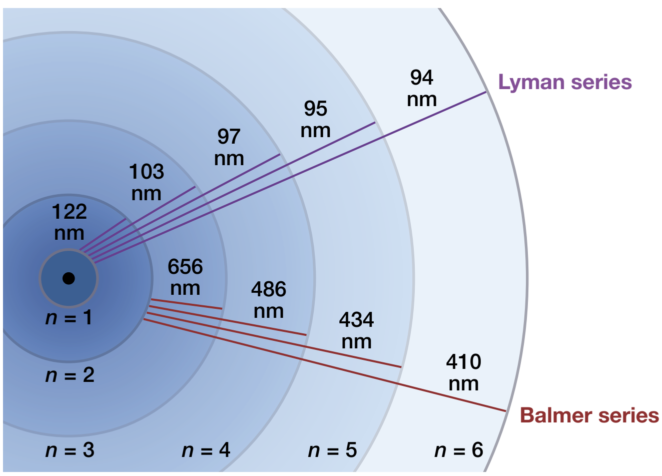
An unexpected uniting of atoms and stars arose from the work of German physicist Max Planck, who in 1900 (the year Payne was born) had a revolutionary insight. He deduced that electromagnetic radiation had to be absorbed or emitted by matter only in discrete packets of energy. Planck's insight became the foundation of quantum theory, which in the early 20th century took the world of physics by storm.



◀ **ROLE MODEL** Considered the dean of English astronomy, Sir Arthur Stanley Eddington (1882–1944) did his greatest work investigating the structure and evolution of stars. His lecture on his 1919 eclipse expedition mesmerized the young Payne.

Danish physicist Niels Bohr decided to try quantum physics out on the simple hydrogen atom. Originally pictured as a miniature solar system with one tiny electron orbiting a proton, Bohr's quantum picture of the atom required electrons to obey two basic rules: Only certain discrete orbits are allowed, and electrons cannot exist between orbits — they can only *jump* among them. It seemed very strange (and still does), but it worked to enable computation of the exact wavelengths and strengths of hydrogen's spectral lines.

If we follow a path inward to this miniature atomic realm, we'll observe the mysterious game-like logic that follows from Bohr's simple rules. If an electron *absorbs* a photon — a discrete packet of electromagnetic radiation from some external source — the electron will become "excited" and jump to a higher orbit (energy level), like climbing up to the next floor in a multistory building. Absorption of even-higher-energy photons will excite the electron to jump to still-higher orbits (going straight to the upper floors). An electron may in time also "relax" and return to a lower energy state (to a lower floor), by single or multiple steps, by *emitting* photons of varying energies.



▲ **JUMPING UP AND DOWN** A hydrogen atom consists of a single electron orbiting a single proton. Yet that electron can occupy a wide range of energized states, resulting in many spectral lines when it absorbs or gives up specific quanta of energy (indicated here by their wavelengths in nanometers). Not shown are hydrogen's four other named series with corresponding energies at infrared wavelengths.

There are some complexities to the picture. English physicist Arthur Stanley Eddington described the electron of an excited atom as "a guest in an upper story of an old-fashioned hotel with many alternative and interlacing staircases; he has to make his way down to the lounge — the normal unexcited condition." He may spontaneously descend along many possible stairways, but sometimes "the guest comes to a cul-de-sac from which there is no way leading downwards." Yet there's another option: If the guest happens to absorb energy, "he may ascend to a higher landing and try a new descent."

Crucially, when an electron jumps up or down to different-energy orbits, the absorbed or emitted photon will have an energy (wavelength) *exactly* equal to the difference of the energy levels in the two states, as depicted at lower left. Energy is thus neatly conserved.

All this is why spectra have discrete lines. The photographic spectrum is a record of photons emitted (as bright *emission lines*) or absorbed (dark *absorption lines*) at specific wavelengths of energy — indicated by the spacing of the lines on the spectrum — which can be calculated. Collectively, each line of a spectral series corresponds to atoms in a discrete state of excitation. And different elements have uniquely different spectral fingerprints.

Still further additions of energy will excite the hydrogen electron to even-higher energy levels (higher stories in the hotel), tempting it away from the proton's nagging pull, until the electron is finally evicted from its atomic home — flung off the hotel's roof! This atom becomes *ionized,* left to wander alone with a positive charge. Its spectrum will be transformed as well. For any ionized atom heavier than hydrogen, its spectral lines will resemble the preceding element in the periodic system (so ionized helium, for example, mimics neutral hydrogen). This fact, unknown before, had caused great confusion in the early interpretation of spectra.

These new realizations helped make sense of stellar spectra. The originally puzzling ultraviolet spectrum of the white star Vega, for example, was astronomers' first acquaintance with the ultraviolet spectrum of hydrogen in the stars and its harmonic sequence. Remarkably, the pattern mirrored the hydrogen-line sequence already discovered in the laboratory by Swiss schoolteacher Johann Jakob Balmer.

A Determined Scientist

Cecilia Helena Payne came of age during this exciting time. Born in Wendover, England, she descended from a family of scholars and historians. Over time, young Cecilia absorbed everything she could about botany, mathematics, physics, and astronomy. Eventually she enrolled in Newnham College at the University of Cambridge. There she encountered Arthur Stanley Eddington.

The foremost astronomer and physicist at Cambridge of the time, Eddington would have a decisive influence on the life of Payne. He had recently returned from his celebrated May 1919 trip to the island of Príncipe off the west coast of Africa, where he had photographed a total solar eclipse to test a key prediction of Einstein's general theory of relativity. During totality, Einstein supposed, the light from stars near the solar limb should be bent by a small but measurable angle by the Sun's gravity — an effect Eddington was able to confirm.

Eddington presented his results at a winter gathering in the Great Hall of Cambridge's Trinity College. The gravitational deflection of stars found by his expedition agreed closely with Einstein's calculations. The news made Einstein world famous. For Payne, the result was "a complete transformation of my world picture," and she would henceforth be "dedicated to physical science, forever." The next day she informed the school's authorities that she intended to major in physics.

It was not easy for women to study physics at Cambridge; they needed thick skins to survive. Payne was the only woman in Nobel-winner Ernest Rutherford's advanced course in physics. Regulations required that women sit by themselves in the front row. Gazing at her pointedly, Rutherford would begin each lecture in a booming voice, "*Ladies* and gentlemen," a witticism at which the men in the room would applaud thunderously and stamp their feet.

But Payne found a kindred and appreciative spirit in the soft-spoken Eddington. During an accidental encounter at the observatory, she impulsively confessed her ambition to become an astronomer. Eddington replied, "I can see no *insuperable* objection," words that she later said, "opened the doors of the heavens to me." Still, Eddington and her other professors knew that, no matter how gifted and passionate Payne might be, the opportunity for a woman to become an astronomer in England was effectively nil.

However, another spellbinding lecture by another astronomer became the impetus for the next great journey of her life.

Payne and Shapley

The amiable Harlow Shapely was the newly appointed director of Harvard College Observatory. For Payne, the talk he gave while visiting London was memorable. "He spoke with extraordinary directness, conveyed the reality of the cosmic picture in master strokes," she later wrote. "Here was a man who walked with the stars and spoke of them as familiar friends. They were brought within reach; one could almost touch them." When introduced to Shapely, Payne came

A Slow Climb up Harvard's Ladder

After earning her PhD, Cecilia Payne remained at Harvard and, in 1934, married Russian-born astronomer Sergei Gaposchkin. Meanwhile, her institutional recognition was slow, measured by the decade. Her first official Harvard appointment came in 1938, yet her courses weren't listed in the university's catalog until 1945. In fact, even though she lectured and advised students (in addition to her research), her title remained "technical assistant."

Observatory director Harlow Shapley urged Harvard's president, Abbott Lawrence Lowell, to promote her. But Lowell flatly refused, stating that Miss Payne (as she was known then) "would never have a position in the University as long as he was alive."

Finally, long after Lowell left Harvard and Donald Menzel became the observatory's director, Payne-Gaposchkin became a full professor in 1956 — "the first woman at Harvard to attain that rank," notes science writer Marcia Bartusiak, "perhaps twenty years after a man of her achievements would have earned the position."

▲ **STELLAR SCIENTIST** Ceclia Payne, in her office at Harvard College Observatory, finally became a full professor there 31 years after getting her PhD.

◀ **A STEADY HAND** Harlow Shapley, seen here in 1946, served as director of Harvard College Observatory from 1921 to 1952. Payne found conversing with him "like a rousing game of ping-pong."

PAYNE: SMITHSONIAN INSTITUTION ARCHIVES; SHAPLEY: UNIVERSITY OF MINNESOTA ARCHIVES

HARVARD OBSERVATORY MONOGRAPHS
HARLOW SHAPLEY, EDITOR

No. 1

STELLAR ATMOSPHERES

A CONTRIBUTION TO THE OBSERVATIONAL STUDY OF HIGH TEMPERATURE IN THE REVERSING LAYERS OF STARS

BY

CECILIA H. PAYNE

PUBLISHED BY THE OBSERVATORY
CAMBRIDGE, MASSACHUSETTS
1925

TABLE XXVIII

Atomic Number	Atom	Log a_r	Atomic Number	Atom	Log a_r	Atomic Number	Atom	Log a_r
1	H	11	13	Al	5.0	23	V	3.0
2	He	8.3	14	Si	4.8	24	Cr	3.9
	He+	12		Si+	4.9	25	Mn	4.6
3	Li	0.0		Si+++	6.0	26	Fe	4.8
6	C+	4.5	19	K	3.5	30	Zn	4.2
11	Na	5.2	20	Ca	4.8	38	Sr	1.8
12	Mg	5.6		Ca+	5.0		Sr+	1.5
	Mg+	5.5	22	Ti	4.1	54	Ba+	1.1

◀ **FIRST OF ITS KIND** The title page of Cecilia Payne's historic, 210-page doctoral thesis.

▲ **STELLAR REVOLUTION** The relative abundances (a_r) of various atoms found in stars, as tabulated in Payne's 1925 thesis. These are log values, so hydrogen (H) is 1,000,000 times (10^{11-5}) more abundant than aluminum (Al), for example.

HARVARD COLLEGE OBSERVATORY ARCHIVES (2)

immediately to the point: "I should like to come and work under you." Shapley replied that he'd be delighted to have her come to Massachusetts, and after graduation she departed for America in the autumn of 1923.

Only two years later, easily established as the brightest light at Harvard College Observatory, Cecilia Payne completed her seminal doctoral thesis, *Stellar Atmospheres: A Contribution to the Observational Study of High Temperature in the Reversing Layers of Stars*. Her goal had been to determine the abundances of elements in the stars using the most advanced techniques in physics. This meant mining data. Fortunately, Harvard College Observatory had the greatest collection of photographic spectra in the world.

Among all the swarms of stars, there are only a handful of temperature-determined spectral types (originally seven: *O, B, A, F, G, K*, and *M*), forming a more or less continuous series from hot stars to cool. Yet mysteries were lurking in the spectra: Helium lines are strong in the hot *O* and *B* stars and nowhere else; hydrogen lines are strong in *A* stars then trend steadily downward; calcium lines peak in *K* stars.

Wonderful as it was, Harvard's grand vault of empirical data still lacked an explanation of exactly why things appeared as they did. To understand the compositions of stars, Payne would have to solve the mystery of these myriad spectral-line intensities.

A breakthrough had occurred in 1920 with the work of the brilliant Indian astrophysicist Meghnad Saha, whom Payne described as "a great and simple personality." Saha emphasized the role of ionization in the appearance of spectral lines, and how lines can appear strong or hidden depending on the condition of what is known as the *reversing layer* of a star's outer atmosphere, gases existing at perhaps ¹⁄₁₀,₀₀₀ of Earth's sea-level pressure.

In her thesis Payne explained how the radiation from a star's brilliant photosphere (which provides the background light in the form of a continuous spectrum) is intercepted by this overlying blanket of gases. Photons rising up from the photosphere are selectively caught by atoms in the reversing layer (via the exact process of absorption and excitation envisioned by Bohr), and consequently those narrow-wavelength slivers of radiation are removed from the photosphere's light. These subtractions show up as the dark lines in the photosphere's otherwise continuous spectrum (thus "reversing" from bright to dark) and revealing the elements present in the reversing layer.

Payne adeptly showed that Saha's equations, along with studies by British astronomers Ralph Fowler and Edward Arthur Milne, quantify how temperature, pressure, and density in a star's atmosphere determine which atoms in its reversing layer will be ionized and the wavelengths at which they'll disappear in the star's spectrum. For example, the so-called H and K lines are due not to neutral calcium but to singly ionized atoms of calcium.

With Saha's tools, Payne could now predict the relative abundances of individual elements in stellar atmospheres — that is, not just *which* elements exist in stars but *how much of each* is there. Payne's mastery of every aspect of this complex astrophysical problem convinced her that stellar abundances quite closely paralleled terrestrial abundances except for hydrogen and helium.

Trouble with Russell

Shapley sent Payne's draft thesis to Henry Norris Russell in December 1924. Shapley's former teacher and mentor at Princeton, Russell was an acknowledged expert in incorporating cutting-edge physics into astronomy. On January 14th, he sent a handwritten letter to Payne, noting that she had some "very striking results which appear to me, in general, to be remarkably consistent [with my own findings]."

But then he continued: "There remains one very much more serious discrepancy, namely, that for hydrogen, helium and oxygen. Here I am convinced that there is something seriously wrong with the present theory. It is clearly impossible that hydrogen should be a million times more abundant than the metals."

The remark must have been a crushing disappointment to Payne. She would later be proven correct in a grand way, but given Russell's formidable influence, she was induced to recant. It is painful to see how her published thesis bears the stamp of Russell's censorship. Even though she had used the same methods for all elements studied, Payne declared the abundance of hydrogen in stars to have an "impossibly high value," her dramatic conclusion sadly "spurious" and "almost certainly not real."

Thus revised, Payne's thesis was accepted May 1, 1925, with Shapley's rather downbeat forward cautioning that "the interpretation of stellar spectra from the standpoint of thermal ionization is new and the methods employed are as yet relatively primitive."

On Further Consideration

Russell's assessment wasn't entirely negative. After he had a chance to study Payne's published thesis with care, he wrote to Shapely later that year, calling it "the best doctoral thesis I ever read." His tone was enthusiastic: "As I read it over — I have eaten it up since I got it yesterday — I am especially impressed with the wide grasp of the subject, the clarity of the style, and the value of Miss Payne's own results." Overall, he declared her findings "very nice indeed."

What Payne had in fact had done masterfully was to confirm the overall chemical homogeneity of the universe. She showed how spectral differences among the stars resulted mainly from physical conditions rather than from varying abundances, and that for many

▶ **FEARED AND RESPECTED** Princeton's Henry Norris Russell (1877–1957) was a formidable figure in astronomy during the early 1900s and initially a skeptic of Payne's results, especially concerning the compositions of stellar atmospheres. When Russell visited Harvard, "we young people put aside all work and sat at his feet," recalled Payne, "listening for hours to a torrent of information . . . until he ran dry."

> The outstanding discrepancies between the astrophysical and terrestrial abundances are displayed for hydrogen and helium. The enormous abundance derived for these elements in the stellar atmosphere is almost certainly not real.

▲ **PAINFUL RETRACTION** As a consequence of criticism by Henry Norris Russell, Payne edited her PhD thesis to dismiss what was arguably her work's key finding.

heavier elements the compositions of stars' outer layers do parallel those of Earth.

With respect to hydrogen, Russell himself soon performed a startling about-face. In his own analysis, written in 1929, Russell found an "incredibly great" abundance of hydrogen in the Sun and concluded that the outer portions of stellar atmospheres "must be almost pure hydrogen." Yet he made no mention of Payne's earlier discovery of the hydrogen anomaly — or his role in suppressing it. Near the end he did acknowledge how his own work, using different methods, agreed with hers, which he found "very gratifying." A giant star, he now proclaimed, evidently had an outer atmosphere of nearly pure hydrogen, "with hardly more than a smell of metallic vapors in it."

For a long while thereafter, Russell was credited with the discovery of the astonishing dominance of hydrogen in stars. For example, his former student Donald Menzel in 1933 wrote, "It is difficult to escape the conclusion that hydrogen is the predominant element throughout the universe," citing only Russell's 1929 paper, with no mention of Payne.

Yet over time the unwarranted wrong was righted, and Payne's fellow astronomers came to appreciate her genius. Today she is universally recognized as one of the true pioneers in astrophysics. Regrettably, however, progress for women in science remained painfully slow. Her advice to young people reflected both her struggles and rewards:

> *Do not undertake a scientific career in quest of fame or money. There are easier and better ways to reach them. Undertake it only if nothing else will satisfy you; for nothing else is probably what you will receive. Your reward will be the widening of the horizon as you climb. And if you achieve that reward you will ask no other.*

■ **DOUGLAS MACDOUGAL** enjoys writing about the history of astronomy and the culture of scientific inquiry (his blog: **douglasmacdougal.com)**. He authored *Newton's Gravity: An Introductory Guide to the Mechanics of the Universe*. He thanks MIT Professor of the Practice Emeritus Marcia Bartusiak for her assistance and early review of this article.

RETRACTION: HARVARD COLLEGE OBSERVATORY ARCHIVES; RUSSELL: HANNA HOLBORN GRAY SPECIAL COLLECTIONS RESEARCH CENTER / UNIVERSITY OF CHICAGO LIBRARY

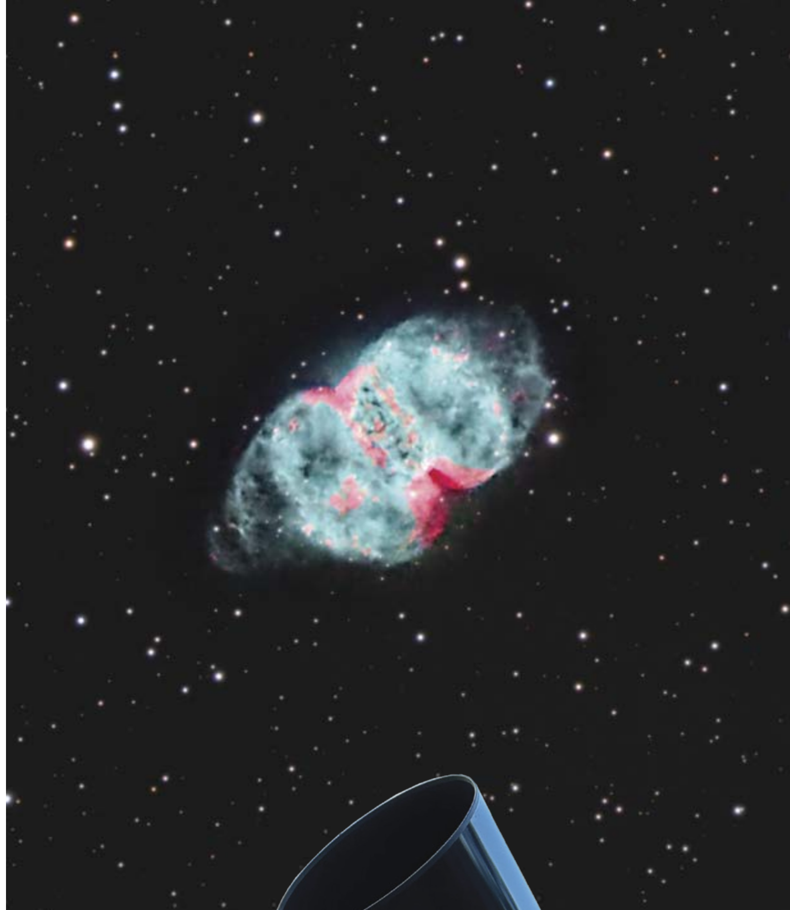
How to be a High-Resolution Imager

Follow these tips to improve your success at resolving fine details in small targets.

Over the 20 years I've been photographing the night sky, I've owned seven telescopes and five cameras of various designs. No, I'm not a shopaholic or an equipment junkie — I'm just an imager with a limited view of the sky. I do most of my imaging from my backyard observatory, where I can only access the skies north of about −10° declination. I spend some three or four years imaging the sky with a particular astrophotography rig, capturing data on everything that is accessible to me and that fits well in my current equipment's field of view. Every few years, I find myself revisiting the same fields with little improvement. When that happens, it's time to update my gear and start anew.

My latest scope is a 14-inch Celestron EdgeHD, which has a focal length of nearly 4 meters — more than twice the focal length of any previous system I've owned. Coupled with my QHY600M astro-camera in 2× binning mode, my pixel scale is about 0.4″ per pixel, allowing me to capture every bit of detail my sky will give me on steady nights. In addition, this high-resolution system puts thousands of new targets within reach — myriad distant galaxies, galaxy clusters, and

ALL IMAGES COURTESY OF THE AUTHOR



◀▶ **MAXIMUM DETAIL** The Little Dumbbell (M76) is a good example of an object that benefits from a high-resolution imaging system. The photo on the facing page was recorded with a 10-inch f/3.6 astrograph and SBIG STL-11000M CCD camera, which together produce a pixel scale of 2″. While it reveals some nice details, the picture at right taken through an f/11 Celestron 14-inch EdgeHD and QHY600M CMOS camera yields 0.4″ per pixel, not only showing far more detail but also filling the field much better.

tiny planetary nebulae are now available to keep me busy for many years to come.

The allure of thousands of new targets to pursue may have you thinking of stepping up to a high-resolution system yourself. But these rigs require some careful planning to consistently produce good results. Here are some tips to help you if you're considering taking the leap.

Focal Length, Aperture, and Resolution

It's worth spending a moment thinking about what high resolution means and why it matters at all. There's no single numerical definition, nor does it refer to the number of pixels on your camera's sensor. Rather, the term refers to a situation in which your equipment can capture all the detail that the atmospheric conditions will yield. For example, my skies in the Great Lakes region of North America often support a pixel scale on the order of 0.5″ per pixel on the better nights. That means the stars aren't fuzzy or bloated, and small-scale details in galaxies, nebulae, and star clusters are adequately resolved.

Since spatial resolution increases with aperture, a fairly large-aperture instrument is necessary to resolve tiny details: A 2-inch f/20 scope won't reveal the same amount of detail as an 8-inch f/5 optic, despite both having the same focal length (1,016 mm, or 40 inches). On the other hand, large apertures are more severely affected by unsteady seeing than smaller ones.

A telescope with both long focal length and large aperture is analogous to a big telephoto lens on an SLR camera. The telescope boosts the apparent magnification of your imaging system, so that objects look bigger than they do at shorter focal lengths. This means that targets that were just small blobs when imaged through smaller telescopes may fill a substantial part of the frame in a high-resolution system, and they'll show lots of detail that was barely hinted at when imaged with smaller instruments.

For example, my 14-inch scope and QHY camera together produce a field-of-view of approximately 31½ by 21′. This is a suitable field size for many individual galaxies or galaxy groups. While my 6-inch f/7 can frame both NGC 7331 and Stephan's Quintet in a single wide field, either target fills a large portion of the field with the 14-inch telescope. For this reason, when I upgrade, I often revisit small targets that I've captured before, in addition to trying my hand at very small objects that other photographers have rarely targeted, if at all.

Speaking of large telescopes, this type of imaging isn't generally recommended for imagers who must travel and set up their equipment each night. Big telescopes are heavy, and

▶ **BIG RIG** The author's Celestron 14-inch EdgeHD telescope and QHY600M camera ride atop a Software Bisque Paramount MX. With a payload weight capacity of 41 kilograms (90 pounds), the mount easily carries the 21 kg of the optical tube, counterweights, and imaging gear, with plenty of room to spare.

the mount that carries one will be even heavier. In addition, they are especially sensitive to wind. High-resolution imaging is better suited to a permanent setup in a backyard observatory or even a remote telescope-hosting facility, to ensure that you can take advantage of each clear night without the hassle of setting up and tearing down.

Your telescope choice is only half of what determines the spatial resolution in your images, though. The other key ingredient is the pixel size in your camera.

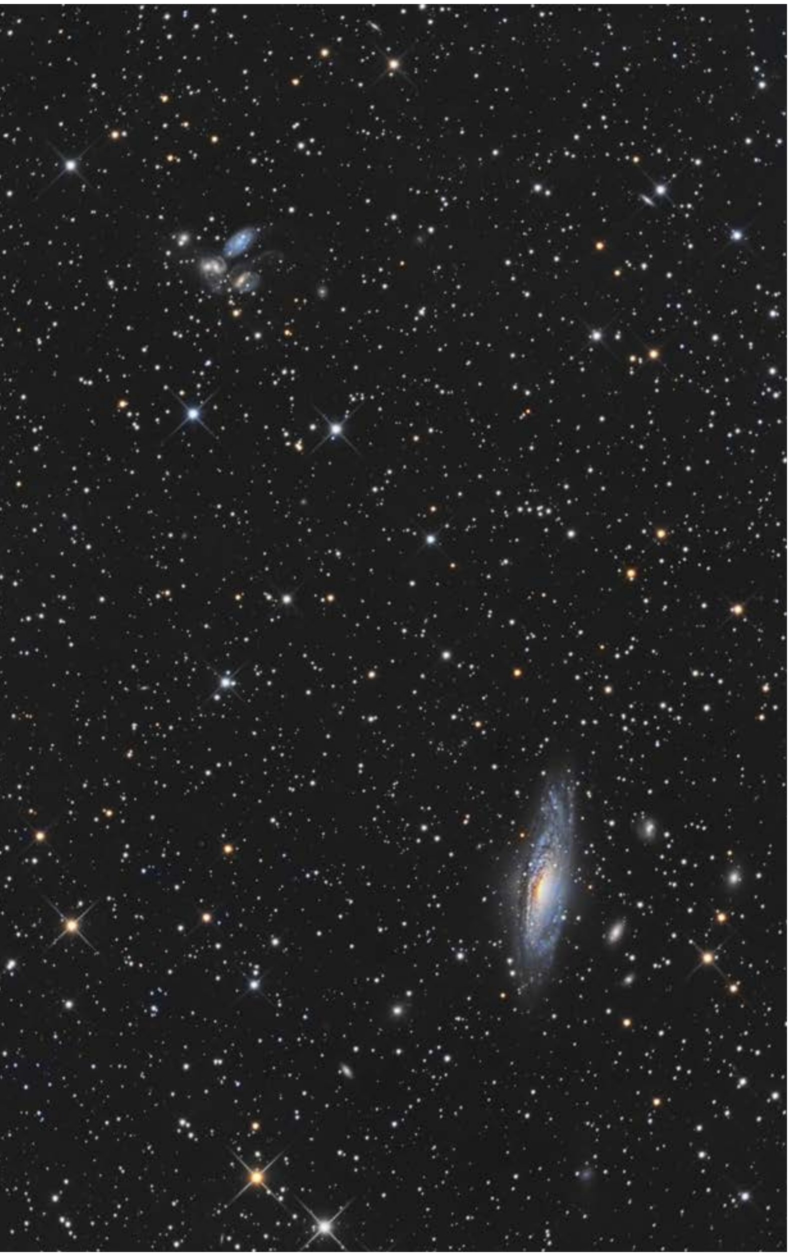
The size of the pixels in your camera's detector sets the final resolution of your system. Here's a helpful formula to determine the resolution or *pixel scale* of an image (measured in arcseconds):

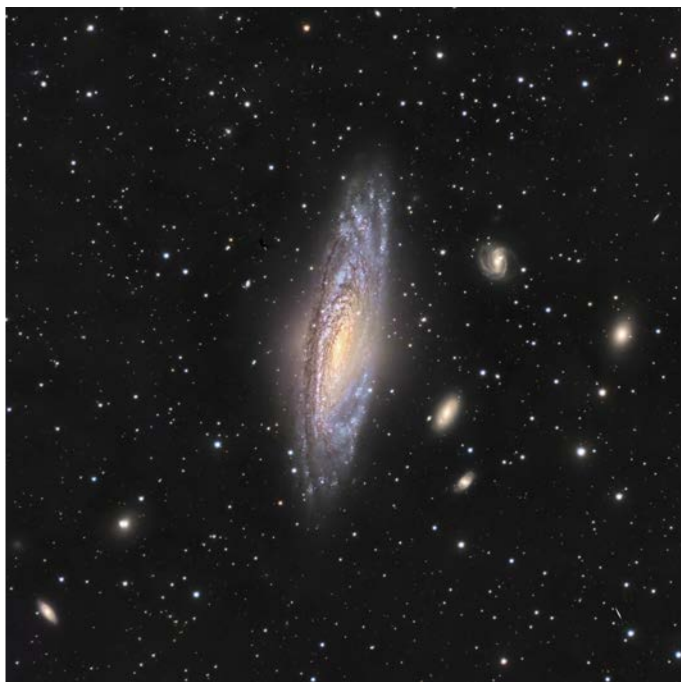
$$\textit{Pixel Scale} = 206.265 \times (P\ /\ F),$$

where P is the size of the pixels in your camera in microns, and F is the focal length of your telescope in millimeters.

Look for a model with pixel size that pairs well with your telescope. The QHY600M camera I use is built around a Sony IMX455 sensor with 3.76-micron pixels, which produces 0.2″ per pixel with the C14. That's much too small when shooting

▼▶ **PARTS OF THE SUM** While the author's 6-inch refractor easily captured both Stephan's Quintet and NGC 7331 in the photo below, either one on its own made excellent high-resolution targets in his C14 (seen at right and bottom right, respectively).





▶ **NOT SO TINY PLANETARIES** A high-resolution imaging system is an ideal rig for resolving small-scale details in some of the more distant planetary nebulae. *Top to bottom:* The author recorded these pictures of planetary nebulae NGC 40, NGC 1514, Abell 84, and Abell 13 using the gear shown on page 29.

at full resolution, because the atmosphere won't support it, but it's a good match when binning pixels 2 × 2, which makes a grid of four pixels act like a single larger pixel. (For more on pixel scale, see my article in the January issue, page 60.) This camera paired with an 8-inch f/10 telescope yields an image scale of 0.38″ per pixel, which ought to be sufficient to record all the detail the system can provide under good conditions. Binning 2 × 2 gives 0.78″, sufficient for imaging resolvable details on less steady nights.

Mount Performance

The challenge of imaging with a high-resolution system is that they are extremely unforgiving of any shortcomings. All your equipment must be "dialed in" and working together perfectly in order to guarantee success.

The heart of your system isn't actually the telescope you image through but the mount it rides upon. Tracking errors of more than 1″ or so result in elliptical stars and smeared details in your images. While minor tracking errors are somewhat correctable during processing, larger tracking errors are not, and these frames cannot be salvaged.

The way to avoid this problem is to start with an extremely accurate mount that has the weight capacity to carry your gear with plenty of room to spare. Don't load up a mount to its advertised weight capacity and expect perfectly guided images. In truth, you should try to keep the total load to about half of what the manufacturer recommends. And before you start optimizing tracking and autoguiding, make sure everything is properly balanced and polar aligned, ensuring your mount can perform at its best (*S&T:* June 2019, p. 64).

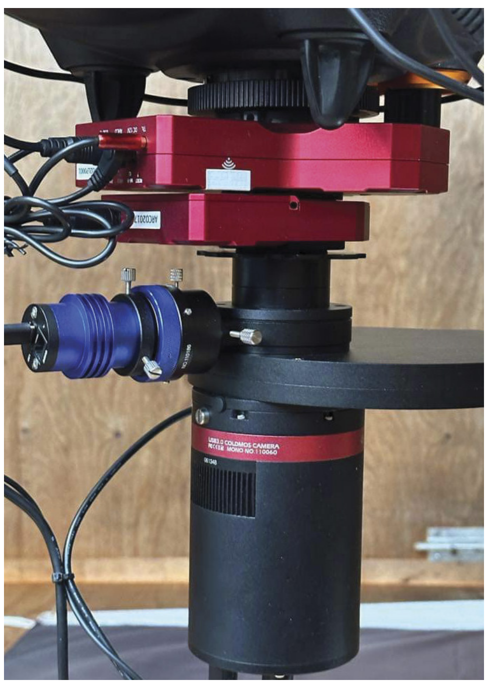
Still, even the very best mounts have some *periodic error* (PE), a repeatable pattern of jumps and wobbles in tracking the sky due to imperfections in the gears driving the scope. These errors are measurable, and those measurements are then used to proactively correct for the PE and improve the tracking, even before autoguiding gets to work. I use a Software Bisque Paramount MX, which has periodic-error correction (PEC) to automatically compensate for small, repeating errors. This feature reduces the mount's (already small) maximum tracking error from about 5″ to around 1″, leaving much less work for the autoguider to do. Most manufacturers of high-quality mounts provide the ability to record and apply PEC. Simply follow the manufacturer's instructions for first recording the PE, then have the mount automatically apply the corrections during every subsequent imaging session.

Even with excellent PEC, you'll still require some additional guiding, at least for exposures longer than a few seconds. While my Paramount MX tracks well enough in 1-minute exposures without additional guiding, longer exposures must be autoguided in order to ensure round stars. You may be able

▲ **HEART OF THE HEART** *Left:* The Heart and Soul nebulae (Sh 2-190 at left and Sh 2-199 to the right) are a great target for wide-field imagers. However, both nebulae contain interesting areas that make for excellent close-ups with a high-resolution system. *Right:* The author imaged the central region of Sh 2-190 with the C14 to focus on the the complex forms within the nebulosity, making a fine composition in its own right.

to get away with an external guidescope if you use a fixed-mirror or lens-based telescope, but those are rare — and, in the case of refractors, extremely expensive when considering apertures of 8 inches or larger. Typical large-aperture amateur telescopes are reflectors and catadioptric systems like Schmidt-Cassegrains, Dall-Kirkhams, and Ritchey-Chrétiens, which all have moveable-mirror systems. With these telescopes, a separate guidescope simply won't produce acceptable guiding, due to a host of issues as they change angles while slowly tracking across the sky. The biggest problem is tiny changes in the position of the mirrors within the scope that a guidescope will not see. Because the guidescope is attached to the outside of the optical tube, it's also subject to differential flexure, par and may appear to be guiding well, but in reality the guidescope is slowly twisting off target.

The best solution is to use an off-axis guider (OAG) to guarantee perfect guiding. An OAG uses the light from the same optics as the imaging camera, permitting an autoguider to accurately see these tiny movements. Even systems with fixed optics may benefit from an OAG instead of an external guidescope. Differential flexure is completely avoided with the use of an OAG.



▶ **GUIDING SOLUTION** Rather than using a separate guidescope and the problems they bring, an off-axis guider is the best choice for high-resolution, deep-sky astroimaging. The author's imaging train includes (from top to bottom) an electronic focuser and instrument rotator (both red), an off-axis guider and guide camera (blue), a filter wheel, and a QHY600M camera.

The challenge with an OAG is that it can be difficult to find a suitable guide star within the guider's tiny field in a long-focal-length imaging system. One option is to add a camera rotator that lets you rotate everything in your imaging train in order to locate a suitable guide star. This approach requires that your target fits completely within the field of view, regardless of camera rotation angle. Another option is to use an OAG with a large pick-off prism and a guide camera with a fairly large sensor. Since adopting this approach, I haven't had the need to rotate the OAG to find a guide star. Keep in mind that if you rotate the imaging camera or OAG, you'll need to acquire new flat frames to calibrate images taken at the new rotation angle.

Staying Focused

Top-notch, high-resolution images require the best possible focus, meaning a software-controlled electronic focuser is an absolute must. The position of best focus shifts as the temperature drops during the night. Fortunately, there are a few ways to maintain excellent focus throughout an extended imaging session.

First, monitor the *full-width, half-maximum* value (FWHM) readings through your acquisition software. Refocus when you see the number increase significantly.

Another way to stay in focus is to incorporate software and a temperature sensor that proactively adjusts focus as the temperature drops. This is referred to as *temperature compensation* and will make predetermined focus

▲ **REELING IN THE (LIGHT) YEARS** This high-resolution view measuring 31½′ across reveals detail in some of the members of the galaxy cluster Abell 426, particularly NGC 1275 located upper left of center.

changes. Using this method requires a few nights to record the relationship between focus position and temperature in your imaging system. This information is then used to automatically adjust focus throughout the night.

Some focusers have built-in temperature compensation capabilities. Those without it can still take advantage of the process with the addition of a temperature sensor and certain acquisition software packages. The popular freeware program *N.I.N.A.* (**nighttime-imaging.eu**) includes a plug-in that performs the necessary actions throughout the night. *FocusMax* (**https://is.gd/focusmax**) is another program that will record and execute focus changes based on temperature and works in conjunction with other automated imaging software.

Collimation, Collimation, Collimation

As noted earlier, the vast majority of large-aperture, long-focal-length telescopes used by amateurs are reflectors or catadioptrics. These telescopes must have their collimation checked and adjusted regularly. Excellent guiding and focus won't mean very much if the stars are distorted due to poor collimation; you need perfect collimation to ensure the highest quality images from any imaging system. Even high-end astrographs can fall out of collimation over time due to the large temperature swings they experience between night and day.

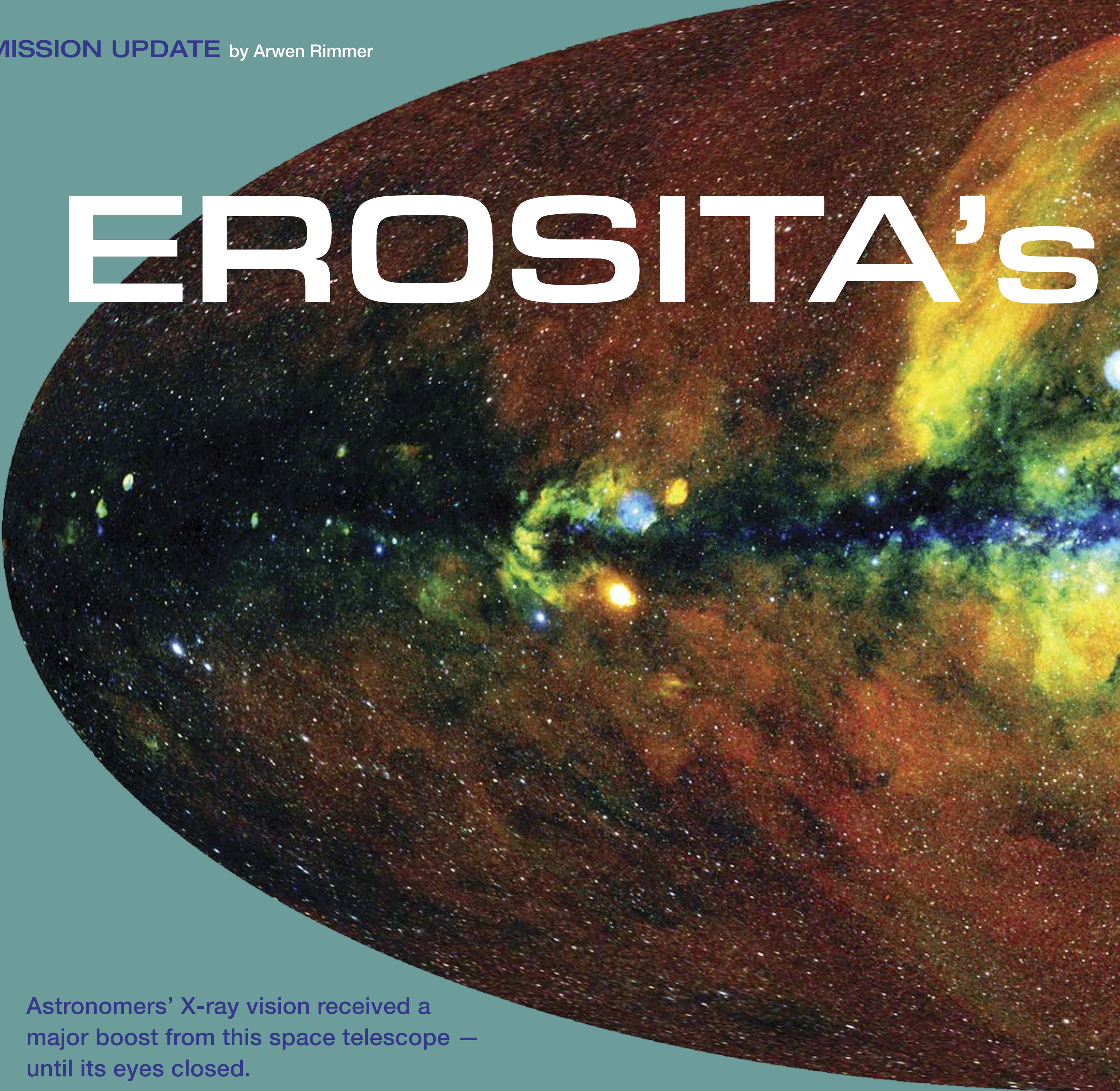
There are various optical, electronic, and mechanical collimation aids available, depending on your system. It's a good idea to discuss collimation with the manufacturer or dealer before you purchase your large reflector or catadioptric telescope, then master the art of collimating it yourself.

Change it Up

Stepping up to a high-resolution imaging system can be challenging, but if done diligently, it may enable you to produce outstanding images. If you're yearning to go after more distant targets or to capture close-ups of tantalizing features in the local galactic neighborhood only hinted at in your past images, maybe it's time to change it up and "go high res." It brings with it a fresh slate of imaging opportunities, with thousands of new subjects both familiar and obscure, and an unprecedented level of detail to your photos.

■ Contributing Editor **RON BRECHER** images at an image scale of 0.39″ per pixel – for now – from his home observatory in Guelph, Ontario. Visit his website at **astrodoc.ca**.

EROSITA's



MPE / IKI

Astronomers' X-ray vision received a major boost from this space telescope — until its eyes closed.

Astronomers have long looked forward to what they could learn about the X-ray sky from EROSITA. EROSITA (short for Extended Roentgen Survey with an Imaging Telescope Array) is the primary instrument aboard the Spectrum-Roentgen-Gamma space observatory, a joint mission between Germany and Russia. Germany's Max Planck Institute for Extraterrestrial Physics designed EROSITA to perform comprehensive surveys in the medium-energy X-ray range (0.2 to 8 kiloelectron volts, or keV), making it ideal for studying broad swathes of the high-energy sky.

Astronomers are keen to study X-rays because they come from regions of space with extreme temperatures, densities, or gravitational forces — places where matter behaves in ways that push the limits of our current understanding of physics. X-rays emanate from particularly energetic sources like accreting black holes and are ejected from powerful transient events like supernovae and neutron star mergers. X-rays can also help illuminate large-scale structures like galaxy clusters, giving us hints to the nature of dark matter and dark energy.

Previous missions like the Roentgen Satellite (ROSAT, 1990–99), which performed the first all-sky imaging X-ray survey, and NASA's Chandra X-ray Observatory (*S&T:* July 2024, p. 12), which excels at pointed observations of sources,

X-ray Sky

▲ **ALL-SKY MAP** This false-color composite shows the sky in three X-ray energy bands: 0.3 to 0.6 kiloelectron volt (red), 0.6 to 1 keV (green), and 1 to 2.3 keV (blue).

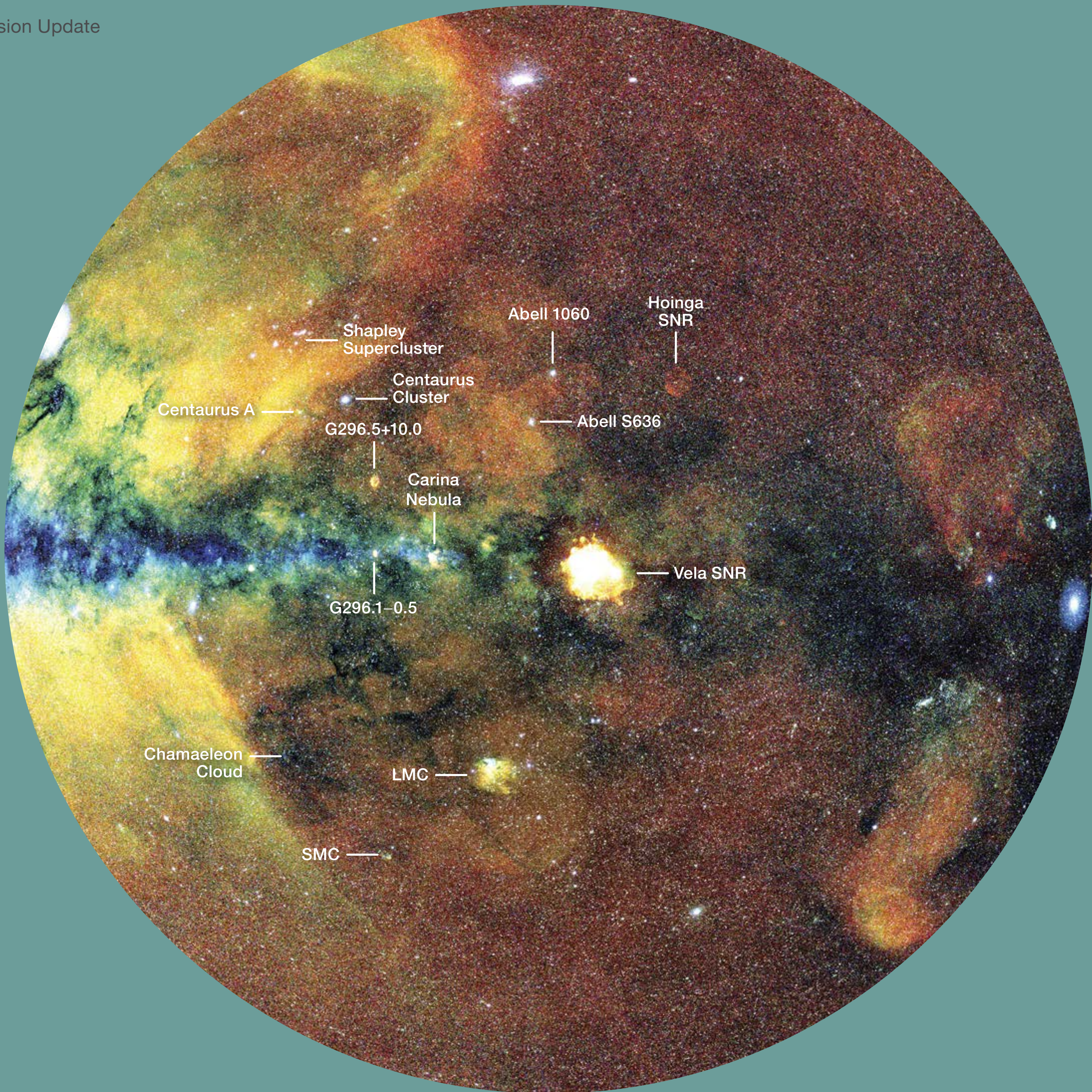
were groundbreaking instruments. But for about two decades, the high-energy community has been calling for an advanced X-ray observatory that could scan wide swathes of the sky multiple times in succession. In this way, they hoped to find many more X-ray sources, some of which are not always active and may only light up for brief flashes of cosmic time.

EROSITA was built to fill that observational gap. It launched aboard the Spectrum-Roentgen-Gamma (SRG) observatory on July 13, 2019, from the Baikonur Cosmodrome in Kazakhstan. After safely escaping Earth's atmosphere, the observatory sailed through space for 1.5 million kilometers (932,000 miles) until it reached the second Lagrangian point (L_2) and parked. Then, from 2019 until 2022, astronomers successfully completed four all-sky surveys and began a fifth.

But then Russia invaded Ukraine.

Following Russia's military actions, the German Aerospace Center (DLR) suspended scientific cooperation with all Russian institutions. This move was part of a broader set of sanctions and responses from the international community. As a result, the team placed EROSITA in safe mode, effectively pausing its observations.

It's still in safe mode today. Fortunately, the completed



WESTERN SKY This image projection shows the western galactic hemisphere, where most of the discoveries discussed in the article lie. The Milky Way's center is on the left edge, with the galactic plane running horizontally across the image. SNR stands for supernova remnant.

J. SANDERS / MPE FOR THE EROSITA CONSORTIUM

surveys have given astronomers plenty to work with for years to come, and some intriguing scientific results have already come to light.

X-ray Vision

EROSITA's design builds on a long series of previous scientific and technological developments. Its architecture can be directly traced to the international ROSAT mission of the 1990s, which surveyed the entire sky and found more than 100,000 sources.

EROSITA utilizes an array of seven identical mirror modules, each of which contains 54 nested, gold-coated shells. The coating enhances the mirrors' reflectivity, boosting the telescope's ability to catch X-rays from distant cosmic sources. The X-rays reflect at glancing angles off the mirrors, directed toward seven state-of-the-art cameras. The whole array has a combined field of view of about 1°, akin to observing an area twice as wide as the full Moon.

During operations, the instrument systematically swept the sky by rotating continuously with a period of four hours.

This arrangement allowed for a complete survey of the celestial sphere every six months. Repeatedly scanning the sky enables the telescope to detect fainter (and thus a larger number of) X-ray sources than previous surveys have done.

Before launch, Roscosmos and DLR agreed that the data from EROSITA would be divided into German and Russian "halves" of the celestial sphere, over which each team would have unique rights. To this end, they split the sky along the galactic poles of the Milky Way; the Russian half is the eastern galactic hemisphere, the German half the western.

So far, there has been one official public data release from the German side, made on January 31, 2024. The release includes nearly 1 million X-ray sources, expanding previous catalogs by more than half. This has sparked a renaissance in the field. Members of the collaboration and astronomers in the wider scientific community have begun using the new sources to unravel the mysteries of dark matter, better map the large-scale structures of the universe, refine models of cosmic evolution, gain insights into the behavior of matter under extreme conditions, and discover fascinating objects.

The Big Picture

One of EROSITA's goals is to detect 100,000 galaxy clusters. Clusters contain hundreds or even thousands of galaxies bound together by gravity (*S&T:* Jan. 2025, p. 12), and they are the building blocks of the universe's large-scale structure. X-ray emission from the hot, turbulent gas filling the space between the galaxies makes clusters bright to EROSITA. By analyzing the distribution of galaxy clusters, scientists hope to refine their models of how the cosmos has evolved over billions of years.

In the first six months of operation, EROSITA found more than 12,000 galaxy groups and clusters in a portion of the western hemisphere, the majority of which are new discoveries. These data enable scientists to better study the distribution of matter in the universe, paving the way for improved constraints on the density of dark matter, which makes up most of the mass in clusters.

One of the most important observations made to date is the first confident detection of X-ray gas in long cosmic filaments, says Esra Bulbul (Max Planck Institute for Extraterrestrial Physics, or MPE), lead scientist for EROSITA cluster science and cosmology. These filaments stretch up to hundreds of millions of light-years and form links between clusters. Both clusters and filaments arose from fluctuations in the density of matter that filled the early universe. The densest regions led to the formation of clusters of galaxies, but less dense regions underwent a kind of compression, forming the filaments, she explains. "Clusters are connected through these structures, and [filaments] also feed the clusters constantly with hot gas."

These intergalactic "highways" are composed of two things: dark matter and hot gas. Now that astronomers can detect the gas, they can draw better inferences about dark matter and the cosmic web it forms.

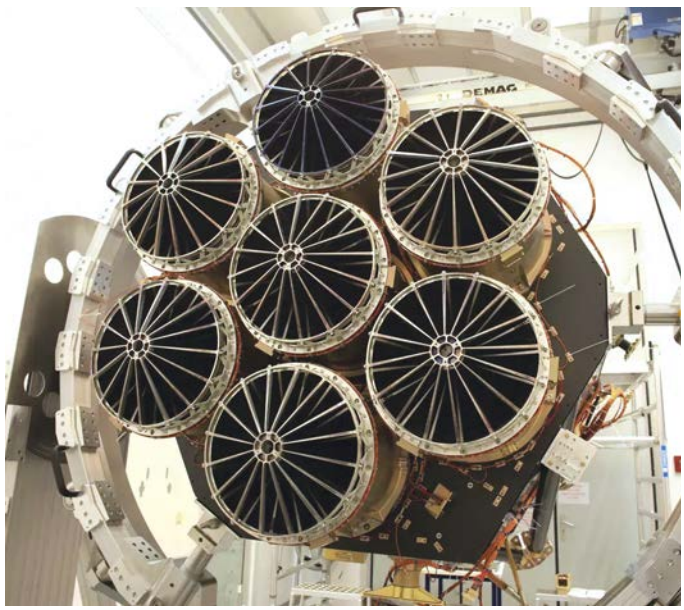
For example, in one of Bulbul's studies, her team was able to use EROSITA cluster data to make precise measurements of the total amount of matter in the universe and its degree of "clumpiness" — in other words, how strongly it concentrates into clusters versus being spread out. Previous measurements have hinted that the universe is smoother than expected, a discrepancy called the *sigma-8 tension*. Like the more widely discussed and stronger Hubble tension (*S&T:* Mar. 2022, p. 14), the sigma-8 tension has led some to wonder if there's something amiss with our understanding of how the universe evolves. But the EROSITA results seem to alleviate the discrepancy and suggest that, when it comes to this tension, we may be able to relax.

Bubbles and Other Diffuse Emission

Scientists are also using EROSITA to enhance the study of supernova remnants, the expanding shells of gas left behind after a star explodes. The shock waves generated by such explosions heat both ejected material and the surrounding interstellar medium to temperatures of millions of degrees. The hot material then emits X-rays.

The characteristics of a supernova remnant vary depending on its age, the energy of the original explosion, and the properties of the surrounding environment into which it expands (*S&T:* May 2024, p. 12). Astronomers are particularly interested in how the hot, shocked gas sent out by supernovae works to enrich the interstellar medium with heavy elements, and how these explosions contribute overall to the dynamic processes shaping their host galaxies.

In an upcoming study, astronomers analyzed EROSITA data of the Large Magellanic Cloud (LMC), one of the Milky



▲ **NESTED MIRRORS** EROSITA's seven identical mirror modules each has a diameter of 36 cm (14 inches) and consists of 54 nested mirror shells, whose design enables them to reflect X-rays at shallow angles and focus them onto cameras.

MPE

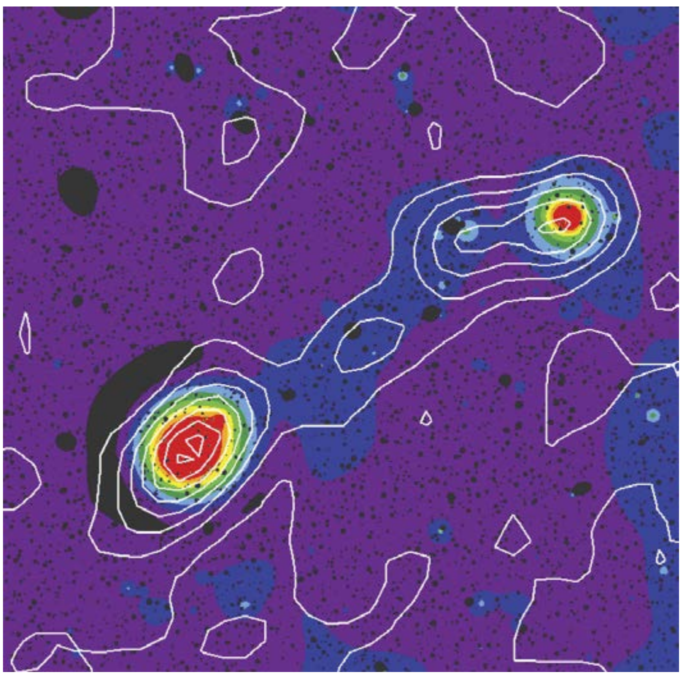
Way's nearest galactic neighbors. The LMC is in an ideal position in the sky for X-ray observations, off the galactic plane and therefore relatively clear of "noise" from the myriad high-energy sources within our own galaxy. The treasure hunt confirmed one previously known remnant and three new ones, as well as identifying 13 candidates. The results set the stage for a better understanding of the ways in which supernovae have influenced the evolution of the LMC.

Remnants are not the only sources of diffuse X-rays that are of interest to EROSITA astronomers. One of the most intriguing finds so far is two enormous bubbles, one extending above and the other below the center of the Milky Way, taking the shape of a giant dumbbell. Astronomers detected the "neck" and lower edges of the bubbles earlier, but it took EROSITA to see that the X-rays trace complete lobes.

Astronomers have observed a similar, smaller dumbbell in gamma rays with the Fermi space telescope (*S&T:* Apr. 2014, p. 26). It's possible that the structures have the same origin. The EROSITA bubbles are almost as large as the entire Milky Way and are filled with gas heated to temperatures of several million degrees.

"I think this is our most impactful result so far," Bulbul says. "We have shown something amazing, not only that [the EROSITA bubbles] are symmetric in the southern and northern hemispheres, but that they basically surround, or envelop, the Fermi bubbles."

Astronomers suspect the bubbles are remnants of one or more powerful, ancient events in our galaxy's core. There are two leading theories (*S&T:* Feb. 2021, p. 60). One posits that the Milky Way's supermassive black hole, called Sagittarius A*, blew out the bubbles during one or more past outbursts. The other theory suggests that intense periods of star formation in the Milky Way generated powerful stellar winds and supernova explosions that collectively pushed hot gas outward to create these enormous structures. EROSITA's X-ray data may help theorists disentangle the scenarios and pinpoint a solution.



▲ **COSMIC BRIDGE** An X-ray look at the galaxy clusters Abell 3667 (left) and Abell 3651 reveals a filament of hot gas (blue) connecting the two clusters. Contours indicate the density of galaxies.

All About AGNs

Active galactic nuclei (AGNs), the blazes created by supermassive black holes voraciously accreting gas in galactic centers, comprise a significant portion of the new X-ray catalog. Astronomers discovered more than 700,000 AGNs in the first survey, and as of this writing the number is at 3 million.

"The number of objects EROSITA detected in the active phase in the first six months of operation is 10 times the number detected by the entire field of X-ray astronomy in the past 20 years," says AGN expert Mara Salvato (MPE), chair of the EROSITA follow-up working group.

By providing a comprehensive survey of these objects across different epochs in cosmic history, EROSITA scientists are hoping to unravel the growth patterns and evolution of supermassive black holes and their host galaxies. This relationship is often described in terms of *feedback mechanisms*, by which black holes' feeding activity affects surrounding gas, potentially regulating star formation and shaping galactic structures around them; likewise, the galaxy's activities can in turn regulate the growth of the central black hole (*S&T:* Feb. 2017, p. 18).

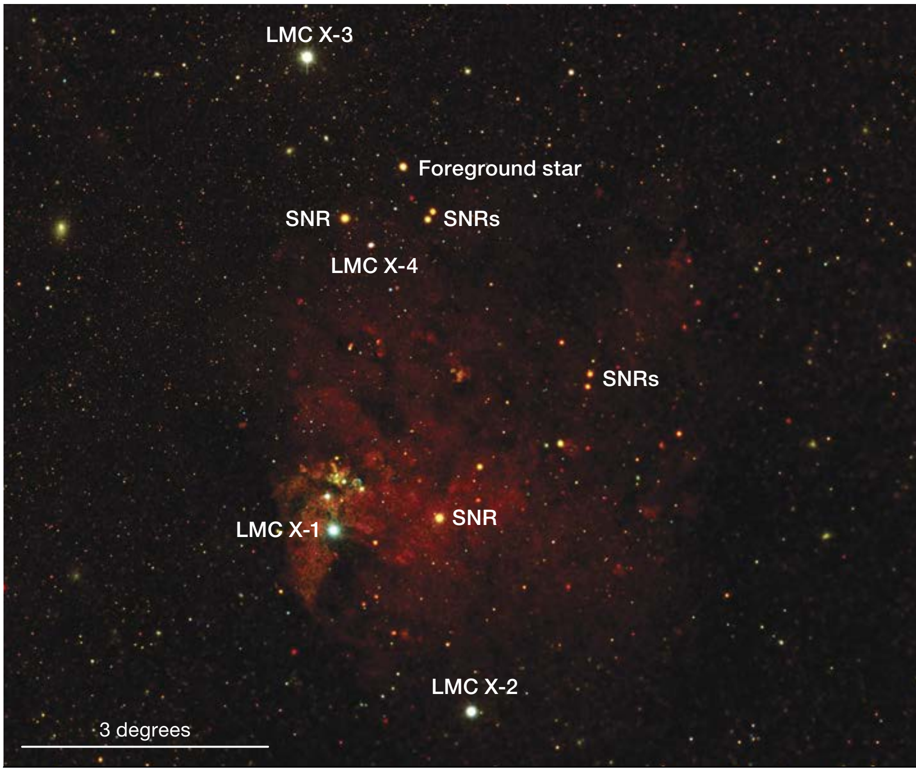
One mystery in particular about black hole evolution that astronomers are investigating is why most AGNs they spot in X-rays appear to reside in massive star-forming galaxies. We don't know what the exact link is between the galaxies, how they themselves change and grow, or how the activation and feedback of their central black holes works.

A recent study suggests AGN activity may arise due to a particular phase in its host galaxy's evolution. The researchers looked at a large sample of galaxies hosting EROSITA-detected AGNs and found that they show a preference for compact, disk-shaped, star-forming galaxies. The team suggests that either instabilities in the galaxy's disk or mergers with much smaller galaxies — but not, notably, mergers with big galaxies — may drive gas toward the galaxy's center, thus fueling both star formation and black hole activity. This result suggests that supermassive black holes' growth doesn't rely on major cataclysmic events.

X-ray Dim Isolated Neutron Stars

EROSITA is also delving into the exotic endpoints of stellar evolution by searching for neutron stars — the dense remnants of massive stars that explode as supernovae. One particular type, called *X-ray dim isolated neutron stars* (XDINSs), is of special interest to astronomers because they essentially offer a direct view of neutron star surfaces.

Till now, only seven XDINSs had been identified — the



◀▲ **LARGE MAGELLANIC CLOUD** *Left:* X-ray binaries (objects with X-number) and supernova remnants (SNRs) appear in this false-color X-ray image of the LMC galaxy. *Above:* This DSLR image taken from Chile covers a similar field of view and shows what we see at visible wavelengths.

X-RAY: FRANK HABERL & CHANDREYEE MAITRA / MPE; VISIBLE-LIGHT: ZDENĚK BARDON / ESO

so-called Magnificent Seven, all discovered by the ROSAT satellite in the 1990s. Finding more has proven challenging because compared to other types of neutron stars, such as pulsars and magnetars, XDINSs are faint, have (comparatively) long rotation periods, and lack strong radio or gamma-ray emissions, making them difficult to detect with traditional methods.

But while making XDINSs hard to find, the dearth of other emissions also makes them straightforward to study — and thus ideal for investigations into the physical properties of neutron stars, such as their structure, composition, and how they cool over time.

EROSITA is more sensitive than ROSAT, especially at lower energies where XDINSs are most visible, so it offers a new window on these objects. Scientists conducted a systematic search using data from EROSITA of the western galactic hemisphere and successfully identified 33 new candidate XDINSs, as well as all five of the known XDINSs in the region and a couple of previously proposed ones, too.

Transient and Exotic Phenomena

EROSITA's ability to monitor transient X-ray events allows it to witness some of the briefest and most powerful occurrences in the universe. X-rays from such cataclysmic events sometimes reach Earth before other light waves. So EROSITA's detections provide prime targets for follow-up observations with optical and infrared telescopes.

One such outburst, known as a *tidal disruption event* (TDE), can occur when a star ventures too close to a supermassive black hole and is torn apart by the black hole's immense gravitational forces. As the material spirals into the black hole, the innermost regions of the accretion disk can heat up to millions of degrees, strongly emitting X-rays. By observing these emissions, scientists can investigate how matter behaves under extreme gravity and at high temperatures. For example, changes in the X-ray brightness over time (tracked in a plot called a *light curve*) reveal how the rate at which the black hole accretes gas changes during a TDE, thus shedding light on how black holes consume matter. Variations in X-ray emissions might also indicate changes in the structure of the accretion disk, including instabilities or the formation of jets.

But it's not always a one-and-done deal. Sometimes the star is entirely destroyed — producing a brilliant display that can last from a few months to a few years. Other times, a star only flirts with danger, coming close enough to the black hole to lose part of its atmosphere.

A recent study looked at a previously observed TDE, called AT 2018fyk, which dimmed and then brightened again. Astronomers were able to show that the emission was likely due to a partially disrupted star on a 1,200-day orbit around a supermassive black hole, which was periodically stripping the star of mass during each passage.

Partial TDEs might be related to another exciting new area in X-ray science — *quasi-periodic eruptions* (QPEs). QPEs are repeating bursts of X-ray radiation that occur over time scales ranging from a few hours to several days. Richard Saxton (European Space Astronomy Centre, Spain) and others announced the first example of QPEs in 2019 in the active galaxy GSN 069, while looking at the remnants of a tidal disruption event. "There were sudden spikes in the light curve — lots of X-rays every nine hours," he says. "And this was completely unexpected."

A second case of QPEs popped up in a different galaxy soon after. Before EROSITA, astronomers had only these two examples, but the collaboration has now observed several additional QPEs, verifying the phenomenon.

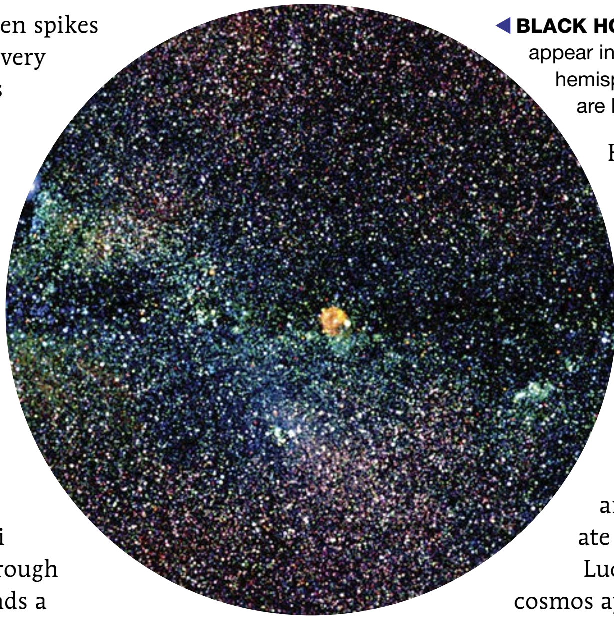
"We're not completely sure what they are," says Saxton, "but we think they could be white dwarfs, or maybe neutron stars or small black holes, that trigger mini explosions every time they pass through the disk of material which surrounds a supermassive black hole."

Earthly Interference

The original mission plan called for EROSITA to survey the entire sky over a four-year period, followed by 3.5 years of pointed observations. But it seems unlikely now that EROSITA will have a chance to do all of that — not due to engineering problems or the space environment, but rather due to geopolitical tensions back on Earth.

Russia, whose spacecraft hosts the instrument, invaded Ukraine in February 2022. In the immediate aftermath, the Max Planck Institute for Extraterrestrial Physics (which owns and operates EROSITA) followed the German government's recommendations to freeze cooperation with Russia and put the telescope into safe mode on February 26th, according to mission principal investigator Andrea Merloni (MPE).

Roscosmos wasn't happy with this decision. Soon after, Russian officials announced plans to reactivate EROSITA unilaterally. This was met by almost universal outcry, including from the highest ranks of the Russian Academy of Sciences:



◀ **BLACK HOLES GALORE** Myriad point sources appear in this X-ray view of the western galactic hemisphere. Between 75% and 80% of them are likely active galactic nuclei.

Hijacking would risk malfunctions, instrument safety, and data integrity. Without the German team's intimate knowledge of EROSITA's systems, even running routine operations could lead to suboptimal performance or irreversible damage.

"EROSITA is a very complex instrument," Salvato says. "It would be almost impossible for anyone who has not built it to operate it optimally."

Luckily, these statements from Roscosmos appear to have just been bluster, and as of this writing, EROSITA is still safely sleeping at L_2. But there is not yet a formal protocol in place to turn it back on.

"At this moment, we still don't have a clear green light about the legality of operating the telescope," Merloni says. "Until we get that reassurance from the ministry in Germany that controls the application of sanctions, we can't do anything."

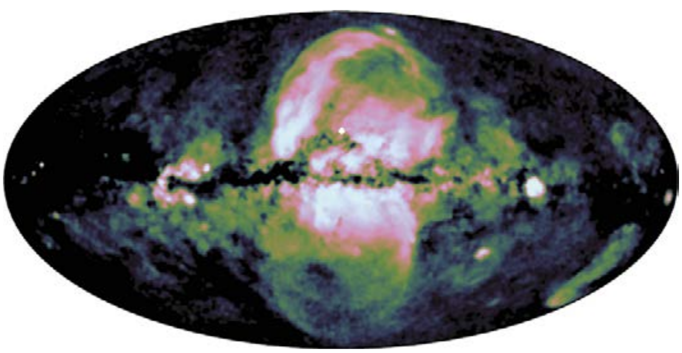
The spacecraft houses several Russian instruments as well, so Roscosmos has its own reasons to keep the satellite up and running. The observatory was launched with enough fuel to last at least 7 years — and that lifetime is slowly elapsing. A return to full functionality in the next year or two would at least enable the telescope to complete more of its planned surveys, enhancing the statistical robustness of its findings and increasing the likelihood of detecting interesting transient events.

The Future: Now in X-Ray

EROSITA's catalog of clusters, black holes, neutron stars, and other exotic objects has already proven invaluable to the scientific community, regardless of whether the telescope will ever be able to finish the job. In the meantime, there are several X-ray instruments still in operation and hard at work investigating the high-energy universe.

Both Europe and China are also working on next-generation X-ray observatories that, if the stars align, could launch in the late 2020s and 2030s. NASA is also considering smaller projects.

In the meantime, astronomers are still processing data from EROSITA, with a second release planned for 2026. Over the next couple of years, we should see a steady stream of new X-ray data — and maybe some intriguing discoveries.



▲ **EROSITA BUBBLES** This false-color map highlights extended emission at energies of 0.6 to 1 keV and is adjusted to enhance large-scale structures, allowing the giant X-ray dumbbell emanating from the galactic center to pop out.

■ **ARWEN RIMMER** is a musician and writer based in Cambridge, United Kingdom.

BLACK HOLES: J. SANDERS / MPE FOR THE EROSITA CONSORTIUM; BUBBLES: MPE / IKI

SKY AT A GLANCE
May 2025

1 MORNING: The month opens with the sparkling view of Venus and Saturn less than 4° apart low above the east-southeastern horizon. See page 46 for more on this and other events listed here.

2 DUSK: Face west to see the waxing crescent Moon a bit more than 2° lower left of Pollux. Jupiter gleams much lower right between the horns of Taurus, the Bull.

3 DUSK: The Moon, one day shy of first quarter, is about 1¼° above Mars in Cancer. Look high in the southwest to take in this sight. Binoculars will bring the Beehive Cluster (M44) stars into view.

5 DUSK: In the south-southwest, the waxing gibbous Moon is around 3° left of Leo's lucida, Regulus.

5–6 ALL NIGHT: The Eta Aquariid meteor shower is expected to peak. Although this display favors the Southern Hemisphere, viewers in the southern U.S. might catch a few meteors. See page 49 for details.

10 MORNING: The waxing gibbous Moon is around 1° below Spica, in Virgo, as they sink toward the west-southwestern horizon.

13 EVENING: Look low in the southeast to catch the waning gibbous Moon and Antares rising in tandem. A bit more than ½° separates the pair.

22 MORNING: The waning crescent Moon and Saturn climb in the east-southeast, with the planet trailing by 3½°. Venus blazes at lower left.

23 MORNING: The thin lunar crescent, Saturn, and Venus adorn the eastern horizon in a graceful arc.

29 EVENING: The waxing crescent Moon is in Gemini, a bit less than 5° below Pollux. Catch this view before it disappears below the west-northwestern horizon.

31 Evening: The Moon, now higher, greets Mars for the second time this month. The earthlit crescent sits less than 4° right of the Red Planet in the west.

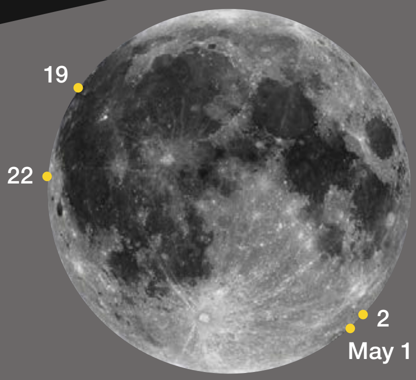
—DIANA HANNIKAINEN

▲ The Milky Way arcs over Dinosaur Provincial Park, Alberta (Canada), in mid-May 2014. Airglow appears as red and green bands at center and right of the image. ALAN DYER

MAY 2025 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart



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

NASA / LRO

MOON PHASES

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

FIRST QUARTER
May 4
13:52 UT

FULL MOON
May 12
16:56 UT

LAST QUARTER
May 20
11:59 UT

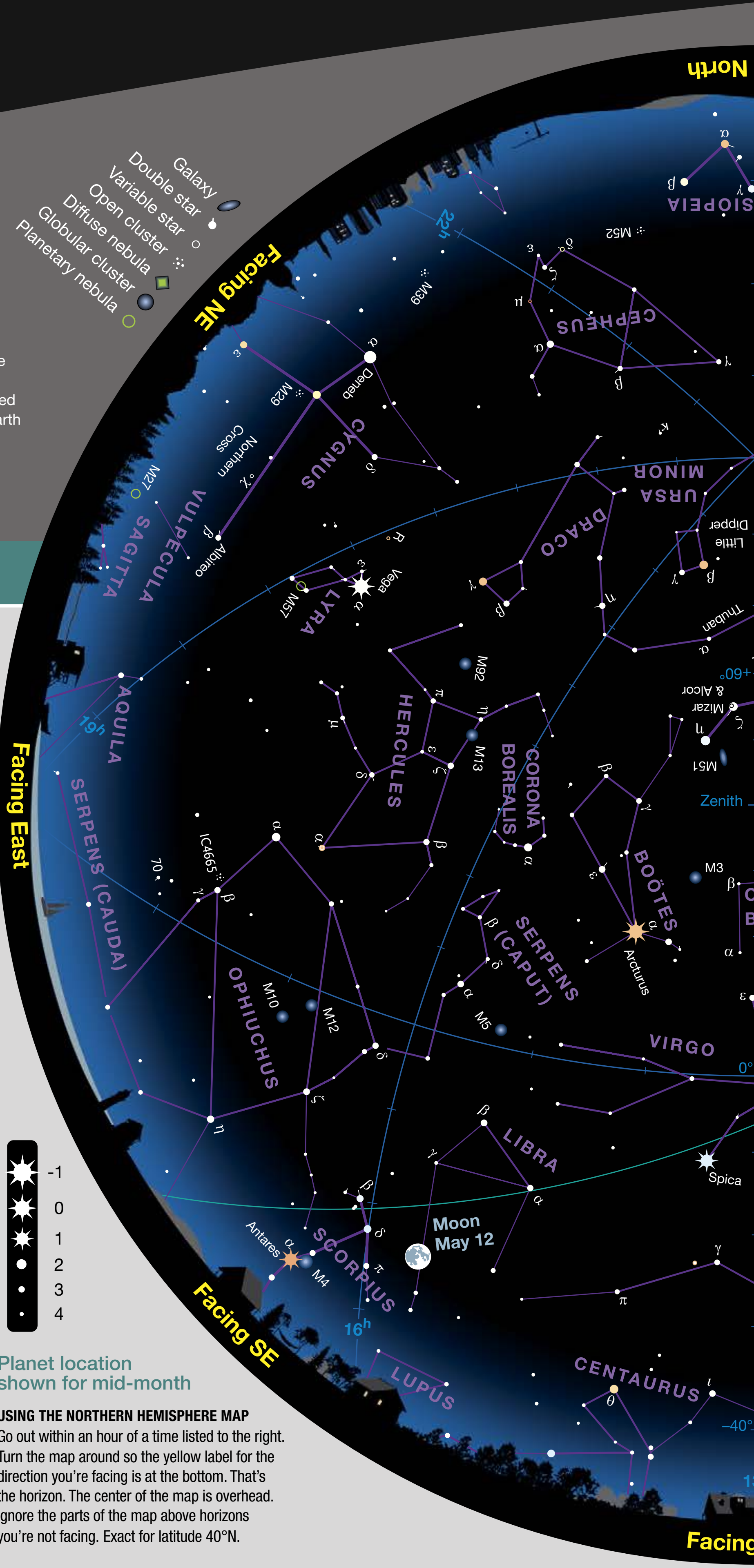
NEW MOON
May 27
03:02 UT

DISTANCES

Apogee	May 11, 1h UT
406,243 km	Diameter 29′ 25″
Perigee	May 26, 2h UT
359,023 km	Diameter 33′ 17″

FAVORABLE LIBRATIONS

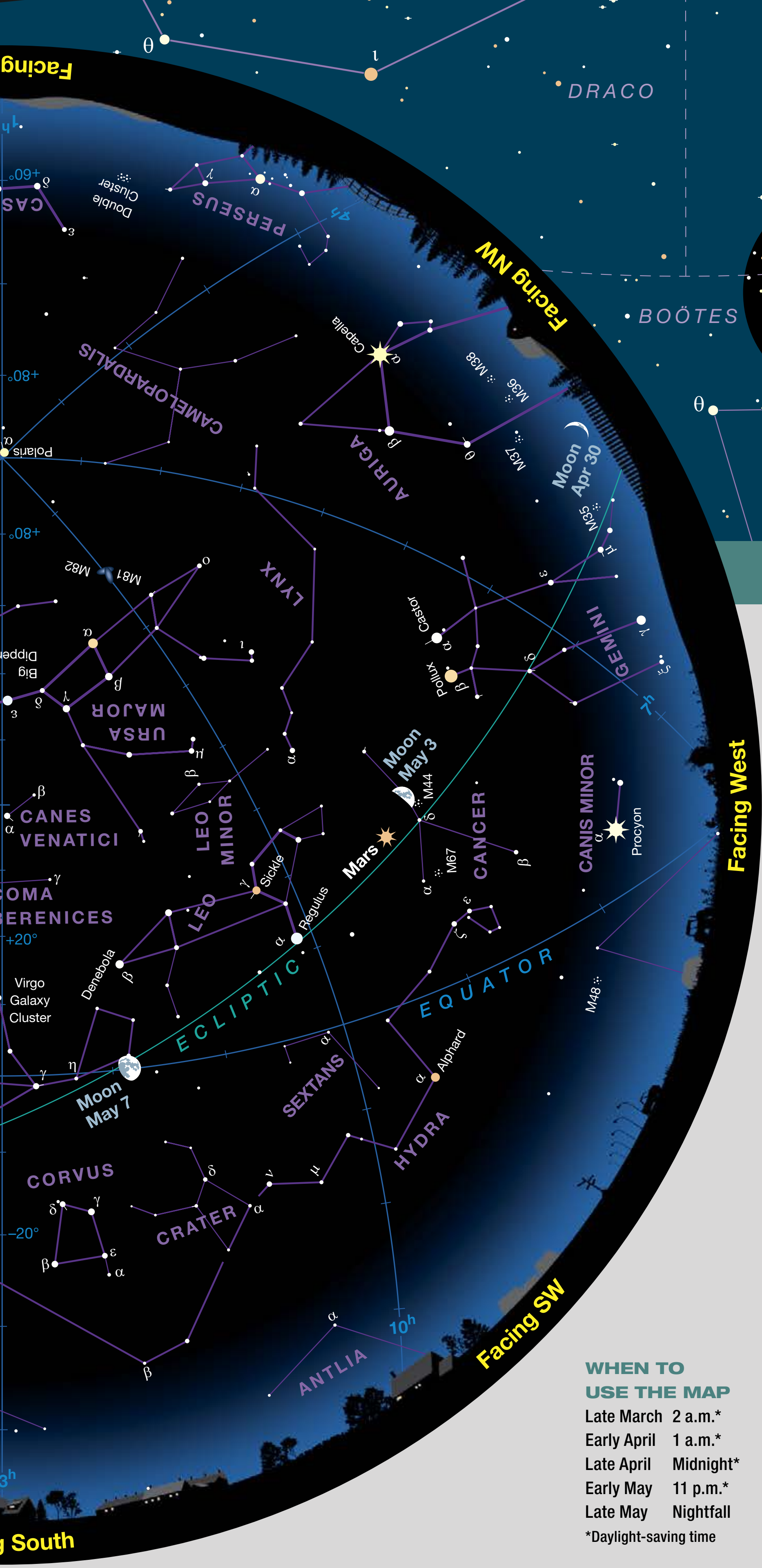
- Brisbane Crater — May 1
- Hamilton Crater — May 2
- Lavoisier Crater — May 19
- Glushko Crater — May 22

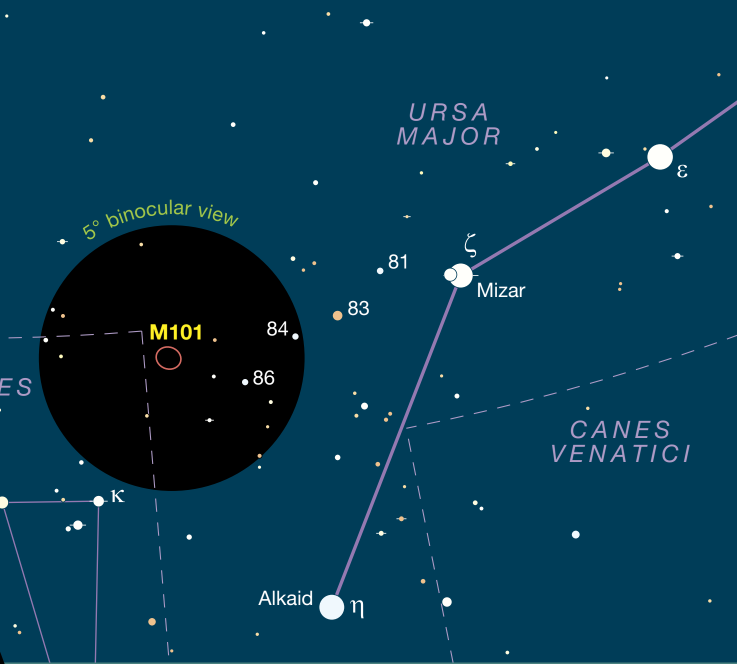


Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

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





Binocular Highlight by Mathew Wedel

Inspiring Spiral M101

Our target this month is a favorite of mine, the lovely spiral galaxy **M101**, in the constellation Ursa Major, the Great Bear. One of the reasons I like M101 so much is that it's a pretty easy find. The galaxy makes a nearly equilateral triangle with Eta (η) and Zeta (ζ) Ursae Majoris, also known as Alkaid and Mizar. A second helpful guide is the chain of four 5th- and 6th-magnitude stars (81, 83, 84, and 86 Ursae Majoris) that trends west-southwest from the vicinity of Mizar. The galaxy floats just 1½° northeast of 86 Ursae Majoris.

Most sources give a magnitude of 7.9 for M101, which makes it one of the brightest Messier galaxies. But that raw number is deceptive. M101 is a face-on spiral, so its light is spread across its nearly ½° diameter, giving it low surface brightness. That's why the galaxy is a distinct challenge in 7×35 and 7×50 binoculars. However, I find it's a straightforward detection in 10×50s, and a walk in the park with 15×70s. Of course, that's only when skies are dark and clear — light pollution and haze are the twin banes of all galaxy hunters. But the challenges of observing these distant objects with binoculars make the successes all the more rewarding.

Recent estimates put M101 at distance of about 20 million light-years. The light we see now left the galaxy when the Earth was substantially different. The oceans were home to fierce predators such as the early sperm whale *Idiorophus* and the giant shark *Otodus megalodon*, and India was still an island, grinding slowly northward toward Asia. I savor the heady vistas of time and space that galaxies like M101 represent. How about you?

■ As a paleontologist by day and amateur astronomer by night, **MATT WEDEL** is interested in everything big and old.

WHEN TO USE THE MAP

Late March	2 a.m.*
Early April	1 a.m.*
Late April	Midnight*
Early May	11 p.m.*
Late May	Nightfall

*Daylight-saving time

MAY 2025 OBSERVING

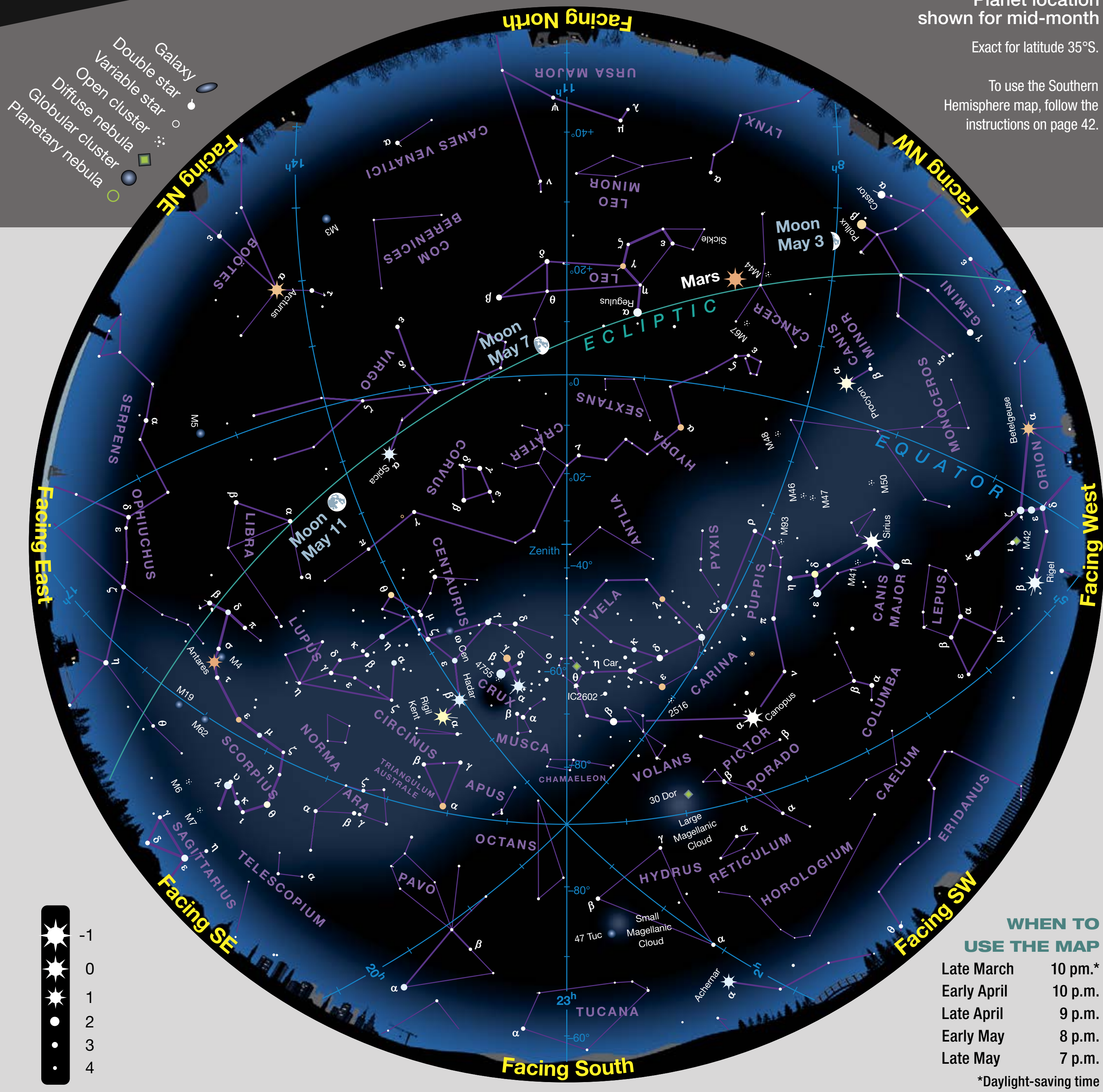
Southern Hemisphere Sky Chart

by Jonathan Nally

Planet location shown for mid-month

Exact for latitude 35°S.

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



WHEN TO USE THE MAP	
Late March	10 pm.*
Early April	10 p.m.
Late April	9 p.m.
Early May	8 p.m.
Late May	7 p.m.

*Daylight-saving time

AS SOUTHERN HEMISPHERE winter approaches, Crux, the Southern Cross, nears the meridian during evening hours. Nestled just 1° southeast of Beta (β) Crucis (also known as Mimosa) is the beautiful open star cluster cataloged as NGC 4755, better known as the **Jewel Box**. It was the renowned British astronomer John Herschel who gave the cluster its evocative moniker, describing the telescopic view of it as " . . . an extremely brilliant and beautiful object . . ." resembling a ". . . superb piece of fancy jewellery."

Visible to the unaided eye as a slightly fuzzy 4th-magnitude "star," the Jewel Box looks great even in binoculars. It resides about 7,000 light-years from Earth, and astronomers believe it is one of the youngest open star clusters in the Milky Way, perhaps only 14 million years old. ■

Origins of the Big Dipper

This popular star pattern has a history of multiple monikers.

▲The star pattern formed by the seven brightest stars in the constellation Ursa Major, the Great Bear, has gone by many names over the centuries. The familiar moniker "Big Dipper" is relatively recent, apparently dating back only to the mid-19th century.

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

The night sky has 88 official constellations, with names and boundaries specified by the International Astronomical Union. These scientifically defined areas in no way reflect the multifarious imaginings by skywatchers from different cultures around the world.

Consider Ursa Major, the Great Bear. Its seven brightest stars form one of the oldest and most constellated groups in the heavens, having been pictured in myriad ways — from a skunk to a hippopotamus, from a basket to a bier, and from a drinking gourd to a canoe.

Today the group is popularly known as the Big Dipper. According to the *Oxford English Dictionary,* the earliest evidence for the name Big Dipper appears in Marc Antony Henderson's 1856 poem "The Song of Milgenwater":

On the edge of the horizon,
He, so fiercely, kicked his foot out,
That he hit the constellation,
Thimbel-nubbin, or Big Dipper . . .
Which was put there, for the Great Bear,
For to come and wash his feet in.

Nevertheless, the name appears not to have been in widespread use. In Noah Webster's 1865 *American Dictionary of the English Language,* the seven principal stars of Ursa Major are listed simply as The Dipper; that name was common not only in America at the time, but also abroad. As J. Ellard Gore, a member of the Royal Irish Academy, shares in his 1909 book *Astronomical Curiosities,* "In America [the star pattern] is known as 'The Dipper.'"

Embellishments, however, did exist. In a journal entry dated October 5, 1858 (but not published until 1892), Henry David Thoreau notes how the impressive Comet Donati "makes a great show these nights. Its tail is at least as long as the whole of the Great Dipper." Similarly, in prose dated July 22, 1878, Walt Whitman writes, "In the northwest turned the Great Dipper." The word Great in these cases may parallel the parent constellation's name, the Great Bear.

The 1889 edition of John Farmer's *Americanisms Old and New* confirms that the word Dipper "is a true Americanism," both in the sense of a small ladle-like utensil and the star pattern in Ursa Major. Big Dipper appears to have come into vogue by 1881; that year, in a self-published lecture, Arthur K. Barlett writes, "The well-known 'Big Dipper' will sometime, in the distant future, assume a different appearance."

The earliest mention of Big Dipper that I could find in a popular astronomy book appears in Martha Evans Martin's 1907 *The Friendly Stars,* in which she writes, "The Big Dipper is a large constellation (part of a still larger one called the Great Bear)."

Readers will note that Evans refers to the Big Dipper as a constellation. Today such a group is known as an *asterism* — a familiar pattern of stars — in this case fully within the boundaries of a single constellation. But in the grander scheme of things, Evans is correct. The seven bright stars of the Big Dipper make up the original constellation out of which the Great Bear grew.

While some early skywatchers did imagine a bear among the stars of the Big Dipper, it appears the first recorded name of the constellation dates to Babylon. Ancient texts describe the seven-star pattern as Margidda, the Wagon, specifically the one that belonged to the Mother Goddess Ninlil, queen of fate and agricultural fertility. Ninlil had power over destinies and cosmic balance, and her wagon symbolized her divine presence — ever watchful of the world below as she wheeled around the heavens above.

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

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

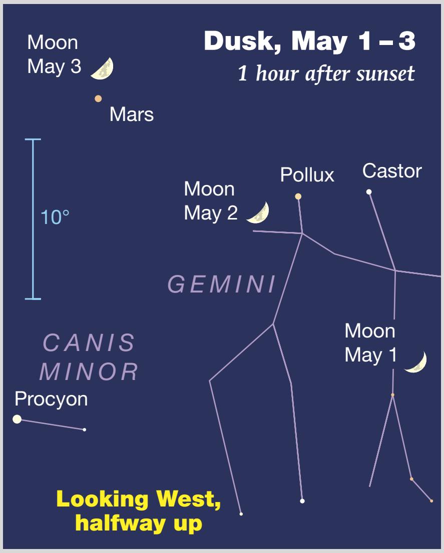
Mars Dances Through the Beehive

The Red Planet has a busy month with several highlights.

THURSDAY, MAY 1

May is a time of transition as we shift our attention from dusk to dawn. The evening sky remains the domain of Jupiter and Mars, but now they have competition as **Saturn** climbs away from the Sun's glare to join **Venus** at dawn. When the month opens, the gap between the pair is a touch less than 4°. They were very slightly closer at the end of April and continue to drift apart as Saturn gains altitude more rapidly than Venus. The Ringed Planet is at the start of an apparition that peaks when it reaches opposition next September. The reigning Morning Star, on the other hand, first ascended to its throne in March and rules the dawn sky until December. And though the pair appear close together on May 1st, they're worlds apart in brightness. Venus is a beacon gleaming at magnitude –4.7, while pallid Saturn struggles against twilight's glow at magnitude 1.2.

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

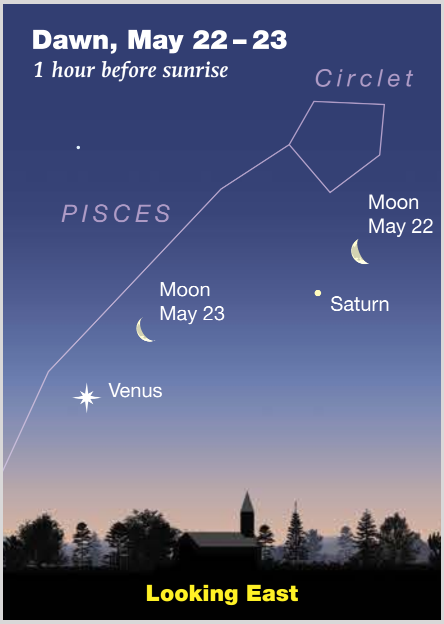


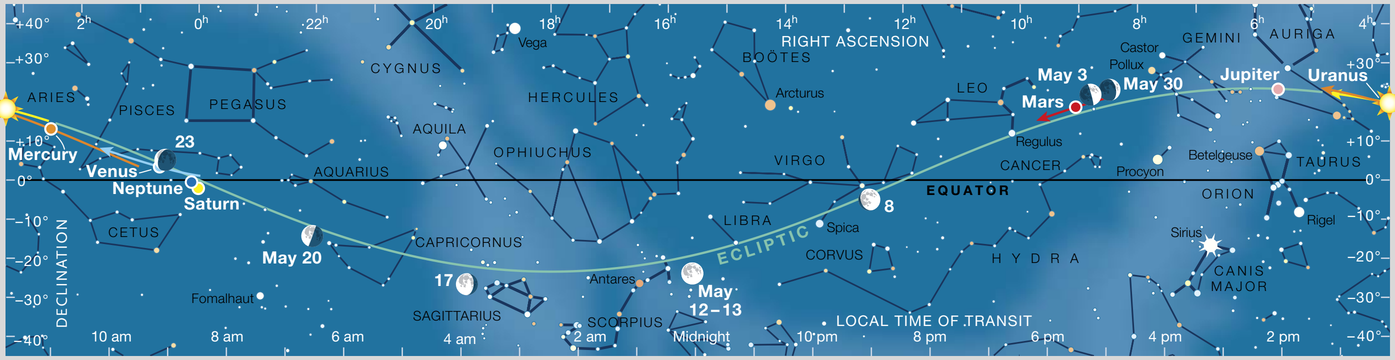
SATURDAY, MAY 3

Turning our attention to the evening sky, we have a lovely conjunction between the **Moon** and **Mars** to enjoy. The duo is nicely positioned high in the southwest as twilight fades and are at their closest around 9:30 p.m. EDT when less than 1½° (roughly three Moon diameters) separates them.

The Red Planet currently shines at magnitude 1.0, so the pairing isn't quite as dramatic as it would have been back in January when Mars was at opposition and nine times brighter. But it's still a fine sight and the closest Moon–planet meet-up in May. It's worth getting out your binoculars to view this conjunction, too — the optical assist helps enhance peachy Mars contrasting nicely with the neutral gray of the lunar surface.

While you have your binoculars handy, direct your attention to the Moon's dark limb. If you time your viewing session correctly, you might see the tiny spark of 4.7-magnitude **Gamma (γ) Cancri** (also known as Asellus Borealis) perched there. Depending on your location, you could even see the lunar disk eclipse the star. This event is viewable across most of the eastern half of the U.S. and Canada. The exact time of the occultation depends on where you are, so fire up your favorite astronomy software and check the circumstances for your specific location. Don't miss out on this bonus treat!

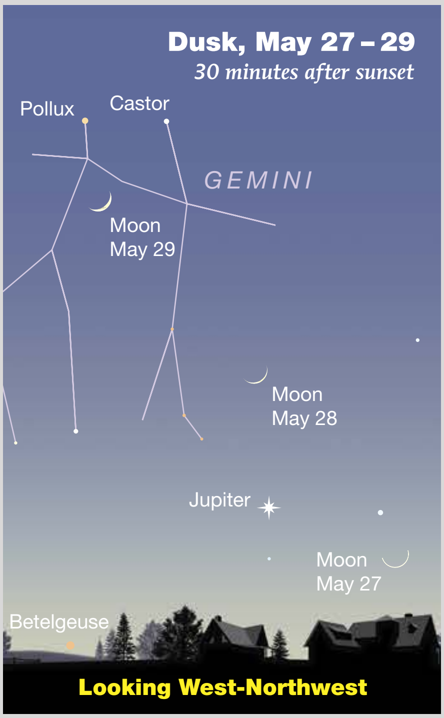




▲ The Sun and planets are positioned for mid-May; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

SUNDAY, MAY 4

For a planet well past the peak of its current apparition, **Mars** is having a busy month. Tonight and tomorrow night it skirts the northern edge of the **Beehive Cluster** (M44) in Cancer, the Crab. The Beehive is one of two naked-eye clusters along the ecliptic, the other being the brighter and more famous Pleiades (M45) in Taurus. However, M44 is tricky to spot unless your sky is nice and dark. Even then, the cluster appears only as small, hazy patch. The brightest "bees" in the hive register as around 6th magnitude, so you're going to want to use your binoculars or a small telescope to fully appreciate the Red Planet's visit. As pretty as this sight is, perhaps the most interesting part is getting to see how quickly Mars moves against the stellar backdrop. With a telescope you can perceive its motion over the course of a single evening — and it's more than obvious from night to night in binoculars. By the 6th, Mars has shifted eastward far enough to sit between Gamma and Delta (δ) Cancri, the former being the star the Moon occulted on the 3rd. Mars won't return to the Beehive again until October 2026, but when it does it passes directly through the center of the Cancer cluster.



FRIDAY, MAY 9

The **Moon** has two notably close encounters with bright stars in May — the first of which occurs this evening. As twilight fades, cast your gaze to the southeast to catch the 94%-illuminated waxing gibbous Moon upper right of 1st-magnitude **Spica** in Virgo. Initially the space between them is about 2°. If you continue to watch past midnight and into the morning of the 10th, you'll see that gap shrink by half when the pair sets in the west-southwest.

TUESDAY, MAY 13

The **Moon** has its best stellar encounter of the month this evening when it climbs above the east-southeastern horizon at around 10:30 p.m. local daylight time. Its partner this time is the red-giant star **Antares** in Scorpius. They'll be at their absolute closest at 11 p.m. EDT, when the Moon sits a bit more than ½° below and right of the star. Full Moon occurred on the previous day, so this evening the lunar disk is a bright waning gibbous, 98% illuminated. The farther south you are, the closer the Moon gets to Antares. Indeed, for observers in much of Argentina, Chile, and Uruguay, the Moon actually covers the star.

As with Mars, the color contrast between ruddy Antares and the silvery gray of the Moon is obvious, especially if you view the scene with binoculars or in a small scope. Indeed, the name Antares means "rival to Ares [Mars]." However, given the star's reddish hue and its brightness being a near-exact match for Mars tonight, Antares is more like an *equal* than a rival.

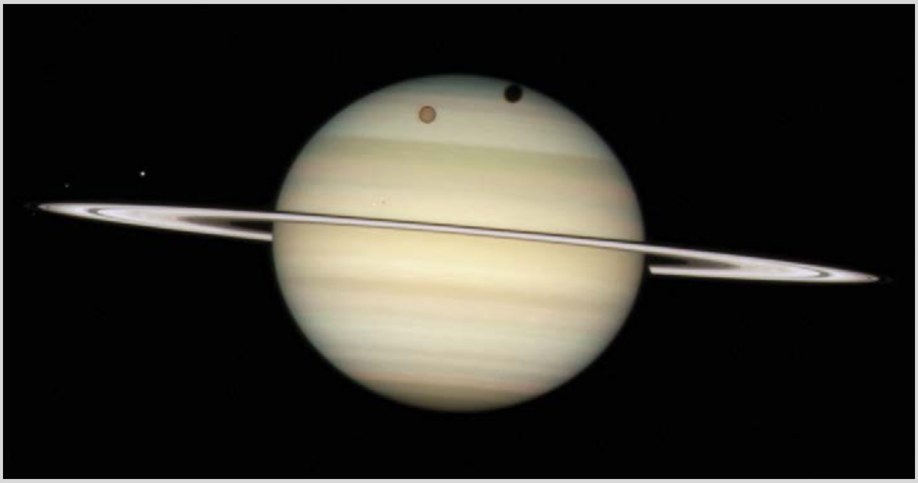
THURSDAY, MAY 22

If you get up just as twilight brightens the sky this morning, you'll be greeted with an eye-catching scene in the east-southeast. There, a waning crescent **Moon** joins the two dawn planets: **Saturn** and **Venus**. Notice how much farther they are compared with earlier in the month. This morning, the Moon is a bit less than 3½° upper right of Saturn. Tune in again tomorrow morning (the 23rd) and it'll be about 6° upper right of Venus instead. Finally, at dusk on the 24th, the slender lunar crescent is 8° left of the brilliant Morning Star.

■ Consulting Editor **GARY SERONIK** is getting ready to set an early alarm.

Titan Throws Shade on Saturn

Take advantage of an infrequent opportunity to watch the satellite's shadow transit the Ringed Planet's disk.



◀ On February 24, 2009, the Hubble Space Telescope captured this view of orange-hued Titan and its shadow crossing Saturn's north polar region. Titan transits the planet again this year — something observers only get to enjoy roughly every 15 years.

NASA / ESA / THE HUBBLE HERITAGE TEAM (STSCI / AURA)

Most skywatchers have a bucket list of celestial sights they hope to witness in their lifetime. Some are easy to achieve, while others are rare and require extraordinary amounts of time and patience. I've seen total eclipses, stood under stirring aurorae, and watched comet fragments blacken Jupiter's clouds. But I've never successfully observed a shadow transit of Saturn's largest moon, Titan.

Unlike Jupiter's Galilean satellites, which undergo multiple transits at every apparition (see the table on page 51), shadow transits of Titan occur in batches at 15-year intervals, when Saturn's rings are presented nearly edge-on. Miss the window, and it's back to the end of the line. Like the other large Saturnian satellites, Titan orbits in the planet's equatorial plane — this means we only see its shadow fall across Saturn's cloud tops when Earth's orbit aligns within a few degrees of the Ringed Planet's equator.

Titan is Saturn's biggest and brightest moon, and the solar system's second largest. It's unique as the only moon having a dense atmosphere and seas brimming with bitter-cold, liquid ethane and methane. With an apparent diameter of about 0.8″ at opposition, Titan is a close match for Europa, the smallest Galilean satellite, which spans 1.0″. So, if you've seen a Europa shadow transit, you have some idea about what to expect from Titan: a mere pinprick of darkness. Adjust your expectations accordingly and use a magnification of at least 150× in your telescope. While you're at it, increase the magnification to 250× and see if you can discern the disk of Titan itself on nights of very calm seeing. (For more on observing Titan, see page 52.)

Titan shadow transits are rare mainly because of two factors. First, Titan orbits Saturn roughly twice as far as Europa does around Jupiter — 1,260,000 kilometers (780,000 miles) versus 671,000 km. Second, Jupiter's orbit is inclined just 1.3° to the ecliptic, compared to Saturn's steeper 2.5° tilt. That means Europa casts a shadow on Jupiter each orbit, but everything must be lined up just so for a Titan shadow transit to occur.

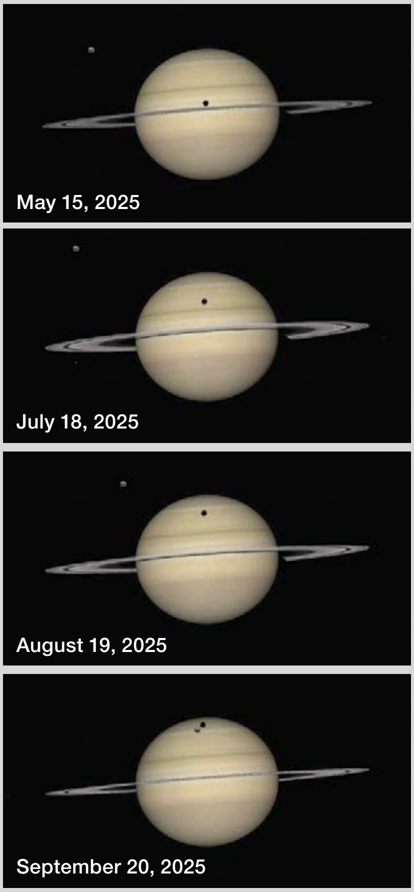
The current shadow-transit series began in November 2024, but these early events were unobservable from the Americas. However, starting on April 29th, that situation changes, and the Western Hemisphere gets the first of 11 opportunities to catch the orangey moon's diminutive shadow crossing Saturn's disk before the series concludes on October 6th.

Titan and its shadow gradually migrate northward from Saturn's equatorial region to the pole during

Upcoming Titan Shadow Transits (UT)

Date	Start	Mid-transit	End
Apr 29	10:35	13:45	16:34
May 15	9:49	12:59	15:44
May 31	9:05	12:12	14:53
Jun 16	8:21	11:24	14:00
Jul 2	7:40	10:35	13:03
Jul 18	7:00	9:44	12:05
Aug 3	6:25	8:52	11:04
Aug 19	5:52	8:01	10:00
Sep 4	5:25	7:09	8:50
Sep 20	5:09	6:20	7:34
Oct 6	—	5:32*	—

*Full shadow on disk only at mid-transit



▲ These simulated views show Titan and its shadow as they will appear on the dates indicated as the shadow crosses Saturn's central meridian. In good seeing conditions, experienced observers have seen the large moon's shadow in telescopes as small as 80-mm (3.1-inch) aperture.

the upcoming transit season. When the moon's shadow passes centrally over Saturn's globe, as it does on April 29th, the transit lasts about 6 hours. As the season progresses, the transit chord grows shorter, and the duration decreases. During the final event, Titan's shadow notches the planet's northern limb, and the transit lasts a little more than 2 hours.

Not every transit listed in the table on page 48 is visible from every location — some happen when the planet is too low or even below the horizon. Shadow transits repeat every 16 days, corresponding to Titan's orbital period. Although this series ends on October 5th, the moon itself continues to cross Saturn's disk through late 2025. After that, the waiting game begins again.

WINJUPOS WITH ADDITIONS

Meteors from Halley's Comet

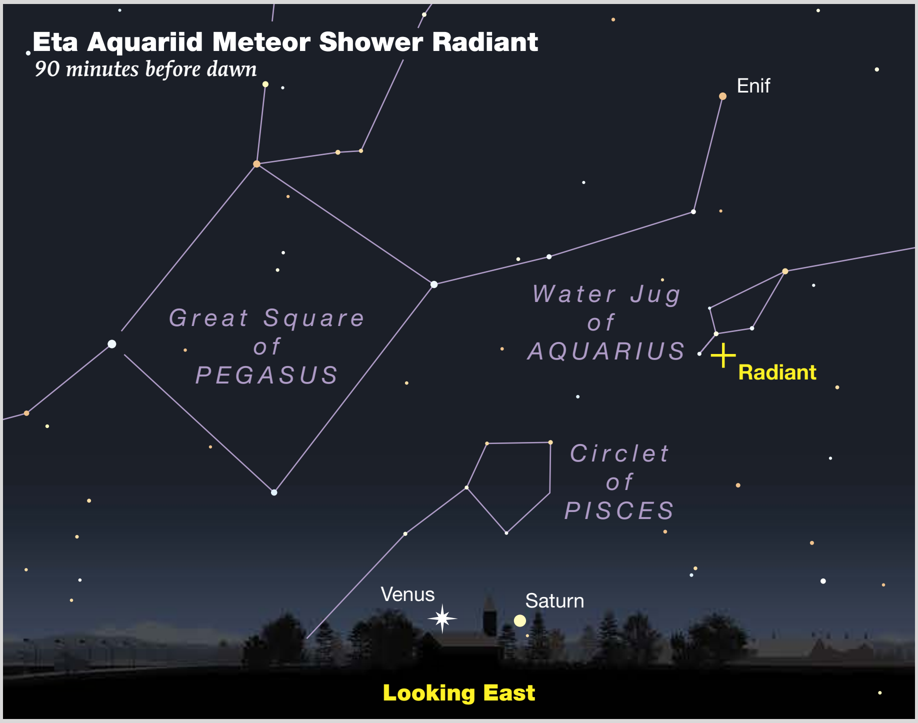
MEMORIES OF HALLEY'S COMET (1P/Halley) come to mind each May when the Eta Aquariid meteor shower returns. Both this display and October's Orionids share the same famous parent: In spring, Earth passes through dust outgassed by the comet along the outbound portion of its orbit, and in October we cross the inbound track.

The Eta Aquariids typically have an extended peak, spanning both the mornings of May 5th and 6th, according to Robert Lunsford, Secretary General of the International Meteor Organization (IMO). The Moon is just past first-quarter phase and sets around the same time that the radiant, located in the Water Jar asterism in Aquarius, climbs high enough in the southeastern sky for the show to begin. Admittedly, the gap between moonset and morning twilight is brief — particularly for observers at mid-northern latitudes. Dawn gilds the eastern sky beginning around 4 a.m., constricting the observing window to about 2 hours. Moreover, the radiant remains rather low, so counts are typically in the range of 10 to 30 meteors per hour.

It's a different story from the tropics and the Southern Hemisphere. Aquarius climbs halfway up the eastern sky before dawn. With fewer meteors cut off by the horizon, the rate jumps to around 60 per hour, making this one of the best showers of the year.

Eta Aquariid meteoroids tear into Earth's upper atmosphere at 66 kilometers per second (150,000 mph) and can leave lingering, bright trails called *trains*. Occasionally, the display has outbursts, as it did in 2004 and 2013. During the 2013 shower, the zenithal hourly rate reached 135. Both outbursts were caused by gravitational effects from Jupiter, which assisted in concentrating particles shed by Halley's Comet. No strong outbursts are predicted for this year, but a surprise is always possible.

For many locations, morning temperatures in May are pleasant, and mosquitoes have yet to arrive. But if clouds threaten, don't lose hope. As Lunford notes, "This shower and the Orionids have a plateau-like maximum in which strong activity can be seen for a solid week centered on the expected night of maximum activity."



Back-to-Back Lunar Crescents

I LOVE THE CHALLENGE of spotting a breathtakingly thin crescent Moon at dusk or dawn but can't recall being lucky enough to see both in succession. Happily, thanks to fortuitous timing, May presents an opportunity to do just that. New Moon occurs on May 26th at 11:02 p.m. EDT — just 25 hours after *perigee*, when the Moon is closest to Earth. This not only makes the Moon appear a little larger than normal (enhancing visibility) but also increases its orbital speed, which means that the Moon escapes the Sun's glare more rapidly as it transitions from being a morning object to an evening one.

If you live in the Eastern Time Zone and have low horizons both to the east and west, you have a chance to see a gossamer-thin lunar crescent about 18½ hours before new Moon on May 26th, and again about 21½ hours after new the following evening. From Boston, Massachusetts, the edgy morning crescent is 0.9% illuminated and approximately 2½° above the northeastern horizon 30 minutes before sunrise. The view on the evening of the 27th is a breeze by comparison, with the Moon 1.2% illuminated and 6° high 30 minutes after sunset.

Sighting the morning Moon from the Pacific Time Zone is more challenging. It has aged an additional 3 hours by moonrise, and the solar elongation is correspondingly reduced. Still, observers with exceptionally clear skies may catch sight of the vanishingly thin crescent 15½ hours before and 24½ hours after new Moon. From San Francisco, California, the Moon is 0.6% illuminated and just 1½° above the eastern horizon 30 minutes before sunrise. The following evening, the time difference of 3 hours helps to boost the Moon higher at dusk. Half an hour past sunset, the 1.6%-illuminated crescent sits at a comfortable 7½° altitude in the northwestern sky. Binoculars go a long way toward helping spot the Moon as it coasts from a.m. to p.m. under the Sun's glaring gaze.

▲ Chasing extreme Moons is one of Ali Ebrahimi Seraji's passions. He photographed this set of lunar crescents from Iran in 2014 at dawn on January 30th (*left*) and dusk on January 31st (*right*). The old Moon's age was 18 hours and 38 minutes and the crescent 1.14% illuminated. The waxing Moon's age was 16 hours and 50 minutes and illuminated 0.93%. On both occasions the lunar crescent was visible to the unaided eye.

Action at Jupiter

EARLY MAY PRESENTS your last chance for satisfying telescopic views of Jupiter as it cruises toward its June 24th solar conjunction and the conclusion of its current apparition. The trick is to catch the planet soon after sunset, when it's highest. Fortunately, as the month begins, Jupiter shines at magnitude –2.0 and can be spotted only a short time after the Sun sinks below the horizon. On May 1st, the planet hangs some 34° above the western horizon as the Sun sets. By the end of the month Jupiter's sunset altitude is only 13° — much too low for sharp images.

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

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

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

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

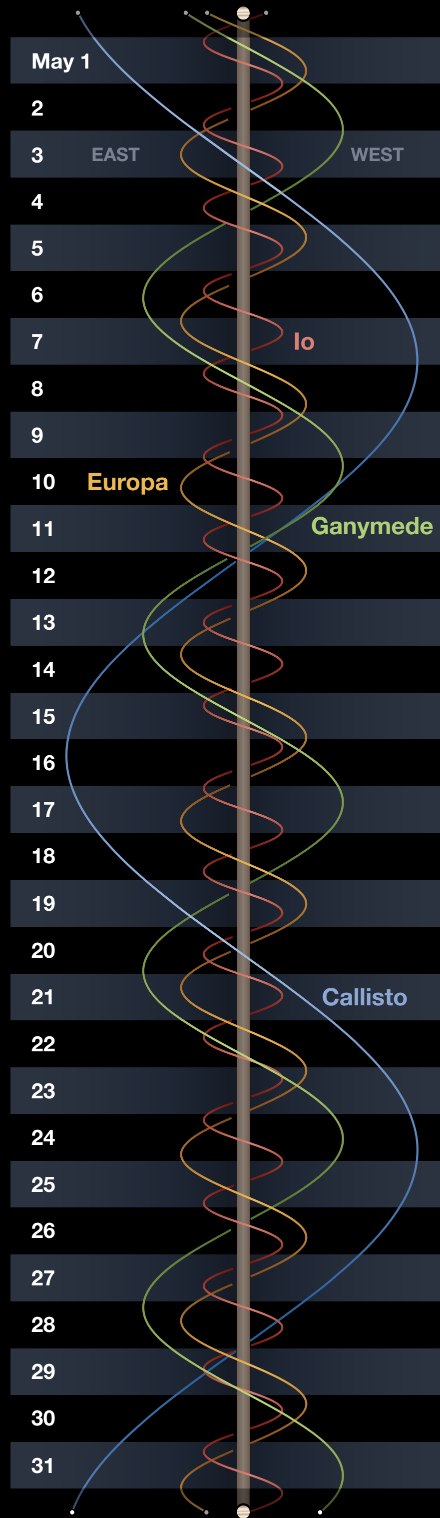
These times assume that the spot will be centered at System II longitude 74° on May 1st. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 74° and $1\frac{2}{3}$ minutes later for each degree more than 74°.

Phenomena of Jupiter's Moons, May 2025

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

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.

Feats of Planetary Observing

Visual astronomy has an enduring legacy of discovery.

Observing the planets is often comparable to watching a movie in which the projector is out of focus except for a few occasional sharp frames thrown in at random intervals. During most of the 20th century, recording the planets using photographic film required exposures lasting appreciable fractions of a second to several seconds. Even in that seemingly brief span, atmospheric turbulence invariably effaces the finest details. As recently as the 1980s, the sharpest photographs of the planets taken through the world's largest telescopes failed to record details beyond the grasp of visual observers equipped with 8- or 10-inch telescopes.

While the human eye isn't quite an instantaneous sensor, it requires less than one-fifteenth of a second to register an image. Experienced visual observers learn to retain the fleeting impressions of clarity and disregard the blurry intervals. The supremacy of the human eye was only brought to a close at the dawn of the 21st century when photographic film's inefficient grains of silver salts were supplanted by far more sensitive silicon chips combined with image-processing software capable of automatically selecting and combining the sharpest frames.

By keeping a patient vigil at the eyepiece, observers enjoy those magical moments that Percival Lowell called "revelation peeps." Here are three discoveries by visual observers that are still difficult to record using today's finest imaging technology.

Cassini's Thin Division

Saturn's bright A and B rings are separated by a dark, 4,700-kilometer-wide (2,900-mile-wide) gap known as the Cassini Division. Although it's comparable in width to the continental United States, the Cassini Division subtends only 0.7 arcsecond for Earth-bound observers when Saturn is at its closest, corresponding to the apparent width of a penny as seen from a distance of a bit more than 5 kilometers.

High-resolution images as well as radio and stellar occultation data obtained during NASA's Voyager spacecraft flybys in the early 1980s revealed that, rather than an empty void, the Cassini Division contains narrow ringlets with particle densities about one-fifth those of the adjacent A and B rings.

▲ In this 2008 image captured by the Cassini spacecraft, the jet-black shadow cast by Saturn's globe across the rings contrasts with the pale reflection of material in the Cassini Division. In 1852 William Stephen Jacob cited this disparity as proof that the Cassini Division is not an empty void.

Although the Voyager spacecraft are widely credited for discovering the presence of material in the Cassini Division 45 years ago, the real credit should go to British astronomer William Stephen Jacob. In 1852 Jacob reported that the Cassini Division didn't appear black but had the color of slate when seen through the 6.2-inch refractor at the Madras Observatory in India. Four years later he reported that the shadow cast by Saturn's globe across the rings "could also be seen across the dark space between the two bright rings, which therefore cannot be a mere opening but must be filled with matter of some kind."

Other visual observers soon confirmed Jacob's eyepiece impressions. Thomas Gwyn Elger, a keen-eyed British amateur who is remembered today chiefly for his lunar studies, commented in the *Monthly Notices of the Royal Astronomical Society* in 1888 that

NASA / JPL / SPACE SCIENCE INSTITUTE

the Cassini Division "... has never impressed me as being perfectly black" through his 8.5-inch reflector. In 1899 the French astronomer Camille Flammarion described the appearance of the Cassini Division through his 9.6-inch refractor as "dark grey, not black" and inferred that "there is probably some matter in it." Fifteen years later his countrymen Georges and Valentin Fournier reported that on the steadiest nights, the 19.7-inch refractor of the Jarry-Desloges Observatory in Algeria showed that the Cassini Division was "not devoid of particles."

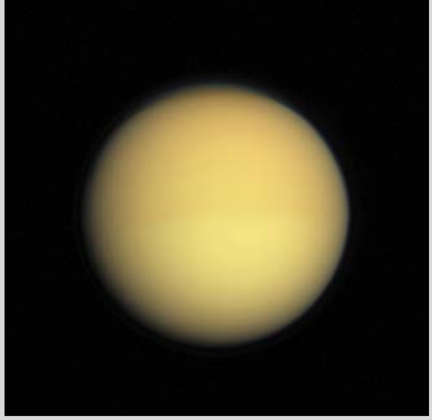
Discovery of Titan's Atmosphere

Saturn's largest moon, Titan, is surrounded by a dense, hazy atmosphere laden with orange photochemical smog. The discovery of Titan's atmosphere is usually attributed to the Dutch-American astronomer Gerard Kuiper, who used the 82-inch reflector at McDonald Observatory in 1944 to photographically record prominent absorption bands of methane gas in the giant satellite's spectrum.

Remarkably, a visual observer beat Kuiper to the punch 37 years earlier. During the first decade of the 20th century, the Catalan astronomer Josep Comas i Solà made an intensive study of Jupiter's Galilean satellites as well as Titan using the 15-inch refractor at the Fabra Observatory in Barcelona. Remote Titan's apparent diameter is a mere 0.8 arcsecond at opposition, only slightly greater than the width of the Cassini Division and almost identical to the maximum apparent diameter of the asteroid Ceres.

On a night of excellent seeing in August 1907, Comas i Solà was able to examine Titan at a magnification of 750×. The miniscule nail's head appeared almost one-third the diameter of the Moon as seen with the naked eye, but much dimmer because the intensity of sunlight is reduced 90-fold at Saturn's orbital distance. He was struck by an appearance that was always lacking whenever he had observed Jupiter's Galilean satellites. Titan displayed pronounced limb darkening which signified the presence of a substantial envelope of gases surrounding the satellite. The following year Comas i Solà announced his discovery in *Astronomische Nachrichten*, the era's leading astronomical journal:

> *... I saw Titan with a very dusky edge that trailed off into the darkness of the sky (something similar to what one observes on the disk of Neptune), while towards the central part, much more clearly, one saw two whitish patches that gave me the impression of a diffuse double star. We can justifiably suppose that the pronounced obscurity of the limb demonstrates the existence of a very absorbent atmosphere surrounding Titan.*



◀ In 2013, the Cassini spacecraft imaged Titan's pronounced limb darkening — a feature first discerned by the keen-eyed Spanish astronomer Josep Comas i Solà in 1907.

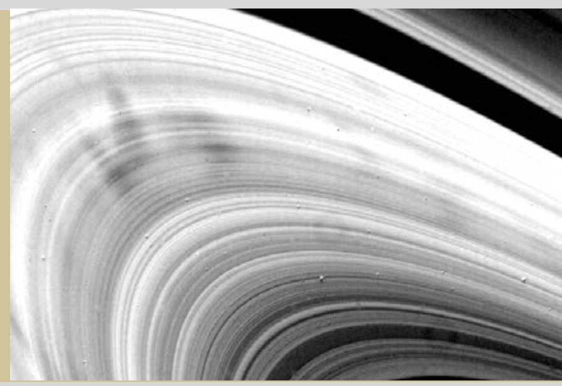
Saturn's Spokes

During the late 1970s, the eagle-eyed observer Stephen James O'Meara repeatedly glimpsed faint dusky streaks crossing Saturn's B ring through the 9-inch Clark refractor at Harvard College Observatory. O'Meara's detailed accounts of ghostly linear features rotating like a lighthouse beacon were greeted with skepticism until NASA's twin Voyager spacecraft flew past Saturn in 1980 and 1981. Voyager cameras captured hundreds of images of faint, shadowy fingers radiating across Ring B. In movies assembled from these images, spokes up to 6,000 kilometers long were seen to form in as little as 5 minutes.

Low-contrast features that are only 10% darker than their surroundings, the spokes are composed of exceedingly fine grains of icy dust levitated above the ring plane by electrostatic repulsion. After these structures coalesce, they orbit Saturn at the same rate as the planet's magnetic field. The spokes gradually shear out as their constituent particles begin to move in trajectories controlled by gravitational, rather than electromagnetic, forces.

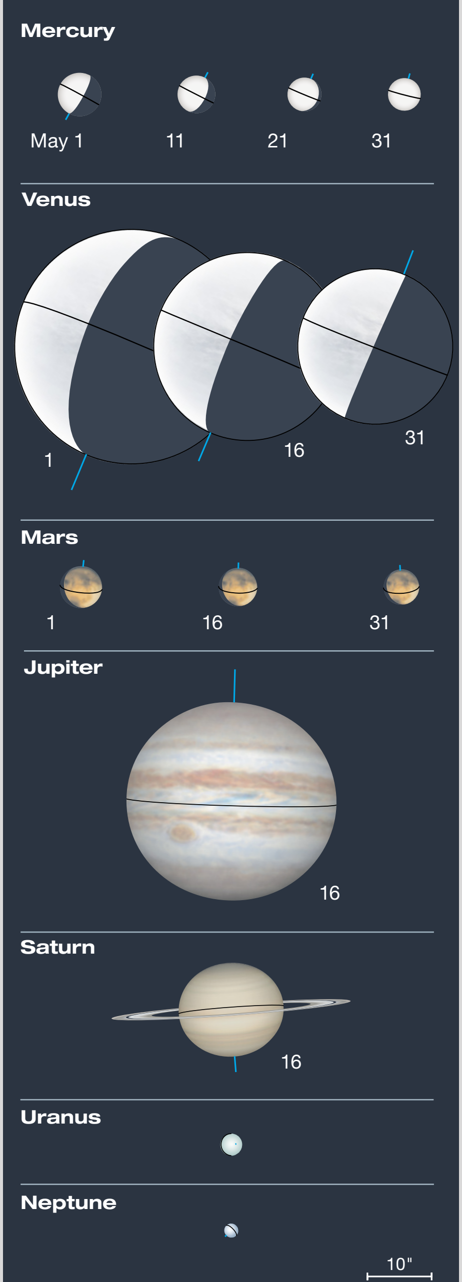
In the next installment I'll recount more remarkable discoveries by visual planet observers.

■ Contributing Editor **TOM DOBBINS** is co-author of *Epic Moon, A History of Lunar Exploration in the Age of the Telescope*, available at **shopatsky.com**.



Right: S&T Contributing Editor Stephen James O'Meara's 1976 drawing is one of the first sketches to show the spokes in Saturn's rings. *Far right:* Five years later, the Voyager 2 spacecraft captured spokes in this image recorded on August 22, 1981.

TITAN: NASA / JPL / SPACE SCIENCE INSTITUTE; VOYAGER PHOTO: NASA / JPL



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

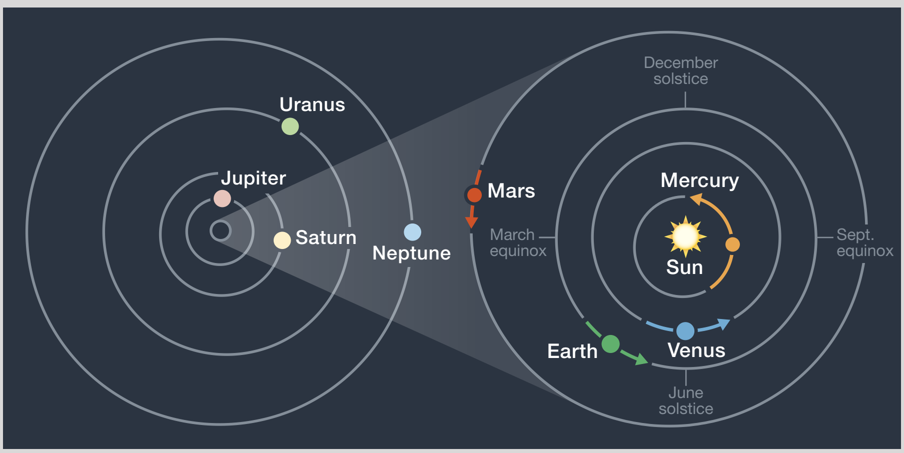
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during May. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** is hidden in the Sun's glare all month • **Venus** visible at dawn all month • **Mars** visible at dusk and sets in the predawn • **Jupiter** visible in the west-northwest at dusk and sets in the evening • **Saturn** visible at dawn all month.

May Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	2^h 32.5^m	+14° 59′	—	–26.8	31′ 45″	—	1.008
	31	4^h 31.2^m	+21° 52′	—	–26.8	31′ 33″	—	1.014
Mercury	1	1^h 00.3^m	+3° 19′	26° Mo	0.0	6.8″	59%	0.993
	11	1^h 56.8^m	+9° 25′	20° Mo	–0.4	5.9″	75%	1.146
	21	3^h 07.8^m	+16° 31′	11° Mo	–1.2	5.3″	91%	1.275
	31	4^h 35.1^m	+22° 43′	1° Ev	–2.4	5.1″	100%	1.320
Venus	1	23^h 57.5^m	+0° 56′	41° Mo	–4.7	36.5″	29%	0.457
	11	0^h 24.0^m	+2° 14′	44° Mo	–4.7	31.3″	36%	0.532
	21	0^h 55.5^m	+4° 26′	45° Mo	–4.6	27.3″	43%	0.611
	31	1^h 30.6^m	+7° 13′	46° Mo	–4.5	24.1″	49%	0.691
Mars	1	8^h 32.5^m	+20° 53′	85° Ev	+0.9	6.6″	90%	1.422
	16	9^h 01.6^m	+18° 43′	77° Ev	+1.1	6.0″	90%	1.558
	31	9^h 32.2^m	+16° 09′	71° Ev	+1.3	5.5″	91%	1.687
Jupiter	1	5^h 21.0^m	+22° 54′	40° Ev	–2.0	33.7″	100%	5.848
	31	5^h 48.8^m	+23° 14′	18° Ev	–1.9	32.4″	100%	6.089
Saturn	1	23^h 54.0^m	–2° 50′	43° Mo	+1.2	16.1″	100%	10.305
	31	0^h 03.6^m	–1° 54′	69° Mo	+1.1	16.8″	100%	9.894
Uranus	16	3^h 38.4^m	+19° 14′	2° Ev	+5.8	3.4″	100%	20.541
Neptune	16	0^h 06.3^m	–0° 43′	54° Mo	+7.9	2.2″	100%	30.476

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**.



Getting Ahead With Serpens

The front end of the celestial serpent rises every May evening.

BIG BRIGHT BEAUTY Of the approximately 150 globular clusters surrounding our Milky Way Galaxy, M5 is among the most spectacular in backyard telescopes. Located in Serpens Caput, it's arguably the finest specimen north of the celestial equator.

PHOTO OF M5: RON BRECHER

I can't say I'm on intimate terms with Serpens Caput, the head of the Serpent. It's the western section of the sky's only two-part constellation — the eastern part is Serpens Cauda, the tail of the Serpent. We'll be exploring the head this month, though it possesses just one star brighter than magnitude 3.5 and barely shows in my light-polluted suburban sky. For me (and maybe you), at first glance Caput is *kaput*!

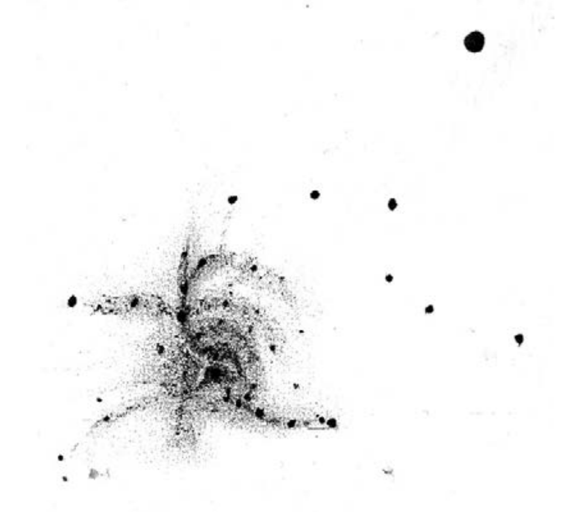
But all is not lost. Serpens Caput houses some perfectly accessible telescopic attractions. Several nice double stars plus an exceptional globular cluster lie inside a rectangular swath of sky 20° high by 10° wide. The various Serpens goodies we'll visit hover above the celestial equator between Ophiuchus and Virgo.

I explored Caput country over a few evenings last May using a 4.7-inch (120-mm) f/7.5 apochromatic refractor and a 10-inch f/6 Newtonian reflector. Both scopes yielded rewarding views — despite my backyard's nightlong light.

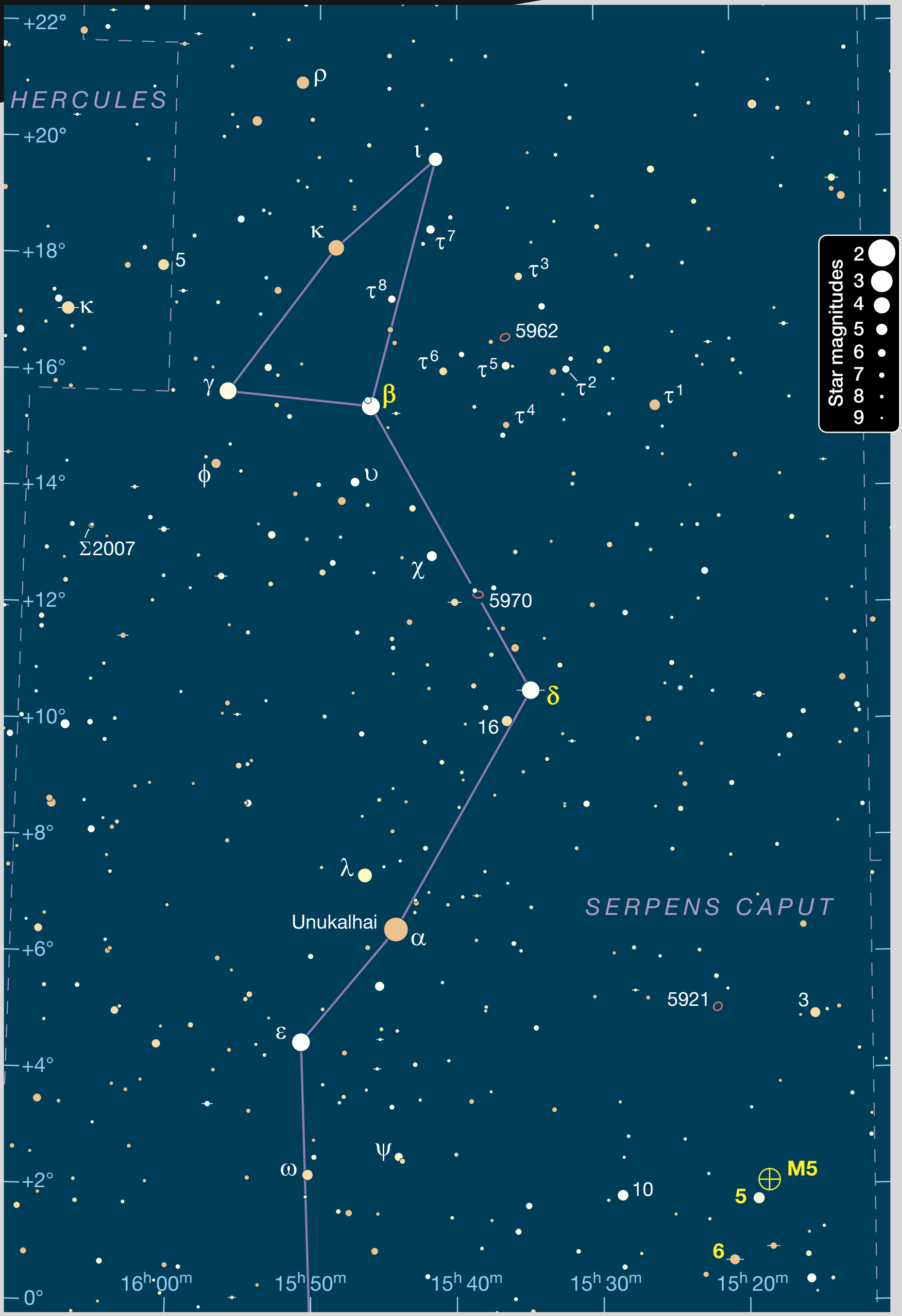
Tongue Test

The Serpent's angular head is outlined by 3.7-magnitude Beta (β), 3.8-magnitude Gamma (γ), and 4.1-magnitude Kappa (κ) Serpentis, the three stars forming a triangle a few degrees across. Some charts (such as ours on pages 42–43) extend the pattern northwestward a couple of degrees to 4.5-magnitude Iota (ι). Last spring, the sky around Serpens was its usual mediocre self. "Beta and Gamma easy," stated my observing log, "Kappa very dim, Iota marginal."

I aimed the refractor first. Its 8×50 finderscope captured Beta, Gamma, and Kappa easily, and a northwestward nudge picked up Iota. I then recentered Beta and swept 5° westward to nab a fifth star, 5.2-magnitude Tau^1 (τ^1) Serpentis. I knew that within the area bounded by Beta, Iota, and Tau^1 there are seven additional Tau stars (τ^2 through τ^8) down to about 6th magnitude. The finderscope pulled in the complete Tau set, plus at least a dozen fainter stars. In a moment of whimsy, I decided to dub this starry stubble "the tongue of the Serpent." The tip of the tongue (τ^1) glowed reddish-orange.



CAUGHT ON PAPER Intricate detail in M5 is revealed in this eyepiece sketch by Stephen James O'Meara for his 1998 book *The Messier Objects*. "Toward the southeast," wrote O'Meara, "stars spiral or fan out in long arms." The crab-like form of the cluster is evident in his sketch. To capture these subtle features, O'Meara used a 4-inch apochromatic refractor under a dark, high-altitude site on the Big Island of Hawaii. (The black dot at upper right is the star 5 Serpentis.)



▲ **CAPUT COUNTRY** The triangular head of Serpens Caput is easily visible from most suburban locations. Many fainter stars scattered just west of the Serpent's head symbolize what the author calls "the tongue of the Serpent." The most famous deep-sky object in Serpens Caput is the globular cluster M5, located next to the 5th-magnitude star 5 Serpentis.

Those twinkling tongue stars provided scenic appeal to a region that was essentially invisible to my unaided eyes.

I wasn't quite done examining the Serpent's conspicuous cranium. **Beta Serpentis** — the most attractive node in the noggin — comes with two extra bits. The finderscope revealed extra #1, the 6.7-magnitude star 29 Serpentis lying 7′ north-northeast of Beta. Extra #2 is Beta itself, which is a strongly uneven double star. Beta's 10.0-magnitude companion, 29.9″ westward, materialized in the refractor (barely) at 53×, though it posed no difficulty for the 10-inch reflector employing slightly less magnification. In both cases, the view included 29 Serpentis.

Serpentine Star-Hop

Next up was a descent down the narrow neck of the Serpent. A 5.6°-long chain of stars trends southwestward from Beta to **Delta (δ) Serpentis**. I love Delta because it's a compact binary star sporting 4.2- and 5.2-magnitude components 4.0″ apart. The Delta duo resolved in each telescope at 100×. A satisfying target!

After Delta, I veered south-southeastward 4.7° to 2.6-magnitude Alpha (α) Serpentis, known to ancient stargazers as Unukalhai (the Serpent's neck). Orangey Alpha is the entrance to Serpens Caput's finest deep-sky object — the globular cluster M5. But beware: M5 resides almost 8° southwest of Alpha. That kind of distance demands a careful star-hop.

Alpha and 3.7-magnitude Epsilon (ε) establish the 2.5°-wide baseline of an isosceles triangle whose vertex is marked by 5.2-magnitude 10 Serpentis 6° southwestward. I began by hopping from Alpha down to Epsilon, then turning south-southwest for 2.6° to 5.9-magnitude Psi (ψ) Serpentis. In both scopes, Psi blossomed into three stars in a bent line 6′ long, slanted northeast-southwest. Psi shines at the northeast end, 7.2-magnitude HD 140489 anchors the southwest end, and 9.0-magnitude HD 140527 flickers between them. A pretty alignment!

At Psi, I veered west-southwestward 3.9° to 10 Serpentis. From there, I could've dashed west straight to the big prize. Instead, I hopped 2.2° southwestward to 5.5-magnitude **6 Serpentis**. This yellow-orange star harbors an 8.8-magnitude attendant a mere 3.4″ northward. The tight binary resolved in my 10-inch at 169×, but it was a tough split in the refractor at 200×. Steady seeing — hardly guaranteed — was crucial. Thankfully, I got it.

After the 6 Serpentis challenge, I hopped a hair more than 1° north-northwestward to 5.1-magnitude **5 Serpentis**, which guards M5 only 22′ farther on. Bonus: 5 Serpentis is another unbalanced binary, whose 10.1-magnitude secondary sun is 5 magnitudes (100 times) dimmer than the yellowish primary. Because the components lie 11.7″ apart, they separated cleanly in my reflector at 95×. For the apochromat 100× was sufficient, though the secondary was a frail spark next to the glaring primary.

Serpens Showpiece

Needless to say, I didn't linger at 5 Serpentis. Every time I centered the lopsided pair in a medium-power eyepiece, my attention wandered toward **M5** — a chandelier of suns blazing at the edge of the field.

The globular boasts impressive features. Its brightness (magnitude 5.7) and diameter (23′) are marginally greater than its famous cousin, M13, the Great Cluster in Hercules. Like the Hercules specimen, M5 is a high-contrast object that takes magnification well. Even so, I couldn't help muttering something impolite when observing M5 through the exceptionally awful sky glow toward the south. Because I live at latitude 49.2° north, the cluster drifts through a lot of light. Bottom line: M5 appeared less than half its official size in my suburban scopes.

And yet, the 10-inch working at 64× presented a speckled sphere strongly concentrated toward the center. M5's dim halo, slightly elongated northeast-southwest, resolved into stars at 95×. Upping to 169×, I saw numerous pinpoints of light scattered across the globular, though its dense core remained impenetrable. I even caught a cluster variable named V42 shining relatively prominently a few arcminutes southwest of center. (The brightest members of M5 are magnitude 12.2, while V42 peaks at magnitude 10.6.) With patient, averted vision I registered stars curving around the northeast and southwest ends of the cluster, roughly in the direction of 5 Serpentis. These subtle streams are nicely captured in the sketch on page 55, made by *S&T* Contributing Editor Stephen James O'Meara.

To my surprise, some of the details described above were within reach of my little refractor. At 28×, it gave me a prominent, compact fuzzball. Doubling the magnification produced a classic globular that was clearly denser and brighter toward the middle. Using averted vision and 100×, I detected several faint stars sprinkled throughout the halo. At 200×, the fuzzy sphere exhibited a granular texture, and variable star V42 was obvious. Not bad!

AKIRA FUJII

▲ **HEAD FIRST** This wide-angle view shows the summer Milky Way rising above the eastern horizon, as it does on May evenings. Serpens Caput lies near the top of the frame. Use the chart on page 42–43 to identify Serpens, Ophiuchus, and the other constellations presented here.

Long Story Short

Staring at a monstrous globular can be an addictive pastime. I never get enough of M5. That said, there's more to Serpens Caput than a single big ball of stars. As is often the case when exploring the night sky, the journey is half the fun. My serpentine ramble from the head of Serpens, down the reptile's *l-o-n-g* neck (such odd anatomy!) then westward to the cluster, turned out to be rewarding even with all that lousy, rotten, good-for-nothing light pollution.

As the calendar shifts from April into May, Serpens rises at nightfall. By late May, springtime's grand globular crosses the meridian around midnight. Observers living farther south than me should get superior views.

Not many globular star clusters visible from mid-northern latitudes can compete with M5. I hope you'll stay up late to savor its beauty.

■ Contributing Editor **KEN HEWITT-WHITE**, a native of Canada, is no serpent-wrangler; he wrestles with words.

Caput Catches

Object	Type	Mag(v)	Size/Sep.	RA	Dec.
β Serpentis	Double star	3.7, 10.0	29.9″	$15^h 46.2^m$	+15° 25′
δ Serpentis	Double star	4.2, 5.2	4.0″	$15^h 34.8^m$	+10° 32′
6 Serpentis	Double star	5.5, 8.8	3.4″	$15^h 21.0^m$	+0° 43′
5 Serpentis	Double star	5.1, 10.1	11.7″	$15^h 19.3^m$	+01° 46′
M5	Globular cluster	5.7	23′	$15^h 18.6^m$	+02° 05′

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

Visions of Space

INFINITE COSMOS: *Visions from the James Webb Space Telescope*

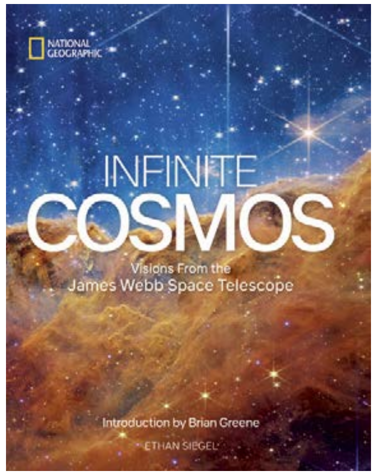
Ethan Siegel, with introduction by Brian Greene
National Geographic Society, 2024
224 pages, ISBN 13-9781426223822
$50.00, hardcover

ONE COFFEE-TABLE BOOK lived in our home all throughout my childhood. It was a marvel, a gorgeously illustrated testament to all that observational astronomers had accomplished and the wonders that remained to be understood. It was the dawn of Voyager, the era of sending spacecraft aloft to find what our landlocked observatories on Earth could not yet discern.

The book, of course, was *Cosmos* by Carl Sagan. It was a massive bestseller. A million coffee tables adorned, countless dreams inspired.

Sitting with *Infinite Cosmos: Visions from the James Webb Space Telescope*, I'm hoping for the same awakening of wonder in a new generation of explorers. With artwork in every way the equal of *Cosmos*, it celebrates the accomplishments afforded by another 40 years of space science. The December 25, 2021, launch of JWST aboard an Ariane 5 rocket showcased humanity's ability to position a telescope beyond the Moon, at the L_2 Lagrangian point 1.5 million kilometers behind Earth when viewed from the Sun. There, it soaks up photons emitted in the infrared spectrum — invisible to human eyes but with the longer wavelengths needed to dart around interstellar dust particles and reveal the marvels behind them.

The text, written by astrophysicist and science communicator Ethan Siegel, tells the story of the conception, development, launch, and first scientific findings of the most powerful telescope ever designed. It is a celebration of science and scientists, with many of the photos showing both the people responsible for JWST's design, testing, and construction — and the enormity of the scope itself. As physicist Brian Greene writes in his introduction, "The fortitude to take on such a mission is nothing short of heroic."



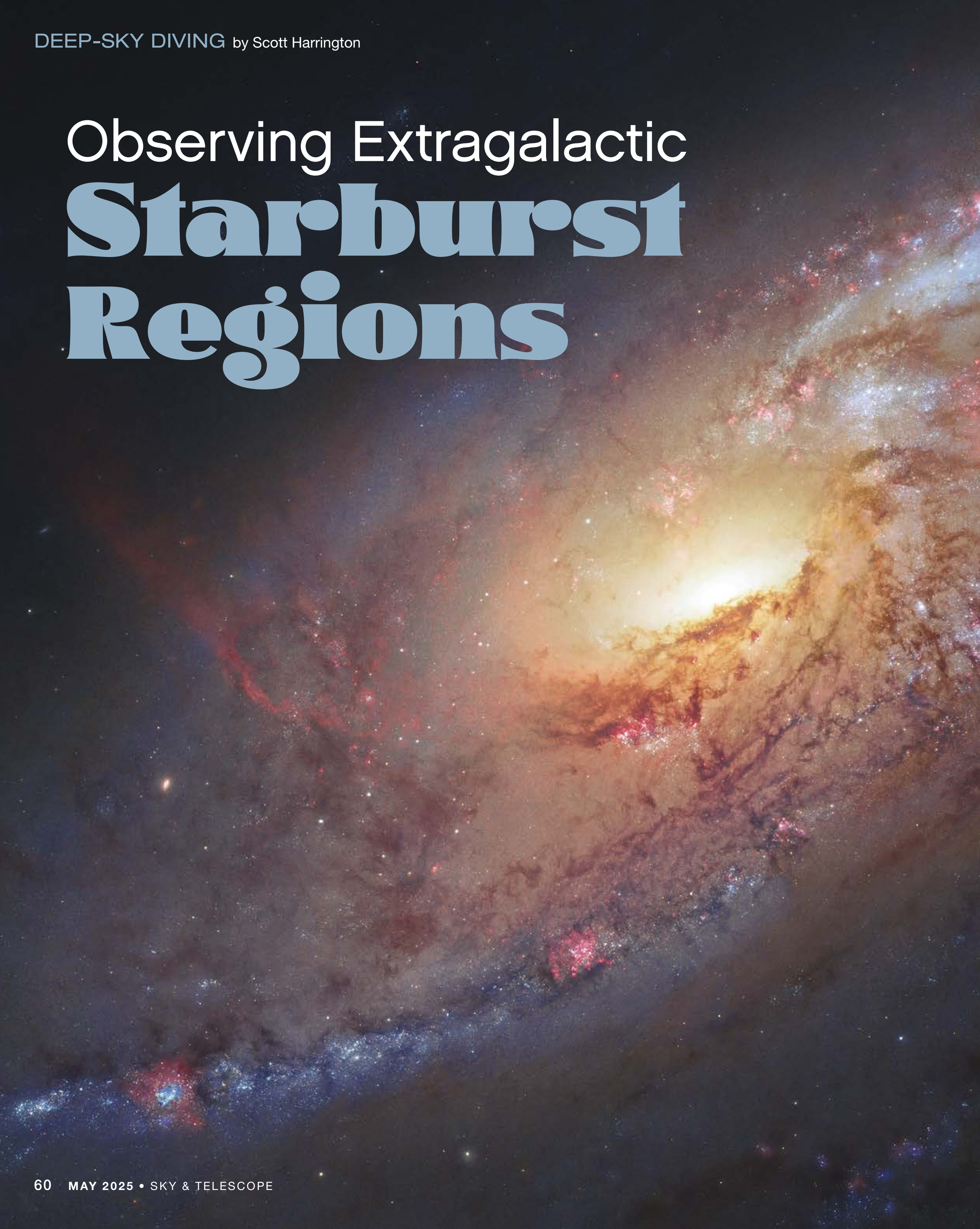
Siegel describes how JWST differs from its cousin, the Hubble Space Telescope (for which National Geographic Books published *The Hubble Cosmos: 25 Years of New Vistas in Space* in 2015), in size, scope, and mission. Launched in 1990, Hubble resides in a low-altitude orbit, close enough that Space Shuttle astronauts could correct a flaw in its primary mirror. JWST, a million miles away, has no such safety net. HST collects visible light, some ultraviolet radiation, and just a bit in the infrared spectrum as well: a span of 100 to 2000 nanometers (visible light spans 380 to 700 nm). JWST's infrared-sensing capabilities far exceed Hubble's, reaching out to 28,000 nm.

Needless to say, it's the photos in this book that blow our minds wide open. *Infinite Cosmos* leans into the visual feast that this incredible spacecraft provides: the trademark, gold-coated hexagonal shape of the 18 separate mirrors comprising the primary mirror, the sunshield unfolding into a kind of celestial kite, and the stunning detail of the deep-space images that result. The release of the first JWST image to the public on July 11, 2022, was so momentous that it merited a White House press conference; President Biden described JWST as opening "a new window into the history of our universe." The detail of the galaxy cluster SMACS 0723 and the more than 1,000 separate galaxies imaged around it (the result of careful decision-making as to how to visualize in visible colors the data that were collected in the invisible infrared spectrum) inspired countless social media shares and a sense of collective wonder that perhaps we have not felt together in some time.

Books like this let us dream and grow. They can inspire us and take us farther into the universe to understand our place within it. They are a testament to what science can accomplish with support and funding, when child dreamers can develop into full-fledged professional engineers and astrophysicists. I suspect more than one of the scientists pictured in *Infinite Cosmos* had a copy of Carl Sagan's magnum opus in their own childhood home. A worthy goal for this title would be for it to do the same.

■ **NICOLE NAZZARO** is a biochemist and science writer based in Edmonds, Washington. She is the managing director of Impact Media Northwest, a science and technology communications consultancy. Reach her at **nicole@impactmedianw.com**, on LinkedIn, or on Bluesky at **@mnicolen.bsky.social**.

Observing Extragalactic Starburst Regions



Take a trip to stellar nurseries separated by space and time.

Four years ago, I wrote an article about springtime galaxies that each host a single, massive star-forming region (*S&T:* May 2021, p. 22). These massive sites of stellar birth are notable for having huge concentrations of ionized hydrogen (H II for short) created by the ultraviolet radiation of the hot, newborn *O*- and *B*-type stars within. I had tracked down eight of these star-forming regions (H II/SFR), each visible in my 10-inch Schmidt-Cassegrain telescope (SCT). Since then, I have learned of many additional "one-hit wonders" and also acquired a 16-inch Dobsonian. My quest is ongoing, but I'm excited to pause now and take you on a tour of nine new targets. And though I enjoy using my big new scope, each one was also visible in my 10-inch!

Mrk My Word

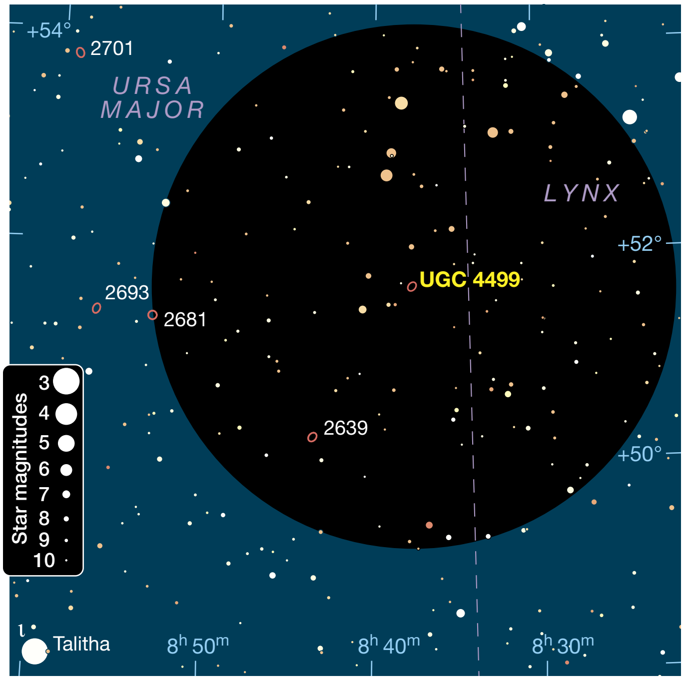
In my 2021 article, I wrote about two relatively bright H II/SFRs known as Markarian 59 and 71. That's a surname you'll see repeatedly when searching for these objects. Beniamin Markarian (1913–85) was an Armenian astronomer who, along with his colleagues, used the 1-meter Schmidt telescope at Byurakan Astrophysical Observatory from 1964 until 1978 to search for galaxies that displayed excess ultraviolet emission. Known today as the First Byurakan Survey (FBS), the astronomers' work was a monumental success tallying nearly 1,500 galaxies on more than 2,000 photographic plates. Later investigations found these "Markarian galaxies" are a diverse mix of objects that includes white dwarf stars, quasars, and my favorite: young, massive star-forming regions in faraway galaxies.

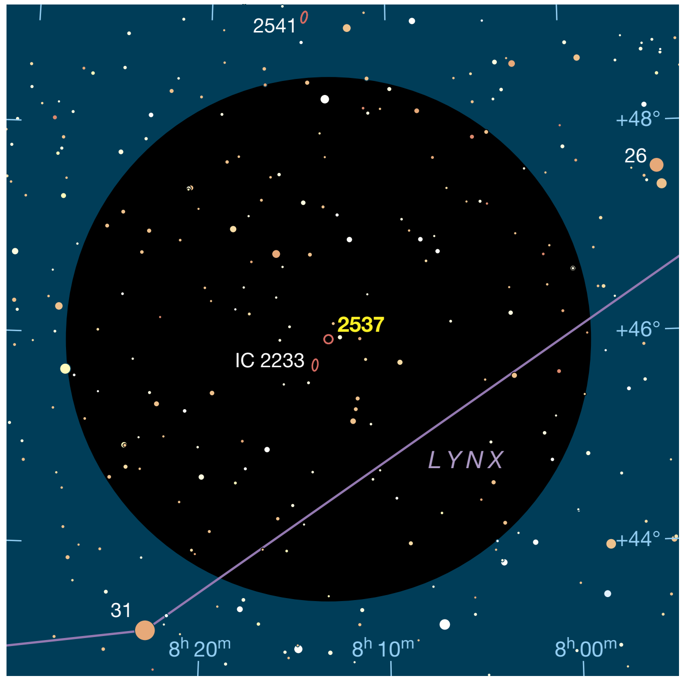
Our first target from the FBS is Markarian 94, an extremely compact H II/SFR in the face-on dwarf spiral **UGC 4499**. It's found 8½° west of Theta (θ) Ursae Majoris, near the border with Lynx. In my 10-inch SCT at 94×, I see only a small, weak glow. With 260×, the central region of the galaxy appears some 30″ wide and about as eye-catching as a 15th-magnitude star positioned 1.1′ south of it. But during moments of favorable seeing, I caught a few glimpses of Mrk 94 as a stellar glow between the star and the galaxy's core.

With the added light-gathering ability of my 16-inch, at 300× Mrk 94 is a much easier find, while UGC 4499 displays a small central glow in a larger halo that appears mildly elongated north to south. In a 2017 study, Francine Marleau (University of Innsbruck) and colleagues found evidence for a supermassive and active black hole in Mrk 94!

◀ **MAJESTIC MESSIER** M106 spans an impressive 18.6′, making it one of the largest galaxies visible in the springtime sky. But its apparent size is more than an illusion — its physical diameter is similar to our own Milky Way Galaxy, spanning more than 134,000 light-years. M106 is host to an H II star-forming region, at lower left in this photo and indicated in the sketch on page 66 made by Belgian amateur Tom Corstjens with a 16-inch telescope.

NASA / ESA / THE HUBBLE HERITAGE TEAM (STSCI / AURA)





▲ **CHARTING A COURSE** On the charts presented in this article, the darkened circle indicates a 5° field of view, typical for many optical finderscopes. Field stars are plotted to 10th magnitude.

Celestial Felines

If you like oddballs, **NGC 2537**, the Bear Paw Galaxy, in central Lynx more than delivers. In fact, John Herschel thought this was a globular cluster when he viewed it in 1828, even though William Herschel (John's famous father) classified this as a planetary nebula when he discovered it 40 years earlier! In 1920, American astronomer Francis Pease described NGC 2537 as a "Nebulosity of the form of a horseshoe or a semi-elliptical line . . . of the mixed type, there being a number of well-defined knots in it." But that description was based upon his inspection of photographic plates captured with the 60-inch reflector at Mount Wilson.

NGC 2537 continued to be an enigma when Russian astronomer Boris Vorontsov-Velyaminov included it in his 1959 *Atlas and Catalogue of Interacting Galaxies* as a "merging triple" galaxy system. American astronomer Halton Arp listed it in his 1966 *Atlas of Peculiar Galaxies* in the "low surface-brightness spiral galaxy" group. It still isn't clear why this blue compact dwarf looks so peculiar.

Using my 6-inch tabletop Dobsonian, I can just make out NGC 2537 as a very faint, out-of-focus "star" 1.9′ west-northwest of an 11.0-magnitude star. At 112×, the galaxy's 50″-wide disk has a high surface brightness and appears mottled. Looking with my 10-inch at 200×, I see a soft-edged disk with several brighter regions flashing in and out of view. At 260×, I can detect two darker areas on the disk offset from the center, while a compact region in the northwestern quadrant stands out. Known as Mrk 86b, this H II/SFR shows a distinctly stellar core at 400×. With my 16-inch at 440×, I was able to resolve a lone 16th-magnitude star just off the northern edge of the disk and easily view the galaxy's famous "bear-paw" shape, with Mrk 86b shining away at 15th magnitude.

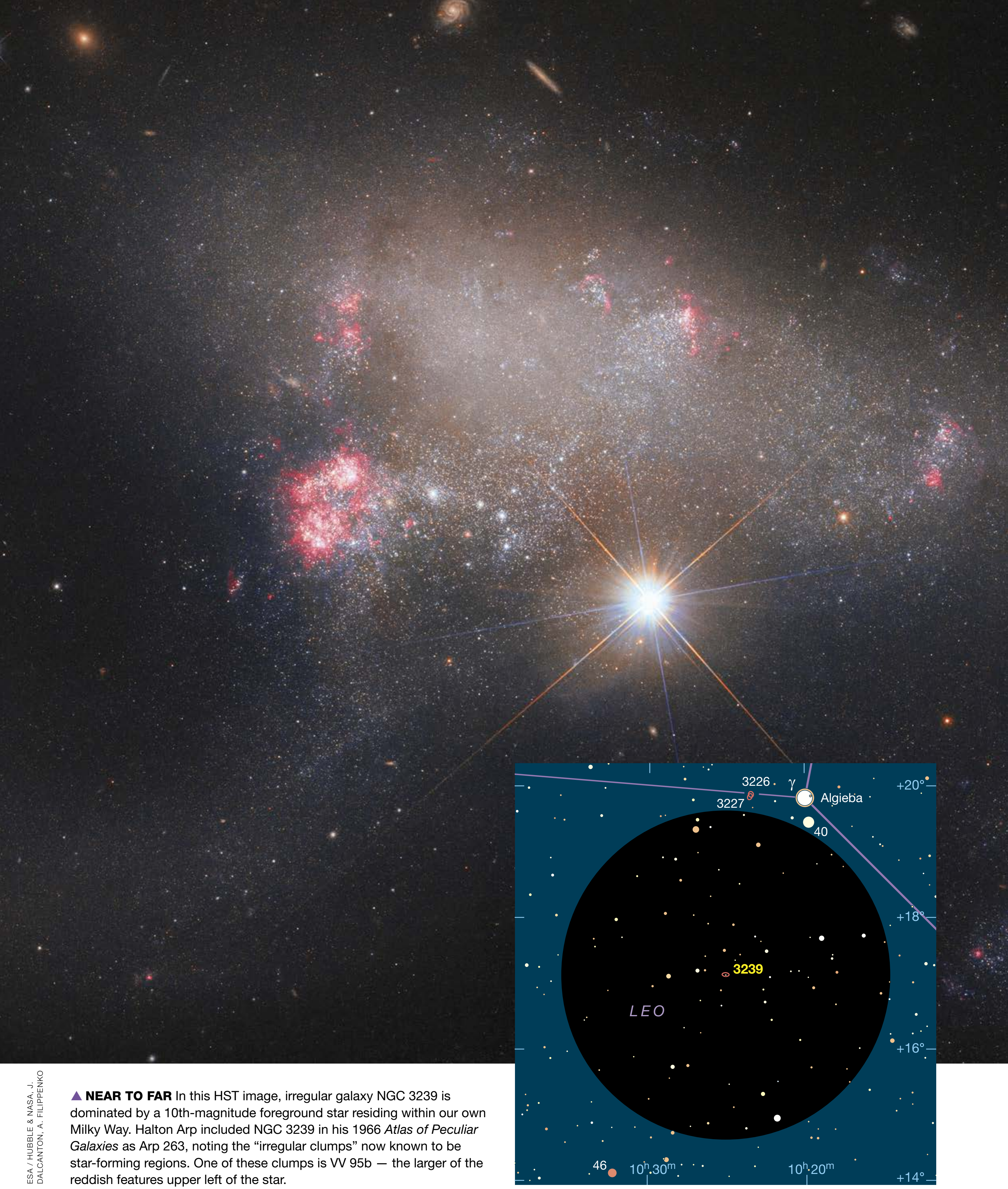
Our second "feline" target is **NGC 3239** in Leo. It's a bizarre-shaped irregular galaxy that displays evidence of a merger with a lower-mass interloper. A careful search 3° south-southeast of the fantastic double star Gamma (γ) Leonis yields NGC 3239. In my 10-inch at 117× it looks like a reflection nebula emanating north and northeast from a 10.1-magnitude star. Increasing to 150×, it's elongated east-to-west and fades out before reaching a 12.4-magnitude star 2.4′ west of the previously noted star. With concentration, I can detect a knot in the southeastern portion of the galaxy, directly east of the 10th-magnitude star. This is an H II/SFR that's dimly visible at 260× with direct vision, clearly nonstellar, and glowing at about 15th magnitude.

In January 2012, many amateur astronomers took their first look at this H II/SFR after a Type IIP supernova peaked at magnitude 13.8 on its western edge. This begs the question: Who was the first ever to spy this impressive H II/SFR? The answer seems to be John Herschel in 1831 with his 18¼-inch reflector when he describes "a star of 9th-magnitude with very faint nebulous atmosphere; rather eccentric. Has two stars preceding and possibly another very small star following."

More than 100 years later, Vorontsov-Velyaminov cataloged NGC 3239 as an interacting galaxy and designated the H II/SFR as VV 95b, thinking it was a galactic nucleus.

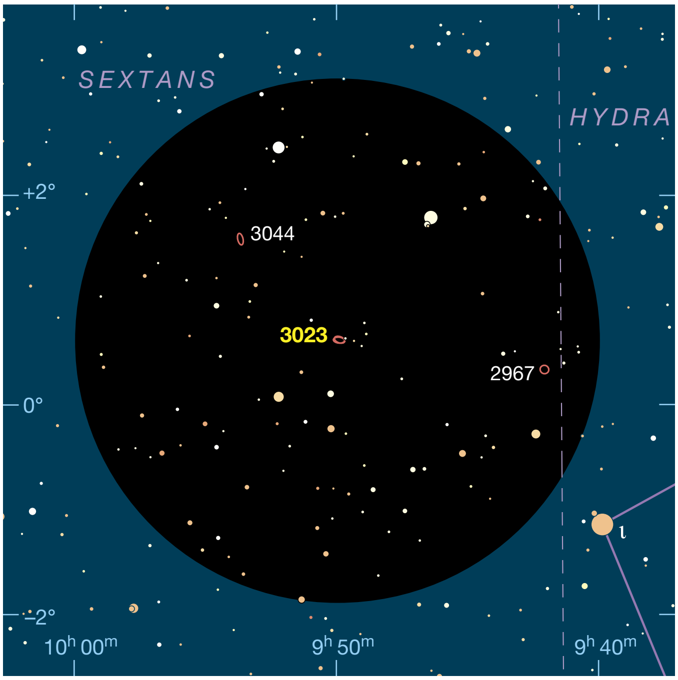
Southbound Searching

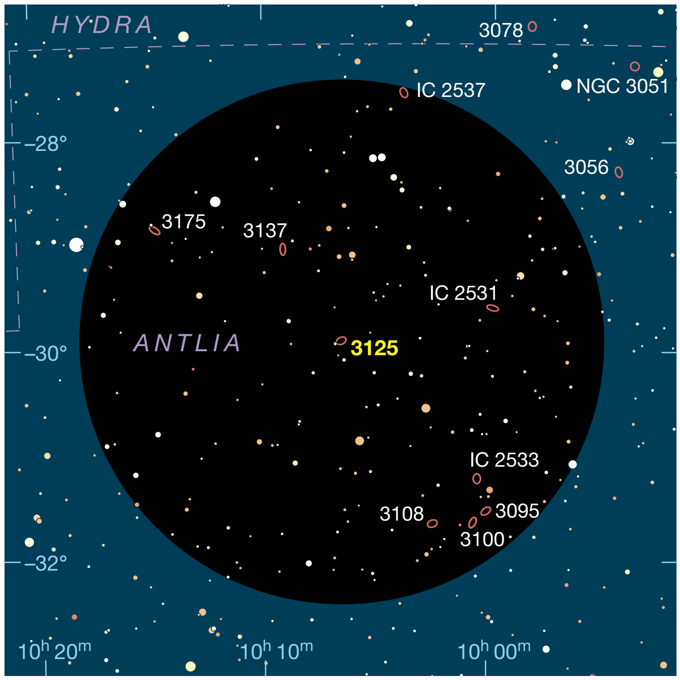
Want to see a star-forming region 88 million light-years away? To do so, you first need to find its host galaxy, **NGC 3023** in Sextans. The easiest way to get there is by first locating 3.9-magnitude Iota (ι) Hydrae, which lies 8.1° north-northeast of 2nd-magnitude Alpha (α) Hydrae, Alphard. A



ESA / HUBBLE & NASA, J. DALCANTON, A. FILIPPENKO

▲ **NEAR TO FAR** In this HST image, irregular galaxy NGC 3239 is dominated by a 10th-magnitude foreground star residing within our own Milky Way. Halton Arp included NGC 3239 in his 1966 *Atlas of Peculiar Galaxies* as Arp 263, noting the "irregular clumps" now known to be star-forming regions. One of these clumps is VV 95b — the larger of the reddish features upper left of the star.





careful star-hop 3° northeast of Iota should bring into view a gentle 10′-long arc of three 10th-magnitude stars. The galaxy is less than 4′ from the easternmost star, HD 85095.

In my 6-inch at 25×, I can just detect NGC 3023 as a tiny smudge. Increasing the magnification to 164× shows an irregular glow with a 13.5-magnitude star 1.8′ to its east. Upping to 224× reveals that the galaxy's nucleus (the most distinct part) is elongated to the southeast, and brings into view the nearby galaxy NGC 3018 as a small phantom 47″ southeast of HD 85095.

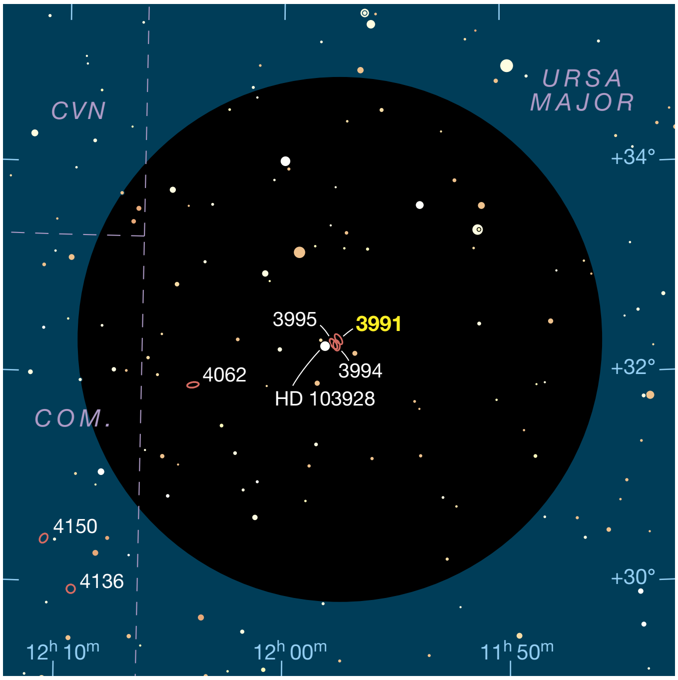
Switching to my 10-inch and 200× uncovers a faint knot just southeast of NGC 3023's core, while in my 16-inch at 300× the feature appears elongated. This knot, a massive H II/SFR cataloged as Mrk 1236, owes its incredible brightness to a swarm of relatively short-lived Wolf-Rayet stars. Mrk 1236 has sometimes been considered the core of another galaxy due to an erroneous classification by Vorontsov-Velyaminov.

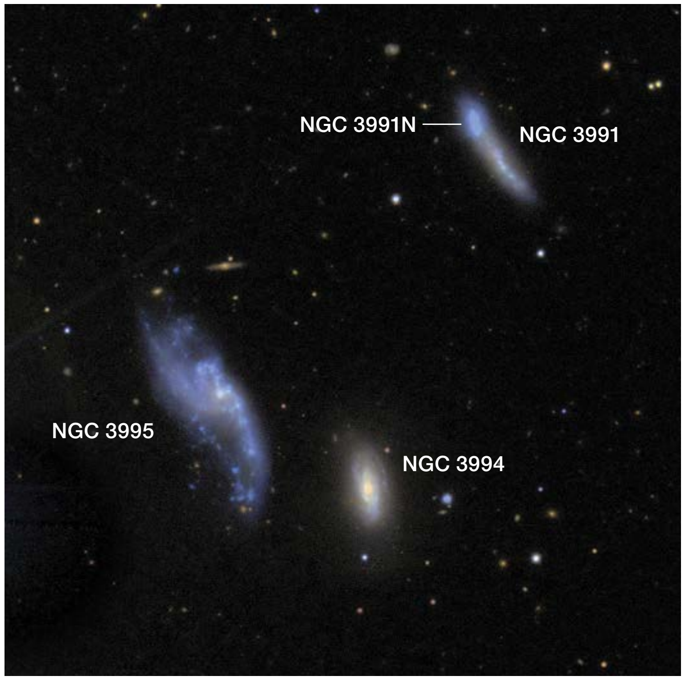
Diving farther south into northern Antlia, we dig out a fun treasure known as **NGC 3125**. Discoverer John Herschel described it as "faint, round, gradually brighter in the middle" when viewed with his 18¼-inch reflector in 1835. But the miniscule galaxy remained obscure until 1976, when an objective-prism survey performed at the Cerro-Tololo Inter-American Observatory in Chile revealed that it displayed a pair of knots and an emission line. Initiated by resident astronomer Malcolm Smith using the 24-inch Curtis Schmidt telescope, this survey was stimulated by the success of Markarian's ongoing FBS.

Singular Delights

Host object	Alternate name	Feature Name	Distance (Ml-y)	Mag (v)	RA	Dec.
UGC 4499	MCG +09-14-078	Mrk 94	32	~14	$08^h\ 37.7^m$	+51° 39′
NGC 2537	Arp 6	Mrk 86b	21	11.7	$08^h\ 13.2^m$	+45° 59′
NGC 3239	Arp 263	VV 95b	35	11.3	$10^h\ 25.1^m$	+17° 10′
NGC 3023	VV 620	Mrk 1236	88	12.3	$09^h\ 49.9^m$	+00° 37′
NGC 3125	Tololo 3	—	52	13.0	$10^h\ 06.6^m$	–29° 56′
NGC 3991	Haro 5	NGC 3991N	150	13.1	$11^h\ 57.5^m$	+32° 20′
M106	NGC 4258	74C	24	8.4	$12^h\ 19.0^m$	+47° 18′
Haro 29	UGCA 281	Mrk 209	15	14.6	$12^h\ 26.3^m$	+48° 30′
NGC 4204	CGCG 128-060	Mrk 1315	40	12.3	$12^h\ 15.2^m$	+20° 40′

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.





Dubbed Tololo 3 in many papers, NGC 3125 garnered a lot of attention in 1981 when observers discovered an unusually strong spectral signature produced by Wolf-Rayet stars embedded within it. Such stars are the highly evolved descendants of the most massive O-type stars and exclusively associated with young stellar populations — an indication that a violent burst of star formation recently occurred in this dwarf galaxy. In a 2006 study using the Very Large Telescope and the Hubble Space Telescope, NGC 3125's two giant H II knots (A and B) were shown to each host two young star clusters that are the primary sites of the WR stars. More recently, observers confirmed that the brightest cluster (A1, within region A) is a *super star cluster* — a collection of stars more luminous and massive than similar young clusters. A1 has some 170,000 solar masses and likely contains some of the most massive stars ever found.

After a star-hop 4.6° west-northwest from 4th-magnitude Alpha Antliae, I found NGC 3125 in my 6-inch at 37×. With 56×, it's a faint, odd-looking speck of light positioned not quite directly between 9.2-magnitude HD 87794 to the east-southeast and an 11.4-magnitude field star to the west-northwest. At 224× I saw a not-so-compact glow with a feebler glow extending a short distance west. In my 10-inch, the galaxy is easy to see and responds mildly to a narrowband eyepiece filter! But it was only with my 16-inch at 440× that I could just discern both the A and B knots within the galaxy.

Angling in the Deep

Our next target lies within Arp 313, a triple-interacting galaxy system some 150 million light-years away in the constellation Ursa Major. Aim your telescope 8.3° east of Nu (ν) and Xi (ξ) Ursae Majoris, the stars making up the southernmost paw of the Great Bear. You'll arrive at a field containing the 6.4-magnitude star HD 103928 and **NGC 3991**, NGC 3994, and NGC 3995.

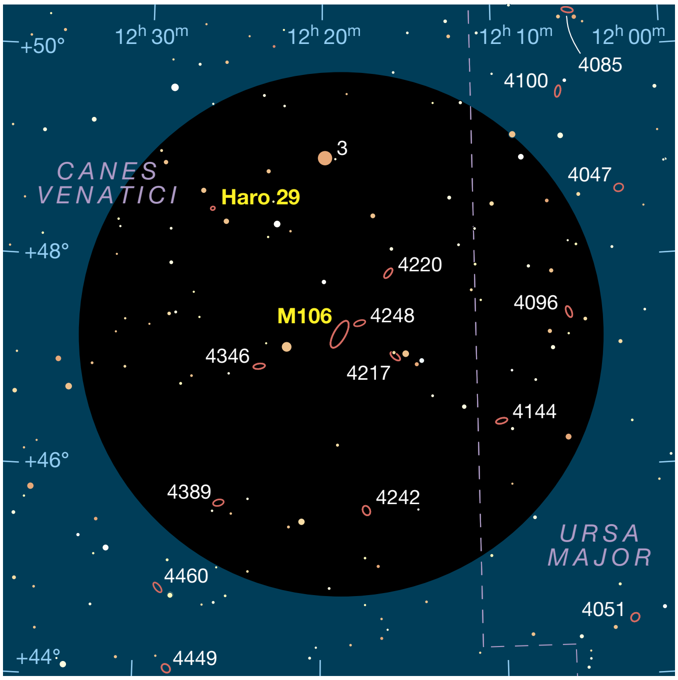
Using averted vision with my 10-inch at 94×, I can just make out three fairly compact glows about 7′ west-northwest of the star. The faintest of the trio is NGC 3991. It's a barely nonstellar smudge with a faint, 50″-long slash angled to the southwest. This smudge, sometimes referred to as NGC 3991N, first caught the attention of Mexican astronomer Guillermo Haro, who included NGC 3991 in his 1956 list of 44 "blue" galaxies. Today we know the feature is a massive collection of H II/SFRs that spans more than 10,000 light-years at the edge of its host galaxy.

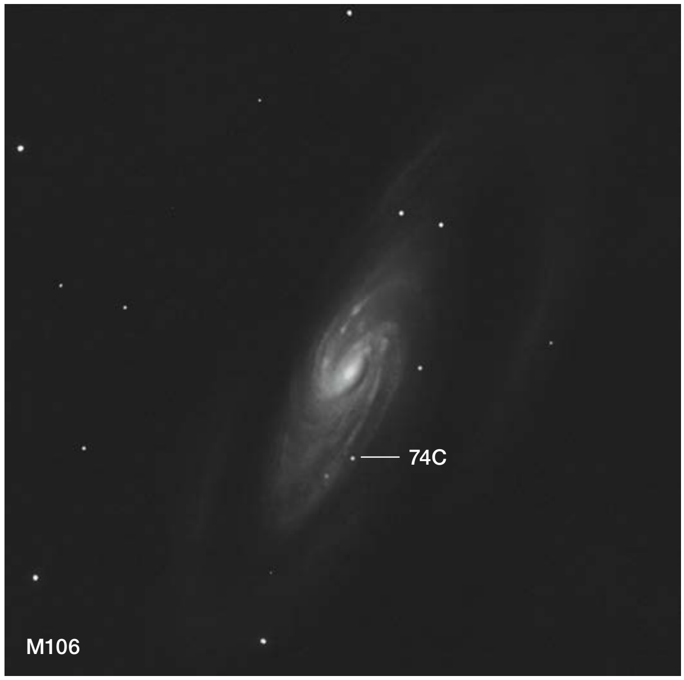
Increasing the magnification to 200× allows me to see that the slender glow of the galaxy nearly fades out before reaching the impressive H II/SFR. With my 16-inch at 300×, this is far more eye-catching than the galaxy itself. And at 440× it's an elongated knot that, with patience, splits into two components whose northern portion is brighter than the southern one. Apparently, NGC 3991 underwent a rare, non-continuous bout of star formation produced by several successive starbursts.

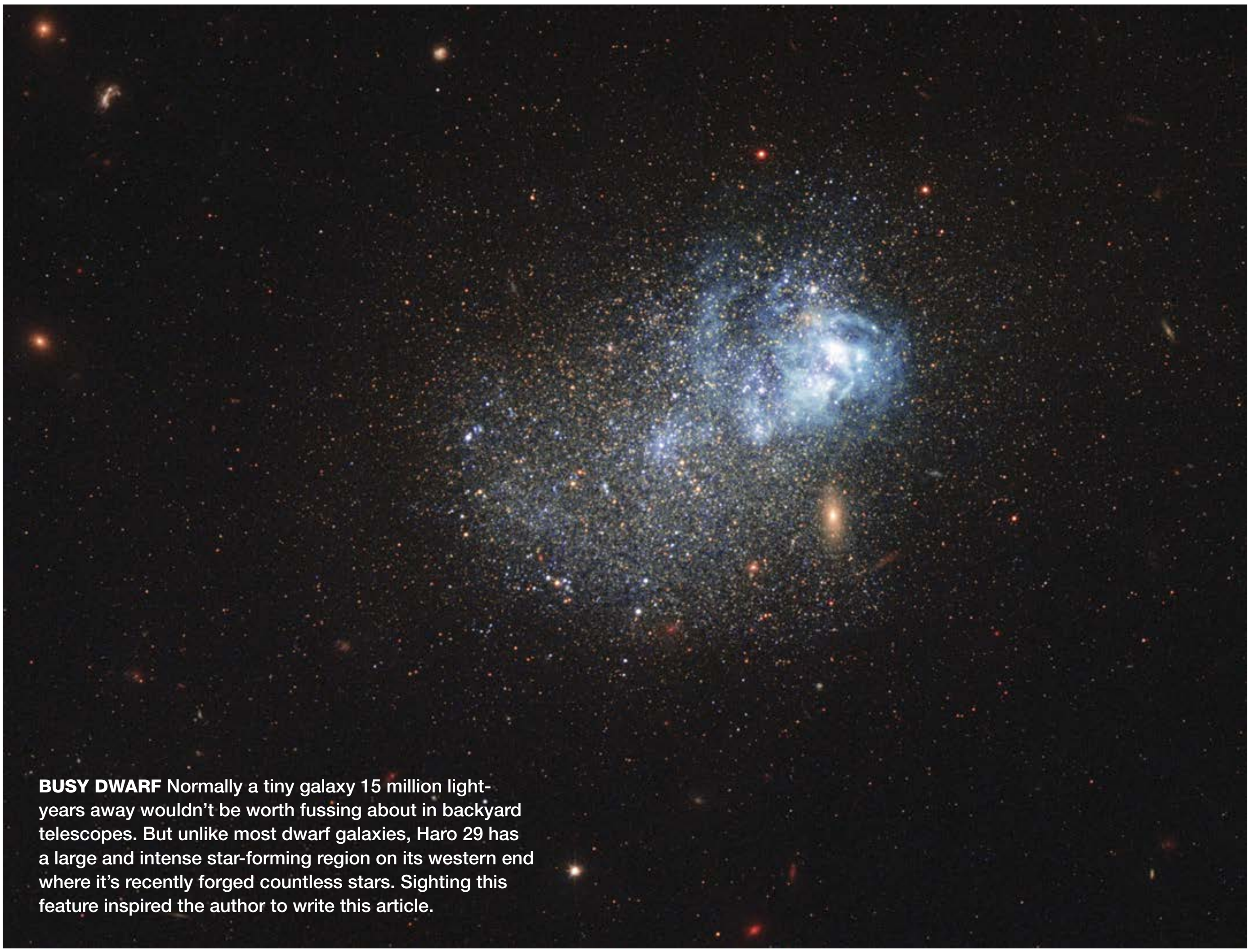
Unexpected Treasures

The brightest galaxy I've paid the least attention to is **M106** in Canes Venatici. I've seen this fine Messier object often with binoculars, but for one reason or another never really gave it much time in my scopes. That changed in late 2023 when I found out it harbored a single, bright H II/SFR. So, last spring, I went about remedying my neglect!

Interestingly, I found that in my 16-inch at 68×, M106 strongly resembles views of the Andromeda Galaxy (M31) I've had in 7×35 binoculars. That makes a lot of sense since M31 is only a tenth as distant, and my binoculars have about

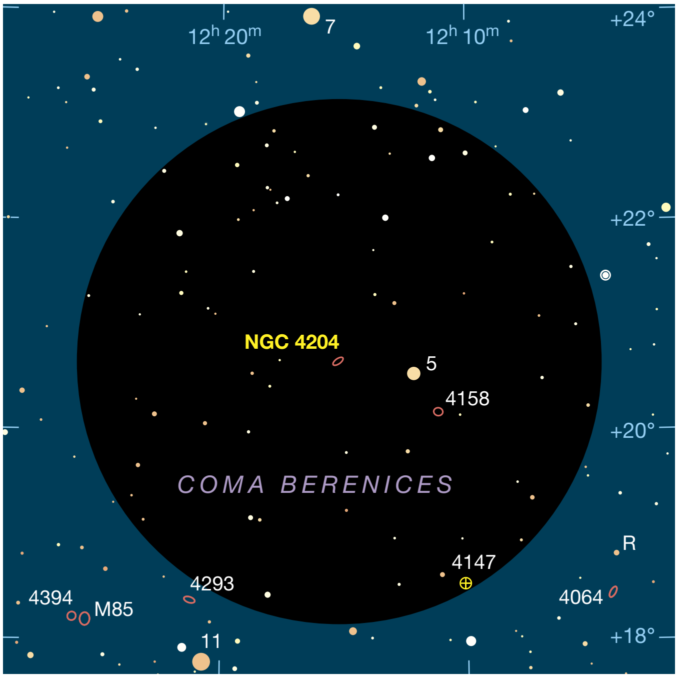


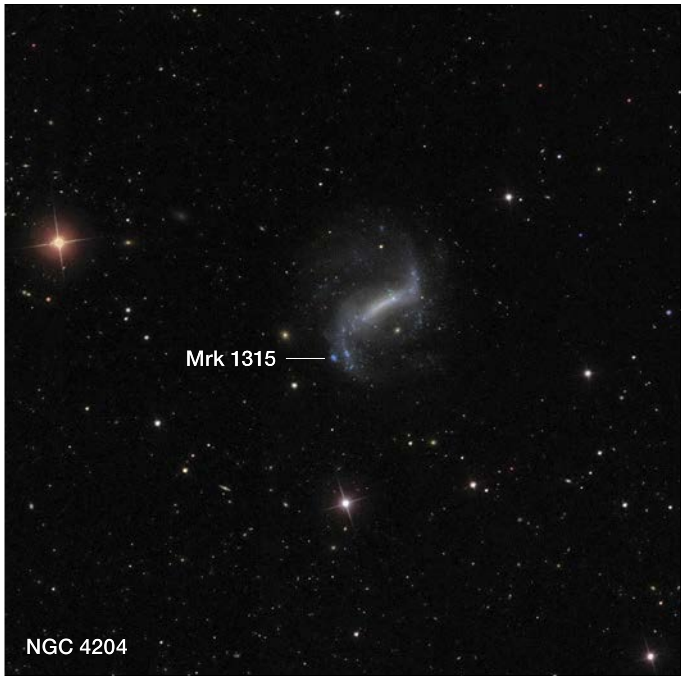




BUSY DWARF Normally a tiny galaxy 15 million light-years away wouldn't be worth fussing about in backyard telescopes. But unlike most dwarf galaxies, Haro 29 has a large and intense star-forming region on its western end where it's recently forged countless stars. Sighting this feature inspired the author to write this article.

SKETCH OF M106: TOM CORSTJENS; HARO 29: ESA / HUBBLE & NASA / ACKNOWLEDGEMENT: NICK ROSE





POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

10 times less magnification than I used in my scope. Increasing the magnification to 440×, I spotted the H II/SFR lying 2.8′ south of the galaxy's core. The feature appeared stellar and was easy enough that I had to try for it in my 10-inch. And sure enough, in the smaller scope at 260×, I could see the tiny object as well as the galaxy's northern inner arm tapering towards a 13.4-magnitude star.

The M106 H II/SFR was cataloged as 74C in a 1993 study of the galaxy led by French astronomer Georges Courtès (1925–2019). At magnitude 15.6 and less than 4 million years old, it's visible primarily due to a dense population of massive, young stars at its heart.

Now, with your telescope still aimed at M106, use your lowest magnification and star-hop 1.7° northeast. You should see two 8th-magnitude stars 22′ apart in your field. You're after a compact dwarf galaxy known as **Haro 29**, which lies between those stars and 55″ east of a 12.0-magnitude field star.

With my 10-inch at 94×, I see a 15.1-magnitude "star" lodged in a small glow that extends less than 20″ eastward. Only with more magnification does the ersatz star reveal itself as Mrk 209 — my sought-after H II/SFR. At 200×, it dominates the western edge of the diminutive galaxy as a compact knot. In my 16-inch at 440× an almost stellar core winks from inside the knot.

Unlike NGC 3991, Haro 29 was an original discovery by Guillermo Haro. And even though it's less than 5,000 light-years across, it plays host to a star-forming region consisting of several *OB* associations, each well-over 250 light-years wide. And at the heart of Haro 29's largest *OB* association are four star clusters, each possibly massive enough to be considered super star clusters. But the reasons why Haro 29 is experiencing so much star formation is unclear. The most likely explanation is that it's an advanced-stage merger between two dwarf galaxies.

One More Delight

Our final galaxy, **NGC 4204**, is so obscure it's the only one in this selection not plotted in my *interstellarum Deep Sky Atlas* (*S&T:* Aug. 2015, p. 57)! It's also one of the most northern members of the Virgo Cluster, lying well into neighboring Coma Berenices and a whopping 9.1° north-northwest of M87, which lies at the cluster's heart.

To find NGC 4204, start at 4th-magnitude Gamma Comae Berenices, then jump 5° south-southwest down to 4.9-magnitude 7 Comae before hopping 3½° farther south-southwest to 5.6-magnitude 5 Comae. In my 10-inch at 94×, NGC 4204 appears as a small, very faint glow 44′ east-northeast of 5 Comae. Increasing to 200× reveals a short, faint central bar running northwest to southeast inside a very anemic haze. Upping the power to 260× and using averted vision, I can glimpse (but not hold) a faint point of light midway between the bar and a 15.0-magnitude star 2.5′ to its southeast. However, that "point" — cataloged as Mrk 1315 — turns nonstellar when seen in my 16-inch at 440×. Images show that it's a prominent H II region embedded in the southeastern arm of this face-on barred spiral. Recent research indicates that Mrk 1315 will brighten in the future as it is undergoing a rapid buildup of massive stars.

If you're like me and find most "normal" galaxies a bit boring, then I hope this tour demonstrates there are plenty of exciting ones out there too!

■ Contributing Editor **SCOTT HARRINGTON** recently learned about a "bright" starburst galaxy not very far from NGC 3023. He hopes to catch it in his 10-inch soon!

iOptron's HAE16C Hybrid Mount

A solid platform for traveling observers and astrophotographers.

iOptron HAE16C Dual AZ/EQ SWG Hybrid Mount

U.S. Price: $1,398 (equatorial head)
iOptron.com

What We Like

Excellent pointing in both equatorial and alt-azimuth modes

Plug-and-play with most third-party apps and imaging computers

What We Don't Like

Lacks a dedicated user manual

Power cable loses connection in cold weather

MUCH LIKE SMALL apochromatic refractors, compact telescope mounts are all the rage these days. It seems every other month there's a new one announced that's both small, yet capable of carrying substantial loads without the need of cumbersome counterweights. iOptron, a company based in Woburn, Massachusetts, is known for its innovative, Chinese-manufactured telescope mounts and is a big part of that push.

Recently iOptron introduced its HAE16C Dual AZ/EQ SWG Hybrid Mount — a Go To unit with both strain wave and belt drives that promise excellent slewing and tracking in an exceedingly lightweight, portable package. I'd been looking for something along those lines for imaging and observing with several of my refractors. Ideally, it would be something that is airline compatible. I arranged to borrow an HAE16C from iOptron along with the company's stainless-steel tripod (a $108 option) for several months of testing with an eye toward deep-sky imaging and long-distance travel.

Compact Drive

The HAE16C is among the smallest of the company's hybrid mounts — they have a strain-wave-gear drive for the right-ascension axis and a worm gear and belt system for the declination axis. The head weighs 12 kilograms (5.7 pounds) yet boasts a load capacity of 8.2 kg without an optional counterweight (or counterweight shaft). That weight capacity increases to 12 kg with the addition of the 20-cm (8-inch) counterweight shaft ($35) and 2-kg counterweight ($45). It's similar in size, capacity, and price to the manufacturer's HEM15 mount, though this new hybrid model has the distinct advantage of being operable in both equatorial and alt-azimuth modes.

The HAE16C is designed for smaller telescopes — perhaps 8-inch aperture or less — and while it's rated to carry 8.2 kg without a counterweight, its load is only one consideration with such a small mount that I'll discuss later. The entire equatorial head is only 20 cm tall and easily fits in your hand. The head connects to tripods or piers with a ⅜-inch threaded screw, the standard for heavy-duty photo tripods.

Fit and Finish

The azimuth and altitude adjustment knobs for polar aligning the HAE16C are easy to use even while wearing winter gloves. Within the altitude axis

◀ The HAE16C Dual AZ/EQ SWG Hybrid Mount is a lightweight telescope platform that operates in both equatorial and alt-azimuth modes. Here it's shown with the optional tripod and Go2Nova hand controller.

▶ The mount comes with a rugged carry case that accomodates the head, cables, hand controller, and iPolar alignment device.

ALL IMAGES COURTESY OF THE AUTHOR

▲ Move the threaded steel pin (arrowed) within the altitude axis from the 45° to the 0° position when switching between alt-azimuth (left) and equatorial modes (right).

is a threaded metal pin that has two positions — the first permits adjustment of the polar axis for latitudes from 0° to 45°, and the second allows movement from 45° to 90° (90° being the angle to choose when setting the mount to alt-azimuth mode). This pin secures a brass fitting that connects to the altitude knob. Users should be careful not to unscrew this component from the altitude knob, as it can be tricky to reattach — something I discovered myself one afternoon.

Above the altitude knob is the power input socket, and a USB-C port that operates at USB 2.0 speed and is used to connect the mount to a computer. The bottom of the declination axis contains a threaded socket that accepts the optional counterweight bar, and also a 6-pin port where you plug in the hand paddle or an autoguider.

A 120-volt AC power adapter is included with the HAE16C, supplying 12V DC at 5 amps. Also provided is a Pelican-style armored case with custom foam cutouts to accommodate the mount, an optional Go2Nova 8411 hand controller, power supply, cables, and various small accessories.

Unlike the other models in the HAE series, the HAE16C's saddle plate only accepts Vixen-style dovetail bars. The saddle itself contains two ports — a USB-C connection and a power passthrough. Both are used to connect and power ride-along mini-computers such as the company's own iMate, or one of the ZWO ASIAir units, among others. I used the latter to control the mount, cameras, and focuser when imaging.

Field Performance

I did some observing using the optional Go2Nova 8411 hand control ($285 when bought separately, or $226 when purchased with the mount), though I preferred controlling it with *SkySafari 7 Pro*, particularly when viewing the Sun (with safe filters, of course). The red text of the OLED display on the hand paddle was simply too dim to see in daylight, but at night it wasn't a problem. The hand paddle works well, particularly when I was using the setup in alt-azimuth mode. I also tried the *iOptron Commander* app for Android devices, which connects to the mount via its built-in Wi-Fi receiver. The hand paddle also contains a USB-C port which allows users to connect the device directly to a laptop computer — a convenient feature that avoids having another cable coming from the drive head that can potentially get snagged during slews around the sky.

There is no manual specifically for the HAE16C on iOptron's website, rather there's just the one manual for all mounts in the line. But aside from each unit's weight capacity and the number and function of power and computer input ports, all models in the HAE series use the same electronics and controller, so I downloaded the manual for the HAE18C. That document does a good job explaining the hand control's setup and operation.

Initialization of the iOptron hand controller starts by entering the date and time along with your location, all of which remain stored in the controller's memory for future use. The mount starts from its "zero position," with the telescope pointed toward the zenith in alt-azimuth mode, or pointing toward the celestial pole with the scope above the polar axis in equatorial mode. In the event of a power failure,

▼▶ *Below:* The Vixen-style mounting plate is marked to indicate the direction in which to install your telescope. On the side of the plate is a USB-C port and a 2.1-mm center-positive power socket. The author took advantage of both to connect and power a ZWO ASIAir Plus, an ASI 071MC Pro camera, and an ASI120MM mini-autoguider (seen at right).

the hand controller includes a ***Search Zero Pos.*** option, which will return the scope to the zero position after power is restored and allows you to resume slewing around the sky without additional alignment.

To align the mount in alt-azimuth mode, aim the side of the unit that has the Wi-Fi antenna toward the south, then choose a bright star or planet using the Select and Slew menu. When the slew is complete, hit the Menu key again and select ***Sync. To Target***, then adjust the aim of your scope using the arrow keys until the target is centered in your eyepiece. Once that's accomplished, hit the enter key and you're ready to navigate around the sky.

This simple alignment worked quite well when observing with my 92-mm Astro-Physics Stowaway refractor. When slewing great distances, I found re-applying the ***Sync. To Target*** routine placed objects within some 50° of the synched area directly in the middle of the eyepiece.

In equatorial mode, alignment is a bit more complicated, as one would expect. You first need to polar align. The hand controller offers two methods for that task, though only one is applicable

▲ On the base of the mount is the 12-volt DC input socket, and a USB-C port for connecting an external computer. The mount's azimuth-adjustment knobs are small but easy to grip even with gloves on. Both the altitude adjustment and locking knobs include deep holes to insert a hex key or screwdriver to increase torque when turning.

for the HAE16C. The first shows the clock position of Polaris around the North Celestial Pole at the current time — handy information for other mounts with a polar alignment scope, which iOptron's strain-wave mounts lack.

The other (useful) option is ***Polar Iterate Align***. Selecting this option lets you choose two bright stars far from the pole to use for alignment. You begin by selecting and slewing to the first star. When the mount stops, the controller beeps and displays a message stating "Manually adjust the ALT knob, and press < or > to bring the star half the distance to the center, then press ENTER." After doing so, choose the second star and the mount slews to its location. When the scope arrives near the destination, the mount beeps and reads "Manually adjust the AZI knob, and press < or > to bring the star half the distance to the center then press ENTER." After this, the process is repeated until you no longer need to adjust the pointing, then you simply hit the BACK button to exit the process. This worked very well and placed targets near the center of the field after each Go To slew.

iOptron also included its iPolar alignment camera ($173) for my review, though I used it just once as it only connects to PC computers or the iMate and isn't supported by other ride-along imaging computers. Pity, as it works quite well to establish excellent polar alignment in just a few minutes.

After these preliminaries, you're ready to explore the sky. The HAE16C's Go To pointing and tracking were extremely good. I occasionally observed with the mount in equatorial mode but only roughly polar aligned. As such, after the first slew, I would nudge the tripod until my target was in the finder's field, then chose the ***Synch. To Target*** option, which then permitted Go To slewing accurate enough to land targets within the field of view of a low-power eyepiece.

The Go2Nova hand controller has an impressive internal database that's said to contain 212,000 objects, including all the popular catalogs typically available with an advanced Go To system. In addition to the Messier, NGC, IC, and Caldwell catalogs of deep-sky objects, the database includes more obscure ones like the PGC and Abell catalogs.

The *iOptron Commander* app works well though its database is very basic, containing the planets, the Sun, "Famous Stars," and 92 "Named Deep-sky Objects." Accessing a specific object requires stepping through every listing

▲ *Left:* The Wi-Fi antenna is visible on the left side of the mount, which also corresponds to south when in alt-azimuth mode. The "top" of the mount includes a protruding bubble level to aid setup in alt-azimuth mode. The power switch is located to its right. On the bottom is the 6-pin port to connect the optional Go2Nova 8411 hand controller. *Right:* In equatorial mode, the optional iPolar device connects to the bubble level fitting with its USB cable facing downward.

numerically, which is quite a chore when searching for a particular star. I suspect most users will be driving this mount with either an app like *SkySafari*, or the planetarium programs on ride-along imaging computers like the ZWO ASIAir.

I did my imaging tests with an ASIAir Plus 256G ride-along computer, which was completely plug-and-play with the HAE16C. Once I set everything up, the mount slewed, centered, and tracked effortlessly all around the sky.

Like most strain-wave-geared telescope drives, the HAE16C has an appreciable amount of periodic error. Its gear period is stated as 360 seconds, and while I didn't measure it precisely, it was easily corrected with autoguiding. I typically used 3-second autoguiding exposures, and none of the images I recorded through my 92-mm Stowaway (operating at a focal length of 490 mm) were trailed. I typically shot 5-minute frames, which is about as long as I can go anyway in my light-polluted skies just south of Manchester, New Hampshire.

The HAE16C's AC-power adapter did its job admirably except on very cold nights. The cable connection loosened up noticeably in such conditions and disconnected with any slight movement. To prevent losing power, I wrapped an elastic band around the altitude axis and power cable near the jack to ensure it was held in place. I also powered the mount from my car without issues last autumn when I traveled to image Comet C/2023 A3 Tsuchinshan-ATLAS.

▲ The HAE16C performed admirably when imaging the deep sky. This photo of NGC 6960, the Witches Broom section of the Veil Nebula is made up of twelve 5-minute exposures shot through an Astro-Physics 92-mm Stowaway refractor working at f/5.3 and a ZWO ASI071MC Pro color camera. An additional 2 hours of exposure through a hydrogen-alpha filter was also used. None of the guided exposures were rejected due to tracking errors.

Unbalanced, or Counterweights?

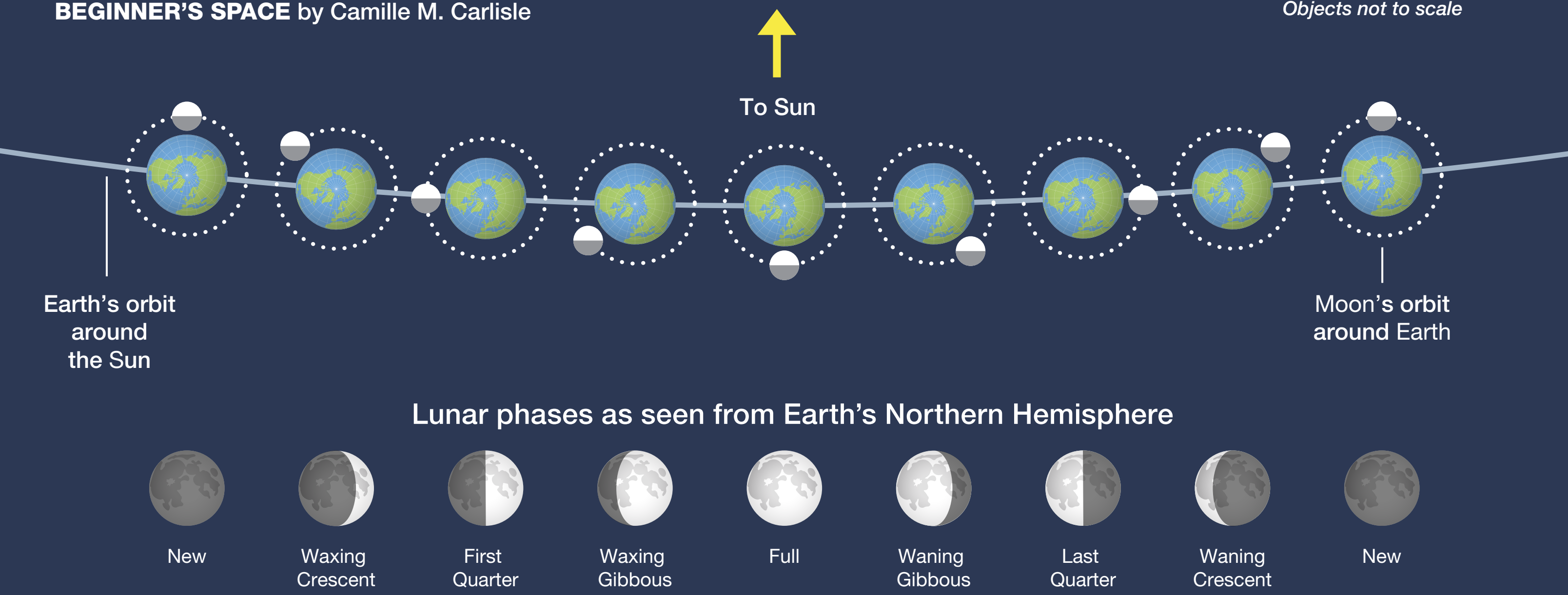
One of the big attractions of strain-wave drives is they don't require a counterweight system to balance your gear. This is true, but only to a point. Yes, the HAE16C does track and slew just fine without a counterweight, particularly in alt-azimuth mode, which was my preferred setup for visual observing. However, unless your pier or tripod has a fairly wide footprint, your scope might be unstable enough to topple over. Fortunately, I had the optional counterweight assembly, which I used when imaging, particularly when I had my ASIAir Plus, a small guidescope, and astro-camera installed on the mount.

The stated weight capacity isn't the only factor that determines what scope you can use on the HAE16C. Some refractors, like my Celestron 102-mm f/10 achromat, though well within the mount's weight limit, was so long it could hit the legs of the tripod I was loaned for the review. One solution is adding iOptron's SkyHunter Extension Pier ($68) to add more clearance. But there's also a feature within the hand paddle that came in quite handy. In the ***Settings*** menu, ***Set Altitude Limit*** permits you to set the upper and lower limits of pointing so that the scope won't hit the tripod legs. This is especially nice if you use a photo tripod that can spread its legs wide to improve the mount's stability in a counterweight-free setup.

▲ The base of the HAE16C connects to any tripod having a ⅜ × 16-thread, standard on most high-quality photo and video tripods.

I found the HAE16C to be an excellent mount for a small to mid-sized telescope, particularly those with a short tube. Its plug-and-play compatibility with most planetarium apps and imaging setups makes it a great choice for astrophotographers who travel to hunt their quarry. I strongly recommend it.

■ Associate Editor **SEAN WALKER** is regularly found taking in the night sky from his backyard observatory in Litchfield, New Hampshire.



BEATRIZ INGLESSIS / S&T

Why Does the Moon Have Phases?

IF YOU GLANCE AT the Moon from time to time (and if you don't, you really should), you'll notice that its appearance changes dramatically as it glides across the sky. Sometimes, it's a delicate crescent — what J. P. in the 1994 movie *Angels in the Outfield* called "God's thumbnail." Other times, it looks like a glorious circle blazing so bright, it serves as a celestial floodlight. (I am purposefully ignoring the grumbling of deep-sky observers.)

These changes happen every month, with clocklike precision. But why?

The short answer is: because the Moon dances a ring around Earth.

The Moon doesn't shine with its own light. Moonlight is actually sunlight, reflected off the lunar surface. The Moon isn't terribly reflective, either: Its surface is less reflective than concrete.

The important thing to note is that regardless of what you see when you look up, one half of the Moon is *always* illuminated — it's just that we don't always see all of the lit half. To visualize this effect, find a ball (a tennis ball will do) and hold it up in front of a lit lamp in an otherwise dark room. If you look at the side facing the lamp, the ball looks fully illuminated. If you look at the side facing directly away from the lamp, it's dark. If you look at the pair from the side, you'll see a half-lit disk.

In other words, depending on where you stand with respect to the lamp-ball pair, you'll see different fractions of the ball's lit hemisphere. It's all a matter of perspective.

This is what happens with the Moon as it orbits Earth. As our satellite revolves around us, we see it from different angles with respect to the Sun. The Moon goes through a complete cycle of phases in 29½ days, which we call a *lunar month*.

When the Moon sits between us and the Sun, its unlit side faces us — that's what we call a *new Moon*.

When the Sun-Earth-Moon trio makes a 90° angle, with Earth at the angle's elbow, we see half of the lit lunar half — in other words, a *quarter*. The version just after new Moon is called a *first-quarter Moon*; when it happens just before new Moon, it's called a *last-quarter Moon*.

When Earth sits between the Sun and Moon, so that the Sun is directly behind us as we look at the Moon, we gaze straight at the fully lit hemisphere and see a *full Moon*.

As the Moon moves through its phases, it *waxes* and *wanes*. A waxing Moon is one that's swelling from new to full; a waning Moon is dwindling. When it's between new and a quarter phase, the Moon is a *crescent*, and between quarter and full it's *gibbous* (from the Latin *gibbus*, or "hump").

Also, because the Moon changes position with respect to the Sun as it waxes and wanes, it appears in the sky at different times over a lunar cycle. For example, a full Moon always rises at sunset and sets at sunrise, since it sits opposite the Sun in space.

When I see a crescent, quarter, or gibbous Moon, I stop and picture the celestial dance to figure out where in the waltz we are. That requires knowing that, when looking at the Earth-Moon system from above the North Pole, both our planet and our satellite rotate and revolve counterclockwise.

You might find it easier to have a catchphrase instead. For Northern Hemisphere observers, you can use "white on the right, getting bright." For Southern Hemisphere observers, the Moon looks upside-down compared to the Northern view (no really, it does), so you might prefer something like "bright on right, fading light."

And for those near the equator, let us know how you tell the phases apart — I haven't spent enough time there to have a suggestion! ■

▲ NEW NAGLERS

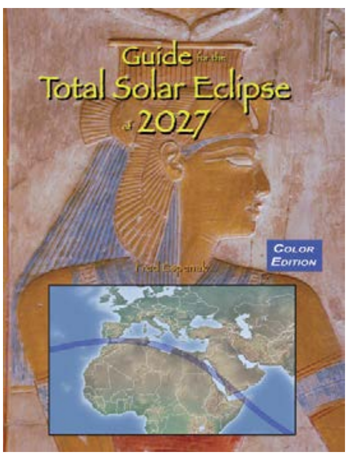
Tele Vue unveils the latest iteration of its famed eyepiece series for the discerning observer. The new Nagler Type 7 eyepieces provide a generous 82° apparent field of view with comfortable eye relief of 19 millimeters, particularly helpful for observers who require eyeglasses. These dual-format oculars operate in both 2-inch and 1¼-inch modes and are based on the advancements achieved in the company's limited-edition Apollo 11 eyepiece in an ergonomic, lightweight body. Available in 19-, 14-, 9-, and 5.5-mm focal lengths, each eyepiece features an extendable, twist-lock eye guard to help position your eye to the correct distance while blocking contrast-robbing stray light. The Nagler Type 7 eyepieces are parfocal with others in the series, as well as Tele Vue's 1¼-inch Plössl, Panoptic, Nagler, and Delos eyepieces when used with Tele Vue's Hi-Hat 1¼-inch to 2-inch adapter. Prices yet to be determined.

Tele Vue Optics
32 Elkay Dr., Chester, NY 10918
845-469-4551; televue.com

▲ VERSATILE IMAGER

Chinese manufacturer QHYCCD announces a camera suited to both deep-sky and planetary imaging. The miniCAM8 ($599 without filters) is a camera with an integrated, customized filter wheel designed around the 8-megapixel, back-illuminated Sony IMX585 sensor with 2.9-micron-square pixels that can record up to 41.5 frames per second. The camera body includes dual-stage cooling and a built-in filter wheel measuring 105 mm (about 4 inches) in diameter that accepts custom-sized filters measuring 19-by-12-by-1.1 millimeters. The camera is offered with either a monochrome or color sensor. Additional options include either a set of Optolong imaging filters for color cameras ($699) or Optolong LRGB and Hα, S II, and O III narrowband filters for the monochrome version ($799). Each purchase includes a 12V power adapter and cable, USB 3.0 cable, C-mount to M48 adapter, a 1¼-inch nosepiece, and additional tools.

QHYCCD
503, Block A, Singularity Center, Shahe Town, Changping District, Beijing, China 102206
Phone: +86(10)-80709022-602; qhyccd.com



◀ ECLIPSE GUIDE

Astrophysicist and frequent *Sky & Telescope* contributor Fred Espenak releases *Guide to the Total Solar Eclipse of 2027* ($21.99), detailing everything you'll need to know about the upcoming event. It contains a series of 20 full-color maps of the path of totality across Spain, Morocco, Algeria, Tunisia, Libya, Egypt, Sudan, Saudi Arabia, Yemen, and Somalia. The large-image-scale (1 inch = 40 miles) maps detail of the path of totality across North Africa and the Arabian Peninsula, and higher-resolution maps (1 inch = 20 miles) focus on selected areas of special interest. Its circumstance tables for hundreds of cities provide times for each phase of the eclipse along with its duration and the Sun's altitude. Cloud-cover statistics identify areas along the eclipse path with the highest probability of favorable weather. Espenak's guide uses the new elliptical model for Earth's shadow, producing the most accurate predictions to date. 8½-by-11 inches, 46 pages, paperback.

AstroPixels Publishing
P.O. Box 16197, Portal, AZ 85632
astropixels.com

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

Find a New Balance

This simple gadget eliminates springs and counterweights.

▲ An unobtrusive lid stay eliminates the need for counterweights or springs.

ONE OF THE MOST common problems when building a telescope is balance. Original-design Dobsonians are relatively easy to balance by moving the scope up and down inside the tube box, but scopes with fixed altitude bearing positions don't provide that luxury. And even with a balanced tube, when you put in a heavy eyepiece, the scope heads for the horizon.

Counterweights are a typical solution, but you wind up adding and removing weight with every equipment change. Springs can prevent the nosedive, but then the scope swings toward the zenith when you remove the eyepiece. Adding friction to the bearings can prevent both upward and downward motion, but this makes the scope's movement stiff. One of my earliest columns (*S&T:* Nov. 2016, p. 66) was about a clutch system that used a hand-actuated brake on the altitude bearing.

There's a simpler way, and Oregon ATM Lauren Wingert, whose innovative work you've seen here many times before, has figured it out. For all I know she might have reinvented the wheel chock, but her approach is new to me, and I figure it's probably new to most of you, too, so I'm calling it to your attention.

The solution? Lid stays, also called chest hinges. You know, those hinges that keep the big, heavy lids on cedar chests and the like from banging back down and busting your fingers. They're designed to allow easy motion in one direction and resist it in the other, so you can lift the lid easily, and it takes about the same amount of force to close it. (Or you can adjust them to allow the lid to drop slowly on its own, but you don't want that in a telescope.)

When Lauren built her Hubble Space Telescope replica (*S&T:* December 2024, p. 74), she had to place the altitude bearings well below the scope's balance point. She added weight to the back, but that still wasn't enough. So she installed lid stays, one to each side, and that held the scope steady as a rock. What's more, she could adjust the tension, so it took just as much effort to push the nose down as it did to lift it up, making the scope much easier to slew than before.

Lid stays are easiest to adapt to scopes with relatively small altitude bearings. The arms are only about 6 inches long, and one arm has to be attached to the rocker box while the other has to attach to the altitude bearing or to the scope. Lauren originally thought that the center of the hinge needed to be at the bearing's pivot point, but it turns out that's not the

▶ *Left:* The lid stay installs with one arm on the altitude bearing and one on the rocker box. Wingnuts provide quick release for transport. *Middle:* Inside the hinge: three gadgets, two furns, and a doohicky. *Right:* The lid stay's pivot point can bend forward as it closes, allowing for creative installation.

case. When mounted on a chest, the pivot point folds forward as the chest lid closes, and you can do the same with a telescope. You can get pretty creative with installation, adding extensions for large bearings or drilling attachment holes through the arms, or even cutting the arms short for small bearings.

Adding lid stays will lock the scope to the base, so you want to make them removable. Lauren uses bolts sticking outward from the scope and from the rocker box and holds the hinges in place with wingnuts.

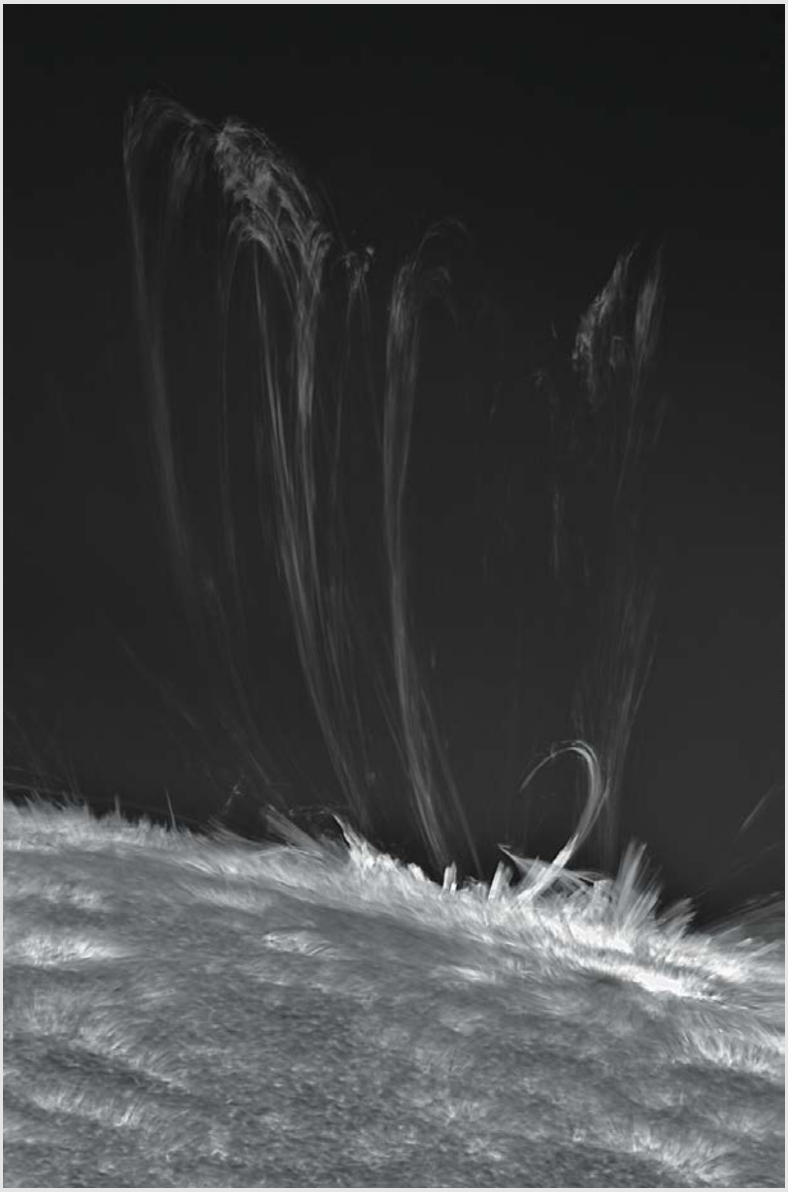
Lid stays won't compensate for wild imbalances, but they're certainly enough to compensate for the weight of a heavy eyepiece. Lauren says there is a mechanical disadvantage (the altitude bearings being the fulcrum point) so you may need higher weight-rated hinges than you might think.

The technology inside them is pretty cool. Lauren, being gadget inquisitive, took one apart and found no springs but rather some "strange notched gear-like stuff inside." It appears to be a nifty combination of friction and ratcheting going on.

Lauren's resourceful Dobsonian balancing idea definitely works and makes eyepiece swapping as seamless as can be!

■ Contributing Editor **JERRY OLTION** loves nonstandard uses for simple gadgets.

LAUREN WINGERT (4)



△ SOLAR LACE

Christian Viladrich

Active Region 3768 put on quite the show on August 2, 2024. Tall, wispy prominence loops decorated the Sun's western limb for several hours after launching a coronal mass ejection into space.

DETAILS: *300-mm solar Newtonian and ZWO ASI462MC camera. Stack of 150 video frames through hydrogen-alpha and calcium-K filters.*

▷ COLORFUL SKIES

Dudley Chelton

A multitude of colorful aurorae shimmer above the snow-covered peak of Mount Rainier in Washington on the evening of August 11, 2024. A Perseid meteor is seen in Boötes to the left.

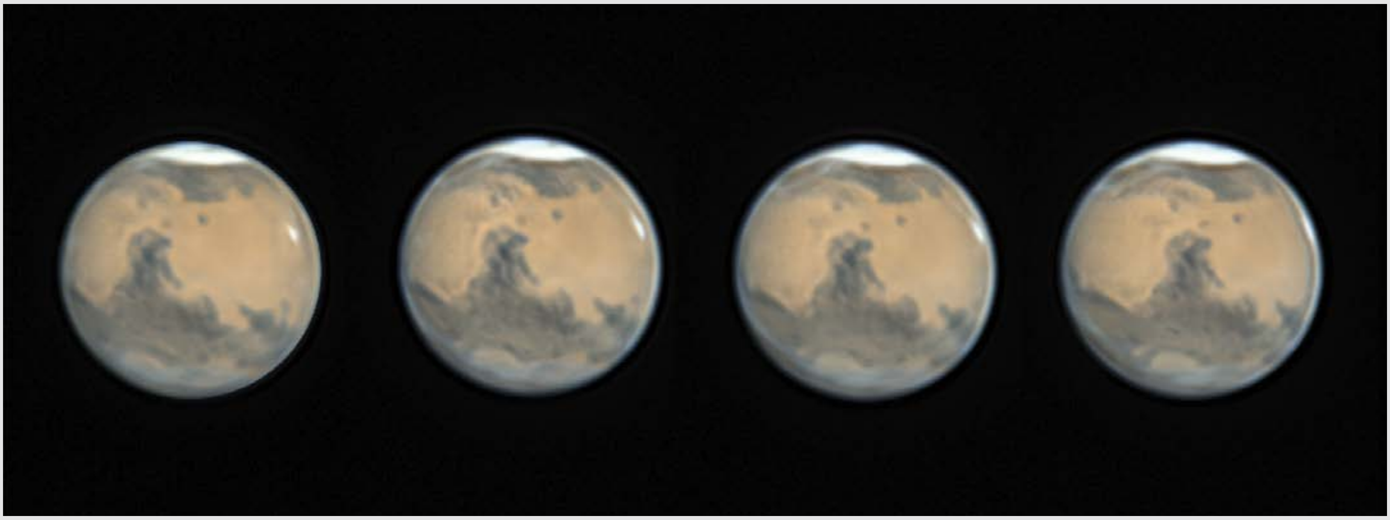
DETAILS: *Nikon D750 with 17-mm lens. Composite of two images totaling 10 seconds at f/7.1, ISO 1600.*

NARROWBAND BUBBLE

Steve Leonard

This gaseous shell formed when the intense stellar winds of WR 134, the orange Wolf-Rayet star right of center, collided with the surrounding gas and dust that permeate this region of Cygnus.

DETAILS: *Astro-Tech AT115EDT refractor and ZWO ASI1600MM Pro camera. Total exposure: 25½ hours through color and narrowband filters.*



△ MARTIAN CLOSE-UP

Tom Nolasco

Syrtis Major, the prominent, triangular albedo marking on Mars rotates into view from 2:14 to 3:32 Universal Time on January 24th. Wispy bluish clouds are seen above the Hellas impact crater in the south.

DETAILS: *Homemade 10-inch reflector and ZWO ASI462MC camera. Series of four images each a stack of 2,000 video frames through an infrared cut-off filter.*

▽ RED PLANET RISING

Benjamin Law

Mars appears to float just above Mare Marginis and Neper Crater after emerging from behind the Moon on the evening of January 14, 2025. The dark albedo features Mare Acidalium (top left) and Mare Erythraeum (lower right) are visible on the Red Planet. North is to the left.

DETAILS: *Celestron EdgeHD 8-inch Schmidt-Cassegrain and Player One Mars-C camera. Stack of multiple video frames.*

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Event Calendar

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

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

April 5–6
NORTHEAST ASTRONOMY FORUM
Suffern, NY
neafexpo.com

April 20–27
TEXAS STAR PARTY
Fort Davis, TX
texasstarparty.org

April 21–28
INTERNATIONAL DARK SKY WEEK
Everywhere!
idsw.darksky.org

April 23–26
MIDSOUTH STARGAZE
French Camp, MS
rainwaterobservatory.org/events

May 3
ASTRONOMY DAY
Everywhere!
astronomyday.astroleague.org

June 13–15
SOLAR ECLIPSE CONFERENCE
Leuven, Belgium
www.sec2025.be

June 21–28
GRAND CANYON STAR PARTY
Grand Canyon, AZ
https://is.gd/GrandCanyonStarParty

June 24–29
OREGON STAR PARTY
Indian Trail Spring, OR
oregonstarparty.org

June 25–28
ASTROCON
Bryce Canyon National Park, UT
https://is.gd/astrocon2025

June 25–28
BRYCE CANYON ASTRO FESTIVAL
Bryce Canyon National Park, UT
https://is.gd/brca_astrofest

June 25–29
GOLDEN STATE STAR PARTY
Adin, CA
goldenstatestarparty.org

June 25–29
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

July 20–25
NEBRASKA STAR PARTY
Valentine, NE
nebraskastarparty.org

July 22–27
WASHINGTON STATE STAR PARTY
Jameson Lake, WA
https://is.gd/WSSP2025

July 24–27
STELLAFANE CONVENTION
Springfield, VT
stellafane.org/convention

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

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Childhood Dreams Come True

A parent's trip to Space Camp with her son gives her the courage to dive into astronomy.

I DON'T REMEMBER what first interested me in Space Camp, but what I do remember is the catalog for Space Camp/Aviation Challenge that I would pore over for hours and hours — I can still see the pages in my mind.

I begged my parents to send me to Space Camp, but they didn't see a science career in my future, so they said no. As a child, math and science didn't come easily to me. I was highly math-anxious, and though science fascinated me, I struggled with it. I excelled at reading and writing; the narrative, then, was that I wasn't a "science person" and somewhere along the line, I began to believe that, too. Over time, I began to see the sciences and my love of space as something that just wasn't for me.

But a little more than a year and a half ago, my then-seven-year-old son caught the space bug. He quickly immersed himself in NASA websites, learning everything he could about astronomy, astrophysics, space flight, and more. Since we homeschool, I decided that the fall semester would be astronomy for science. Putting together our lessons and supplemental materials, I once again became enthralled by space. On a whim, I went on the Space Camp website, realized they had a Family Space Camp, and off we went to pack our bags.

On our drive from the airport to the hotel before camp check-in, we drove past the U.S. Space and Rocket Center campus. My heart pounded as I saw the Space Camp sign. The next day, when we stepped onto campus, tears sprang to my eyes, and all weekend I kept thinking *I can't believe I'm finally here*.

Camp was two-and-a-half days of learning and activities. We trained for and executed two missions — one shuttle, one lunar — while also attending workshops on packing for Mars, stargazing, and living on the International Space Station. We built and launched rockets, explored the museums and rocket park, attended a planetarium show, and tried out the multi-axis trainer and one-sixth gravity chair.

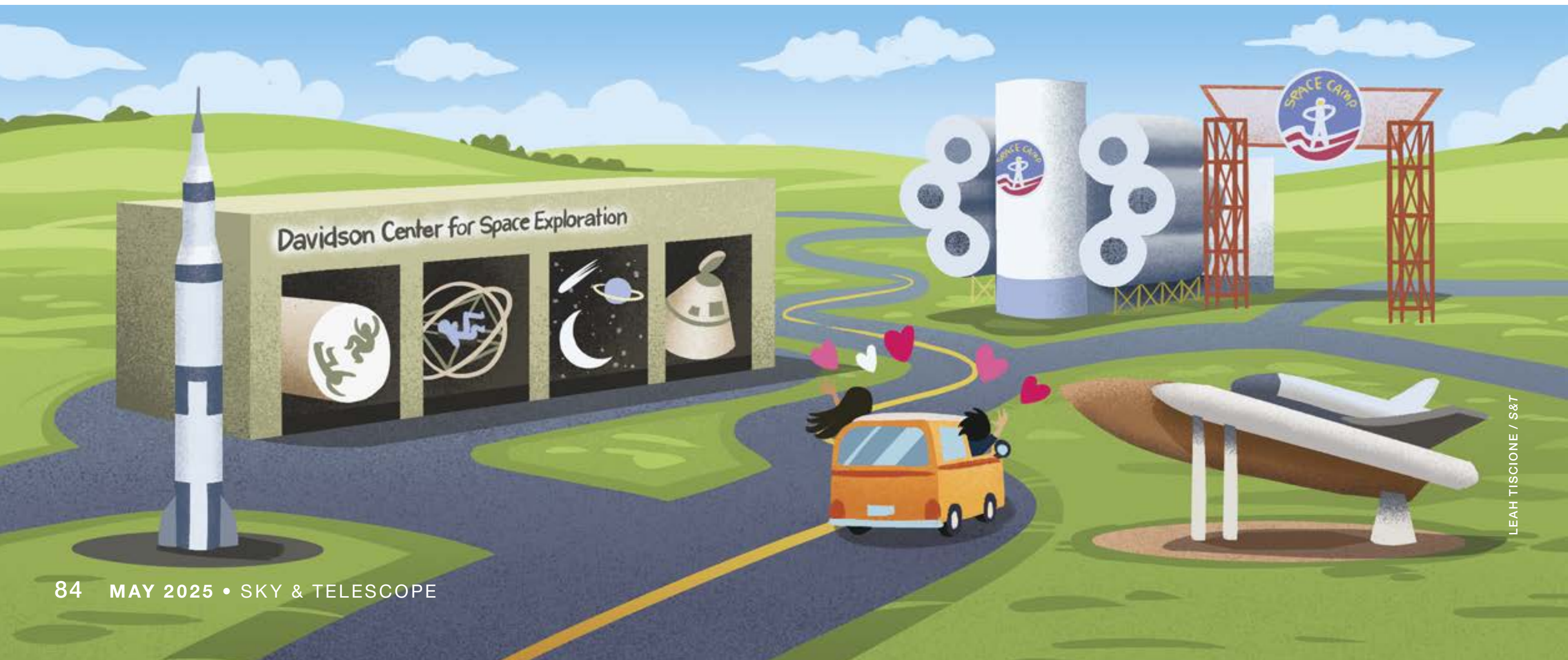
My son has severe speech apraxia, which is a speech disability — and yet not once did our teammates say anything about it; I watched in awe as he gave orders and data reports as the commander of our first mission.

I saw my son flourish that weekend, immersed in his passion. When it came time to go to the airport, we left campus reluctantly. My son was already planning his future adventures: "I think I want to do Space Camp next year, and then Space Camp Robotics. And then maybe when I'm older, Space Academy."

But he wasn't the only one. I returned home invigorated about astrophysics and space. I found out about the Space Camp Educators program (home educators can attend). My son is planning on applying for a scholarship at some point, and I'm dreaming of either another Space Camp adventure or my own Educator experience. Attending the Camp reminded me of how vast the cosmos is, and more importantly, of the power of wonder.

As adults, we are so rarely encouraged to dream. There are bills to pay and work to do, with never enough time in the day for it all. In one weekend, though, not only did I realize a childhood dream, but I was reminded to hold on to present dreams of my own, as well.

■ **JAIME HERNDON** is a science writer and editor.



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