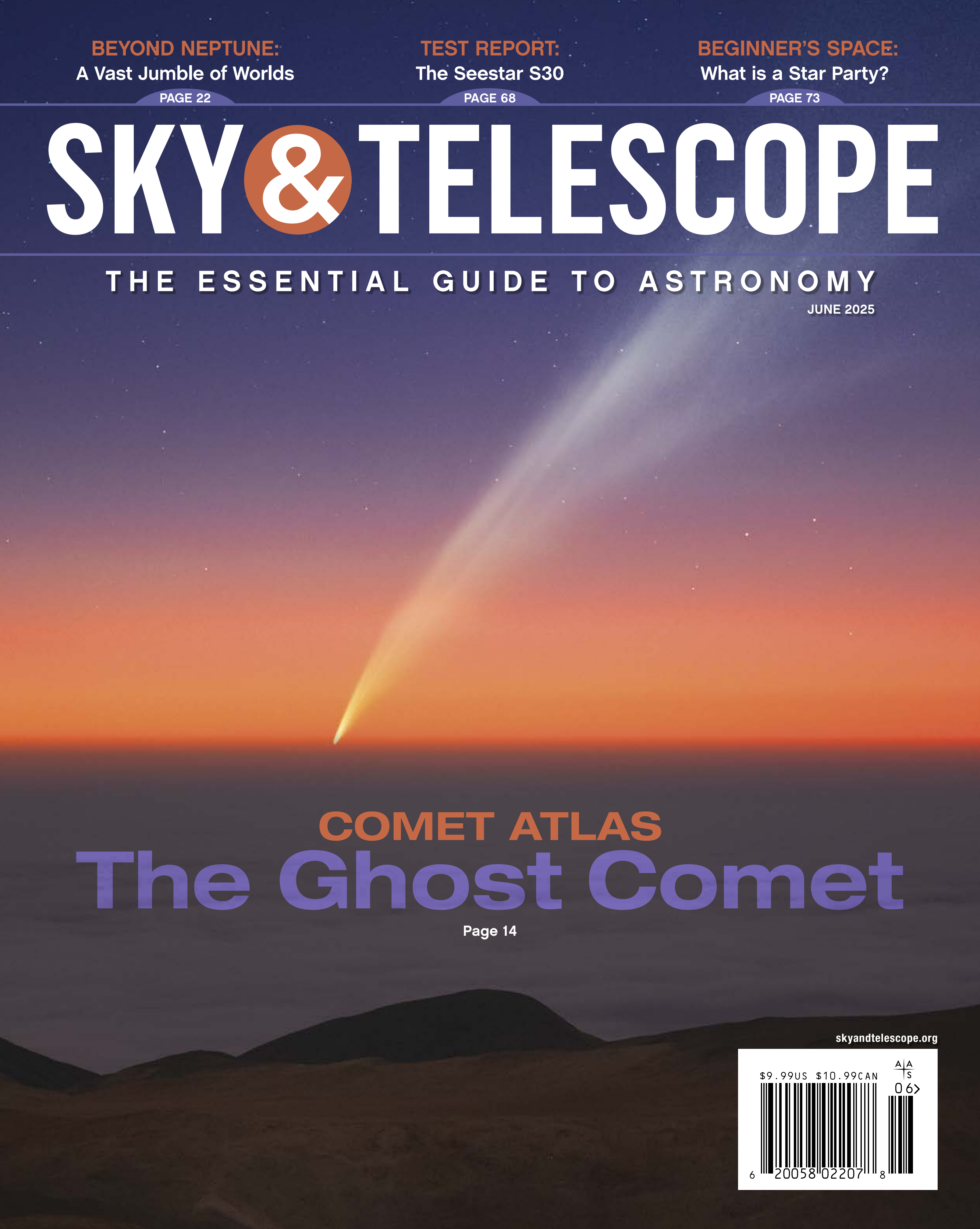

BEYOND NEPTUNE: A Vast Jumble of Worlds PAGE 22

TEST REPORT: The Seestar S30 PAGE 68

BEGINNER'S SPACE: What is a Star Party? PAGE 73

SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

JUNE 2025

COMET ATLAS

The Ghost Comet

Page 14

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The image on the right is the famous Pillars of Creation (M16) taken with the Wide Field Planetary Camera of the Hubble Space Telescope. The image on the left is taken with a QHY600M-PH Camera through a 7-inch refractor from the author's backyard in Buenos Aires. Courtesy Ignacio Diaz Bobillo. To see the original composition, resolution and acquisition details, visit the author's Astrobin gallery at https://www.astrobin.com/users/ignacio_db/

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CONTENTS

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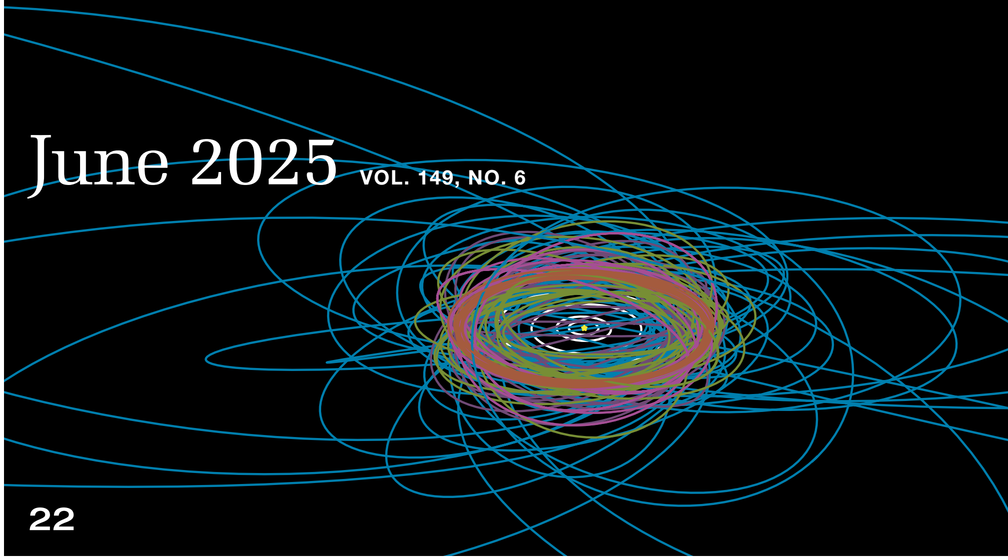

June 2025 VOL. 149, NO. 6

FEATURES

OBSERVING

S&T TEST REPORT

COLUMNS / DEPARTMENTS

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ON THE COVER

C/2024 G3 above Cerro Paranal in the Atacama Desert, Chile
PHOTO: YURI BELETSKY

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Under a Shared Sky

IT'S GALAXY SEASON! For those of you who enjoy chasing faint fuzzies, we have not one but two articles dedicated to those sometimes-elusive targets. On page 62, Mario Motta delights us with a tour of multiple island universes that share the same field of view. You can also take out your big scopes and dive deep into the inspiring selection of galaxies in Boötes that Contributing Editor Ted Forte has carefully curated (starting on page 58).

If you prefer stories set somewhat closer to home, explore the tale of the Milky Way stars that orbit each other at such large distances, it seems preposterous that gravity could keep them together (page 30). Gravity was also at work creating the mess of tiny worlds at the edge of our solar system (page 22), but an orderly ring within that mess is teaching us much about how our planetary system coalesced.

▲ Kosovo's new observatory is for all to share the sky.

Right in Earth's own skies, Comet ATLAS (C/2024 G3) put on a great display . . . for Southern Hemisphere skygazers. Whether you saw it yourself or were stuck in the Northern Hemisphere while the comet flaunted its tails (yes, that's plural — it showed off six tails!), turn to page 14 for the story by our own Sean Walker.

Shrinking distances is not only fun when it comes to what we observe; we can also shrink the distance between us and other observers. If you've heard of star parties but were hesitant to venture forth, you can learn what to expect in my column on page 73. Whether hauling a 30-inch Dobsonian or attending with nothing save for your own eyes, you may find yourself delighted by stepping away from astronomical solitude.

Thankfully, there are clever people making new technologies available for us to enjoy, whether on our own or together. Contributing Editor Rod Mollise introduces us to the latest in a line of smartscopes that allows you to image your favorite targets using a neat, lightweight gadget controlled by an app on your device. You can sit in the comfort of your own living room and readily share views of the night sky with family and friends.

Whatever your favorite item in this month's selection, let's all remember one last thing: what brings us together is our passion for the night sky. And in unsettled times we mustn't lose sight of the fact that we all share the same sky. Our Focal Point by Harvard student William Gottemoller leaves us with that thought to ponder.

Diana

Editor in Chief

EURON ILAZI

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The Essential Guide to Astronomy

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

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Advertising Information:
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Subscription Rates:
U.S. and possessions: $59.46 per year
Canada: $75.38 (including GST)
All other countries: $91.29, by expedited delivery
All prices are in U.S. dollars.

Customer Service: Magazine customer service and change-of-address notices: skyandtelescope@omeda.com
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SCAN ME

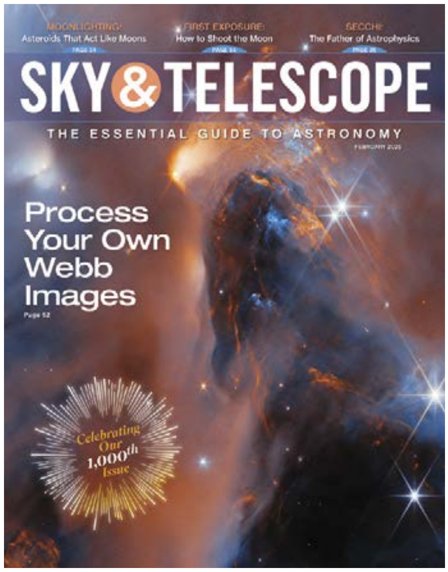
One Thousand And Counting

As I looked over your "Celebrating 1,000 issues" timeline (*S&T:* Feb. 2025, p. 12), I overlaid my life events on top of it. I became hooked on astronomy when my parents bought me a Celestron refractor between your 500th and 600th issues. By issue 650, I was serious about observing — actively going outside any clear night. Around issue 700, I was lost in college and remember treating myself to issues of *S&T* as a respite. About the same time issue 825 arrived, I got married and shared my love of astronomy with my wife. Now, with issue 1,000 in hand, I'm using the telescope I always promised myself I would buy to stargaze from my backyard.

Sky & Telescope has been an enduring aspect of my life. Like a childhood friendship, it helped form who I am. I remember learning the constellations, reading about exoplanets, and gazing at Hubble images. Age and circumstances have sometimes diverted my attention elsewhere, but *Sky & Telescope* has always been on those magazine shelves, a quiet and loyal friend awaiting my return. So thanks for 1,000 issues and the lifelong friendship.

By the way, I keep smiling at the idea of *S&T* sharing a category with *Vogue*. I hope there is a basement somewhere with decades of the two magazines lovingly preserved together.

Mike Fitzgerald
Syracuse, New York



▲ This cover proclaimed the February 2025 edition as *Sky & Telescope*'s 1,000th continuous issue, a feat that few other monthly magazines have achieved.

Congratulations to *Sky & Telescope* on its 1,000th issue (*S&T:* Feb. 2025, p. 84). What a milestone! And special thanks to Peter Tyson for being at *Sky & Telescope*'s helm for the past 10 years. I wish him all the best in the next phase of his career and will miss his monthly editorials.

I enjoyed the "Celebrating 1,000 Issues" infographic. However, one notable celestial event that I remember dearly was missing: the transit of Venus on June 8, 2004, the first since 1882. No one who witnessed this historic event will ever forget it!

Eli Maor
Morton Grove, Illinois

Congratulations on your 1,000th issue! It's a grand accomplishment. Here's another magazine for your elite list: *Model Railroader* was first published in January of 1934 and reached its 1,000th issue in April 2017.

David Wilkins
Philadelphia, Pennsylvania

I have been subscribing for a number of years, and I enjoy each issue immensely. The other paper magazine I read faithfully is *QST*, the monthly magazine of the American Radio Relay League. It's been published continuously since 1919, so please add it to the list of magazines that are at least 80 years old — and keep up the good work!

Ron McCollum
Winthrop, Washington

Rick T. Fienberg replies: *I knew when I wrote my essay that my list of long-lived monthly magazines still in print was likely incomplete. I searched the internet to compile my list, and I discovered that the answer you get depends critically on how you ask the question. My list was a "merge/purge" of about a half-dozen different sets of search results, none of which included* Model Railroader *or* QST. *But if I go back and look up those two magazines, they're reported to have been published every month since before* Sky & Telescope *was launched and, like* S&T, *are still going strong. I have no idea why they didn't show up in response to my earlier queries. There's a lesson here: Don't believe everything the internet tells you!*

Fine Craftsmanship

In leafing through my February *Sky & Telescope*, I was strangely warmed at the sight of the wooden structure appearing in Richard Wright's "Wood Wonders Eyepiece Case and Stand" (*S&T:* Feb. 2025, p. 68).

In a world of plastic, metal, and synthetics, this beautifully functional accessory chest for both amateur and professional astronomers alike is a welcome intrusion in a sea of mass-produced product lines. Having been involved in a family-owned, architectural woodworking firm producing beautiful pieces of custom-designed furnishings for notables such as Frank Lloyd Wright, the late King Faisal of Saudi Arabia, and a railroad company, I have a great appreciation for the thoughtfulness and skill going into such wooden designs. While I understand the cost benefits of manufacturing processes, it's refreshing to take in the craftsmanship of Wood Wonders. The only astronomical work of art I enjoy as much is the leather case housing my Questar 3.5!

Ed Huff
Tucson, Arizona

I just wanted to say that the February issue was the first time that I immediately placed orders for two of the products reviewed in the same issue. First, I bought the large Wood Wonders handcrafted eyepiece box. And I'd been considering purchasing the Starfield Herschel wedge (*S&T:* Feb. 2025, p. 70) after using a front-mount filter for the April eclipse. So I opted for the 2-inch model, and it's definitely a quality item. Keep up the reviews on these out-of-the-norm products!

John Svensson
Lititz, Pennsylvania

Color Conundrums

I thoroughly enjoy *S&T*'s emphasis on amateur astronomy endeavors. So, when I saw "Pixel Scale for Deep-Sky Imaging" (*S&T:* Jan. 2025, p. 60), I went straight to it. I can only afford a One-Shot Color (OSC) camera, so it did lead me to wonder do I need to consider each group of RGGB pixel members as one pixel for the formulas in the article? Also, if the light of a star enters an OSC camera and that star's photons touch a single pixel of only one color, could it theoretically yield false color and brightness levels compared to the star's true color?

Randall Kayfes
Tucson, Arizona

Ron Brecher replies: *I am glad you enjoyed the article. Each pixel counts, even in an OSC situation. While four pixels are used to make one, CFA Drizzle Integration will produce an image of the same dimensions as the sensor, not a ¼-size image. Dithering (moving the camera a few pixels between subframes) is necessary to use Drizzle integration.*

To your second question: The reality is that starlight gets spread out on multiple pixels in most images, except if you are severely undersampled (for example, a wide-field nightscape). In those cases, dithering and drizzling ensures that all the colors are represented in the star images and help round out the stars, which would otherwise look square in the situation you describe.

McHale's Rule

I enjoyed Steve Mazlin's "Blame It on That Darn Corona!" (*S&T:* Jan. 2025, p. 84). Most of us are probably aware just how much "fun" capturing the brief moment during a total eclipse is, let alone any other special event. After all, as Murphy says, "Anything that can go wrong, will go wrong." But I like to add "at *the worst* possible moment." Which brings me to the time-tested rule that a mentor taught me early in my career. It's the same rule that plagues Mazlin during his eclipse photography sessions. We call it "McHale's Rule." It simply states that "Murphy was an optimist."

Mike Atkins
Alamogordo, New Mexico

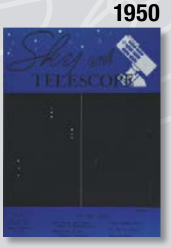
FOR THE RECORD

• In T. E. R. Phillips's pastel drawing of Mars on page 53 of the March issue, Syrtis Major had just emerged on the morning limb at left, and the orographic clouds above Elysium appear just to the right of center.

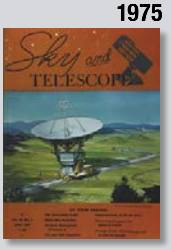
SUBMISSIONS: Write to *Sky & Telescope*, 1374 Massachusetts Ave., 4th Floor, Cambridge, MA 02138, USA, or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1950



1975



2000

◖ June 1950

Light Speed "From Annapolis, Md., radio signals have been sent to the National Bureau of Standards station 50 miles away at Sterling, Va., but by the *longest* instead of the shortest route. Traveling all the way around the earth, the radio waves arrived in Virginia a little over 1/10 second after they had been transmitted. . . .

"In going around the earth, these waves are either reflected back and forth many times between the earth's surface and the ionospheric layers of the atmosphere, or they curve gradually in the 'wave guides' formed by the concentric spherical surfaces of the earth and the ionosphere. Within the limits of the observed data, either explanation may be accepted."

This curious observation came just four years after the first radar detection of the Moon. In that case, the signal's round trip (at the speed of light) took 2.5 seconds.

◖ June 1975

CH3CH2OH in Space "The detection of ethanol (ethyl alcohol) molecules in interstellar space [is announced] by B. Zuckerman of the University of Maryland and 12 co-authors. The discovery was made by searching the radio source Sagittarius B2 with the NRAO precision 36-foot radio telescope at Kitt Peak, Arizona. . . . Three emission lines of ethanol were found at wavelengths of 3.5, 3.3, and 2.9 millimeters. Their identification seems sure, for all three yield the same radial velocity of +60 kilometers per second for Sagittarius B2.

"[They write,] 'Preliminary estimates indicate that the alcoholic content of this cloud, if purged of all impurities and condensed, would yield approximately 10^{28} fifths at 200 proof. This exceeds the total amount of all of man's fermentation efforts since the beginning of recorded history.'"

◖ June 2000

Lunar Leonids "By the time Texas amateur Brian Cudnik began his observing vigil on the evening of November 17th, the stream of Leonids that had peppered Europe and the Mideast was headed toward the Moon. Hopeful but not optimistic, he strained at the eyepiece [while watching] the shadowed lunar landscape looming before him at 122×. Suddenly he glimpsed a flash of yellowish orange light . . . Cudnik pegged its brightness as 3rd magnitude, like that of nearby Psi^1 Aquarii. 'There was no doubt,' he recalls, that he had witnessed a Leonid hitting the Moon.

"Cudnik's flash was indeed no atmospheric fluke or weary-eyed illusion, [for] it also turned up on a video recording made by occultation guru David W. Dunham."

This independent confirmation wiped out decades of skepticism that meteorite impacts on the Moon produced flashes visible from Earth. Such sightings are now routine.

SOLAR SYSTEM

Ingredients of Life Found on Asteroid Bennu

SCIENTISTS HAVE FOUND molecules key to life in samples returned from the near-Earth asteroid 101955 Bennu.

The Origins, Spectral Interpretation, Resource Identification, and Security-Regolith Explorer (OSIRIS-REX) mission captured a sample from Bennu's surface, returning it to Earth in 2023 (*S&T:* Jan. 2024, p. 8). Now, analyses of that sample published January 29th in *Nature* and *Nature Astronomy* have revealed multiple complex molecules, such as amino acids, as well as remnants of saltwater.

Scientists have long thought that asteroids like Bennu could have delivered water and organic compounds to primordial Earth and other solar system bodies. The new findings demonstrate that the ingredients for life might have been common in the early solar system.

▲ NASA's OSIRIS-REX mission imaged 101955 Bennu while visting the asteroid between late 2018 and mid-2021.

Small, well-preserved asteroids such as Bennu probe the early solar system's composition. "Carbon-rich asteroids are leftovers of the early solar system that have been minimally altered for 4.5 billion years," says Jason Dworkin (NASA Goddard Space Flight Center), a coauthor of both studies. "They preserve the chemistry that was happening at that time and was available at the origin of life."

While scientists have found similar organic molecules in meteorites, Bennu provides a rare opportunity to study a sample that hasn't been contaminated by a fall through Earth's atmosphere. Preserving the integrity of the 120 grams of material — around the mass of a bar of soap — was essential to the OSIRIS-REX mission.

◀ Project scientist Jason Dworkin holds up a vial that contains part of the sample returned from Bennu.

In these few grams, the team detected 33 amino acids, including 14 of the 20 that make up the proteins in terrestrial biology, as well as all five nucleobases that make up DNA and RNA on Earth.

Interestingly, while most amino acids found in life are shaped in a way that scientists dub "left-handed," the team found an equal proportion of both left-handed and right-handed molecules in the Bennu sample.

Astronomers also used the sample to trace Bennu's history back to a 4.5-billion-year-old parent asteroid, from which Bennu broke off some billion years ago. The presence of ammonia, methane, and other volatiles on Bennu suggests its parent body formed far enough from the Sun for those molecules to accrete as ices onto its surface.

Other evidence suggests that parent body hosted saltwater. The Bennu sample shows a sequence of 11 salt-rich minerals that were left behind as water containing those dissolved salts evaporated. Those minerals are similar to ones found in dried lakebeds on Earth; in fact, the sodium-rich carbonate known as *trona*, which is common on Earth, had never been detected in extraterrestrial samples before.

These brines could have served as a primordial "broth," allowing the building blocks of life to combine and intermingle. For example, ammonia might have reacted with formaldehyde, another molecule the team detected, to form amino acids.

"This discovery [of brines] was completely unexpected," says Timothy McCoy (Smithsonian Institution), who led the *Nature* study. "Which is why we explore space: not just to confirm what we think we know, but to make new discoveries."

The findings from Bennu demonstrate that nucleobases, amino acids, saltwater, and other molecules might have been ubiquitous in the early solar system. Asteroids could have delivered this life-starting kit not only to Earth but also to the inner terrestrial planets and icy worlds of the outer solar system.

■ ARIELLE FROMMER

BENNU: NASA / GSFC / UNIVERSITY OF ARIZONA; SAMPLE: NASA / JAMES TRALIE

ASTRONOMY & SOCIETY

The Space Industry and Light Pollution

THE BURGEONING SPACE industry is affecting the night sky on multiple levels. Even as bright satellites become increasingly visible, other impacts are more insidious.

Rocket launches and reentries can set the conditions for one unexpected and little-known phenomenon: *ionospheric holes*. These holes in the ionized layer of the upper atmosphere can be an impressive sight, creating patches of sky with a red glow, dominated by emission at 630 nanometers.

Stephen Hummel (McDonald Observatory), presenting at the 245th American Astronomical Society (AAS) meeting, says those glowing patches are appearing regularly over the southwestern U.S., where many world-class observatories are located. “They appear quickly with little warning, are optically bright (producing their own light rather than reflecting sunlight), persist for minutes to hours, occupy a relatively large area on the sky, and a lack of accurate launch information makes them hard to predict,” he notes.

Rocket launches also create plumes of gases and combustion products, and reentries deposit stratospheric aerosols. These pollutants impact the atmosphere as well as astronomical observations. The expected launch rate of SpaceX’s Starlink satellites alone could inject some 8,000 tons of metals into our atmosphere every year — more than the natural accumulation from meteoroids. Because of these effects, the AAS adopted a resolution last September stating grave concern “about the impacts of emissions and residual effects from extensive space launches and space object reentries upon Earth’s sky and upper atmosphere.” A month later, the AAS issued another resolution regarding “obtrusive space advertising,” another component of space economics that remains underregulated.

However, skyglow from artificial light at night remains a more difficult problem to address than launches, satellites, or even space billboards.

“I think it is fair to say that right now the bigger concern for ground-based astronomy is certainly light pollution, by far,” says John Barentine (Dark Sky Consulting). “Artificial light at night emissions have been rising around

▲ Rocket exhaust created a multi-tailed plume after the Firefly Alpha launch from Vandenberg Space Force Base, as seen from McDonald Observatory in Texas, 1,000 miles away.

the world at a fairly alarming rate.”

But he pointed out that there have been some successes in implementing regulations that may help, such as the European Union’s recent Nature Restoration Law. “We’ll see if that is successful,” he says. “I think in the end, it has to be the totality of all these efforts that’s eventually leading towards the same goal, I hope, which is the protection of the night sky overall.”

■ **DAVID L. CHANDLER**

Watch the formation of an ionospheric hole at https://is.gd/redpatch.

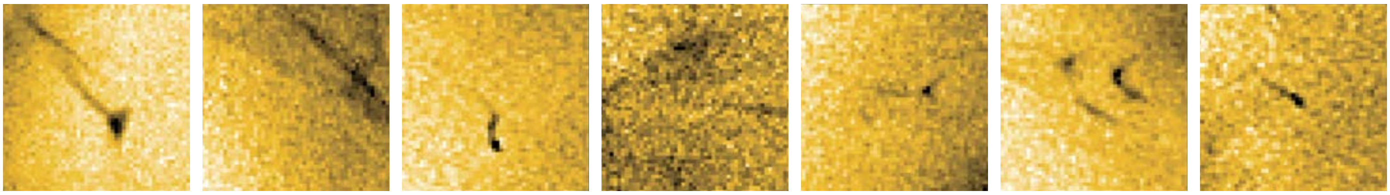
The Nine-Ringed Bullseye Galaxy

The Hubble Space Telescope has revealed a galaxy in Pisces with an unprecedented nine concentric rings. Likened to ripples in a pond, the rings of LEDA 1313424 (nicknamed “Bullseye”) owe their configuration to a blue dwarf galaxy that passed straight through the larger galaxy’s core 50 million years ago. The fly-through sent material sloshing, triggering mass star birth in the expanding rings. The dwarf (visible at center left) now lies 130,000 light-years from the ring galaxy; tenuous gas connects the two. Bullseye’s many rings surprised the team, led by Imad Pasha (Yale), as previously observed collisional ring galaxies have featured only two or sometimes three rings. The astronomers found eight rings in Hubble data and a ninth ring in data from the W. M. Keck Observatory in Hawaiʻi. Using the Dragonfly Telephoto Array, they also saw faint patches at the galaxy’s outermost edges that might be associated with an older, dissipated ring with a radius of approximately 230,000 light-years. The data appear in the February 10th *Astrophysical Journal Letters*.

■ **IVAN FARKAS**

Read more at https://is.gd/nineringbullseye.

ROCKET PLUME: STEPHEN HUMMEL; BULLSEYE GALAXY: NASA / ESA / IMAD PASHA (YALE) / PIETER VAN DOKKUM (YALE)



THE SUN

Solar Orbiter Traces Origin of Solar Wind

TINY "PICOFLARE" JETS might be the origin of the *solar wind* — the large-scale stream of particles from the Sun.

A team led by Lakshmi Pradeep Chitta (Max Planck Institute for Solar System Research, Germany) first imaged the mini-jets with the European Space Agency's Solar Orbiter in 2023. In the February *Astronomy & Astrophysics*, the researchers present new evidence for the jets' actions.

Solar physicists know that the fastest wind particles emanate from *coronal holes*, gaps in the white-light corona where magnetic field lines stretch outward into space instead of curling back toward the Sun. These field lines act like highways along which charged particles escape. Another, slower wind component has been harder to track down.

To find out what throws particles onto these magnetic highways in the first place, the team had the Solar Orbiter's Extreme Ultraviolet Imager peer deep into coronal holes. It turned up ubiquitous *picoflares*, each one a twister of plasma only a few hundred kilometers wide and lasting hardly longer than a minute. The observations showed that the jets can accelerate particles to 100 km/s (200,000 mph).

In the recent work, the scientists went a step further. Using magnetic field maps made by the Solar Orbiter and by NASA's Solar Dynamics Observatory, they traced magnetic fields at the spacecraft back toward the Sun. They then monitored the speed, temperature, and magnetic configuration of solar wind particles near the spacecraft, finding that they'd traveled from the same region where the jets were located.

The team also found evidence that both fast and slow solar wind components come from the same place. That's surprising, as the connection between the slow wind and coronal holes hadn't been fully established.

▲ The Solar Orbiter imaged a multitude of tiny jets of material escaping from the Sun's outer atmosphere, appearing as dark streaks against the bright solar surface.

Michael Hahn (Columbia University), who wasn't involved in the study, notes that the results align with recent findings from NASA's Parker Solar Probe. The Parker team found evidence that the solar wind accelerates as open and closed magnetic field lines on the Sun reconnect into new configurations (*S&T:* Oct. 2023, p. 11).

"These results are about different aspects of the same thing," he adds. "In both cases, an emerging theme is that the solar wind is not a smooth continuous flow but instead appears to be emitted in small bursts."

■ **JAN HATTENBACH**

Einstein Ring in NGC 6505

During a routine scan of the cosmos, the European Space Agency's Euclid mission has found an *Einstein ring*, hidden in plain sight around a galaxy known for more than a century. Euclid Archive Scientist Bruno Altieri led the team that published the discovery of the rare gravitational-lensing phenomenon in the February *Astronomy & Astrophysics*. What makes this particular find unique is its proximity: The foreground galaxy, NGC 6505 in the Draco constellation, is relatively nearby — only 590 million light-years from Earth. The background galaxy, whose light has bent into a ring shape as it traveled past NGC 6505, is likewise unusually close compared to other lensed objects — though its light still took 4.42 billion years to reach Earth. This is the first time an Einstein ring has been found centered around the nucleus of a galaxy in the *New General Catalogue of Nebulae and Clusters of Stars*, a list of deep-sky objects compiled in 1888. American astronomer Lewis A. Swift discovered NGC 6505 in 1884. "We're detecting many more Einstein rings in Euclid's survey," Altieri says. "But we expect none quite as spectacular as this one."

■ **ANANYA PALIVELA**

To see a close-up of the ring, visit https://is.gd/ngc6505.

OBITUARY

Glenn Schneider, 1955–2025

ASTRONOMY HAS LOST one of its most passionate chasers of total solar eclipses with the passing of astronomer Glenn Schneider on February 5th at age 69.

Glenn was a well-known and highly regarded expert who first coined the term *umbraphile*, literally meaning "shadow lover." He witnessed his first total solar eclipse in March 1970, and it changed his life — even though his professional research didn't actually involve total solar eclipses.

He came to the University of Arizona's Steward Observatory in 1994 and later served as the project scientist for the Near Infrared Cameras and Multi-Object Spectrometer (NICMOS), which was installed on the Hubble Space Telescope. Schneider used NICMOS and other instruments to study the disks of dust and gas around stars beyond our solar system. To do that, the instruments must block much of the stars' intense light — ironically, not unlike an eclipse. His passion and work were, to quote him "incredibly symbiotic."

Glenn truly made his mark as an assiduous calculator and chaser of total solar eclipses. He prepared numerous flight paths for eclipse expeditions over three decades, including flights over Antarctica in November 2003, over the North Pole in August 2008, as well as two flights involving a commercial airliner in March 2016 and August 2017.

He was involved in some amazing extremes, including witnessing a total solar eclipse near Iceland in October 1986 that lasted a fraction of a second. He also implemented an airborne expedition on July 11, 2010, that intercepted the Moon's shadow near Tahiti, French Polynesia, stretching totality's duration to an astounding 9 minutes 23 seconds.

By 2019 Glenn had attained a world record for the greatest number of total solar eclipses ever experienced: 35. He retired in 2022, and in 2023, a minor planet was named for him: 12936 Glennschneider.

■ JOE RAO

IN BRIEF

Lunar Mission Updates

NASA has announced that it intends to press forward with its Volatiles Investigating Polar Exploration Rover (VIPER) mission, to be delivered to the Moon by an industry partner. VIPER was built as part of the Artemis initiative and is set to search for water ice in the permanently shadowed regions of the Moon using four scientific instruments, including a meter-long drill. A call for proposals has gone out with a deadline of March 3rd for responses from industry. More detailed proposals will follow, with a final decision expected by the summer. In the meantime, Astrobotic's Griffin lander, which was originally slated to carry VIPER to an area west of Nobile Crater at the lunar south pole, will instead carry the Flexible Logistics and Exploration (FLEX) Lunar Innovation Platform (FLIP), to be built by Venturi Astrolab. The FLIP rover, unlike VIPER, carries little in the way of science. The four-wheeled platform is mainly a technology demonstration for Astrolab's larger FLEX rover. The plan, after Griffin lands around lunar sunrise, is that the solar-powered FLIP will roll onto the lunar surface, where it's expected to last two weeks until lunar sunset. Griffin and FLIP could launch by the end of the year.

■ DAVID DICKINSON

STELLAR SCIENCE

Rare Kind of White Dwarf Could Foster Habitable Worlds

THE FATE OF SUN-LIKE STARS is to collapse into dense and ever-cooling white dwarfs. But for some of them, an extra amount of an uncommon element offers a last gasp of energy. The excess heat might even enable habitability around them, Andrew Vanderburg (MIT) announced at the 245th meeting of the American Astronomical Society.

In 2018 astronomers using the European Space Agency's Gaia telescope discovered *Q-branch* white dwarfs, which, remarkably, have paused their cooling for some 10 billion years. Without any fuel left to burn, these white dwarfs may get their heat from the heavy element neon-22. As buoyant crystals form in a hot white dwarf's interior, heavier neon-22 atoms, if present, are forced out. The crystals rise while the neon atoms sink, releasing gravitational energy as heat. The process requires at least 2.5% of the white dwarf's mass be neon-22, which only occurs in about 6% of higher-mass white dwarfs.

Habitability around white dwarfs had looked bleak because the habitable zone shrinks as the stellar remnant cools. Q-branch stars, though, offered hope of a stable habitable zone. So Vanderburg and colleagues modeled the environments around white dwarfs with and without neon-22 reshuffling. They found that neon-rich white dwarfs host habitable zones for as long as 10 billion years. Those habitable zones are also farther from the star, which mitigates the white dwarf's gravitational pull that heats planets from the inside.

▶ An artist's impression of a planet orbiting a white dwarf, along with sundry debris

Understanding the origin of neon-rich white dwarfs may help astronomers search for more of them as well as any habitable worlds they support. "If it inspires astronomers to go out and now look for that," says Jay Farihi (University College London) who wasn't involved with the current study, "that's the real payoff."

■ HANNAH RICHTER

Aureoles of Planetary Delight

Thin clouds can transform light from the Moon and planets in wonderful ways.

ON NIGHTS WHEN thin clouds caress the Moon, an alluring display of light and color may spring forth, crowning our nearest neighbor with rings of prismatic splendor. A careful look will reveal that the rings form a colorful interference pattern, with blue on the inside and red on the outside — like that of a primary rainbow. Known collectively as the atmospheric *corona* ("crown" in Latin), these colored rings are centered on a nimbus of silvery light immediately surrounding the Moon. They're much smaller than the 22° halo also associated with the Moon (and Sun).

In the finest displays, the *first-order corona*, also called the *aureole,* appears as a blue glow bordered by a rusty collar. Most coronae form in *altocumulus translucidus* (thin altocumulus) clouds, with water droplets or needlelike ice crystals ranging in size from about 10 to 100 microns. The phenomenon is produced by the diffraction of light as it interacts with individual water droplets or ice crystals. When light encounters a particle, its waves scatter primarily from the droplet's periphery. They then combine and interfere, resulting in a colorful ringed pattern.

At night, aureoles are not confined to the Moon. They can also adorn the brighter planets and stars. The queen of atmospheric planetary coronae is Venus; spotting them around the other naked-eye planets requires a more concerted effort. However, on the evening of February 4, 2025, I saw the Moon, Venus, Jupiter, and Mars simultaneously sporting aureoles just as night fell — and while Saturn was close to Venus at the time, clouds miraculously avoided it.

To the unaided eye, the Moon presented a classic blue- and rust-colored aureole. The one surrounding Venus had a slight wash of blue that hugged the planet, beyond which shone a diffuse burnt orange band. The aureole of Jupiter was more bronze colored without a trace of blue, while Mars's appeared as a burst of fiery orange.

▲ **KALEIDOSCOPE OF AUREOLES** On the evening of February 4, 2025, the author photographed aureoles around (left to right) Venus, Jupiter, and Mars from Maun, Botswana. The aureole of Mars stood out due to its bright, yellowish interior and rich red collar.

As shown above, my photographs from that evening brought out even more color and detail. The aureole of Venus possesses a narrow yellow ring lining the inside of the rusty collar. The center of Jupiter's aureole appears as a soft mix of yellow embraced by an outer bronze glow. Mars's aureole, on the other hand, has a carrot-colored core surrounded by a fiery reddish fringe. Five nights later, the Moon displayed a series of ordered coronal rings, adding a sense of completeness to this visual journey.

The aureoles described here do not represent what we should always expect to see. For instance, a lunar aureole's size can vary from one sighting to the next, with the apparent diameter ranging from less than 1° to 5°. The glow's intensity and color depend not only on the brightness and color of the illuminating source, but also on the size of the particles scattering the light: the brighter the source, the more pronounced and colorful the aureole; the smaller the particles, the larger the aureole. Given these variables, my guess is that the cloud particles on the evening of February 4th were at the larger end of the scale.

▲ **LOVELY LUNA** In this photo of the Moon's corona on February 9, 2025, the aureole appears mostly white as it is overexposed.

Looking upon these visual wonders, I could see how the aureole is reminiscent of the eponymous luminous glows surrounding the body (not just the head) of key figures in Renaissance Christian art. As George Ferguson writes in his book *Signs & Symbols in Christian Art,* first published in 1954, "the aureole follows the form of the body and clings closely to it, appearing as a fringe of light . . . A blue aureole, indicating celestial glory, is occasionally seen." One can now wonder if this dramatic atmospheric phenomenon inspired the blue aureoles found in art — especially in portrayals of the Virgin Mary, to whom the Sun and Moon are attributed.

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

STEPHEN JAMES O'MEARA (4)

ATLAS: The Great Ghost Comet

An icy visitor flames out in dramatic fashion.

This year started off with a bang, particularly for those in the Southern Hemisphere. That's the consensus among observers after Comet ATLAS (C/2024 G3) emerged from perihelion in mid-January. Many say ATLAS put on the best evening display since the Great Comet of 2007, Comet McNaught (C/2006 P1). Some are even calling it the Great Comet of 2025.

When first swept up by the Asteroid Terrestrial-impact Last Alert System (ATLAS) survey on April 5, 2024, it was a 19th-magnitude object with a diffuse coma and short tail. Within days, scientists calculated its orbital path, which revealed it would pass within 0.09 a.u. (13 million kilometers) of the Sun on January 13, 2025. Its path across the celestial sphere meant it would only be visible in dark skies from the Southern Hemisphere. For skygazers in the Northern Hemisphere, the comet would be briefly visible around perihelion — and only then for those willing to chance daylight observations close to the Sun.

Observers carefully monitored the icy snowball as it plunged toward its rendezvous with the Sun in late 2024, only interrupting while Comet Tsuchinshan-ATLAS (C/2023 A3) put on a wonderful show from September through October (see the March issue, page 34).

Comet ATLAS more or less followed predictions, and by late December it had achieved a respectable brightness of about 5th magnitude while sporting a modest coma and a dust tail some 15 arcminutes long as it passed through Scorpius. Though technically a naked-eye object, the comet hung low on the horizon and was difficult to see without optical aid.

On January 2nd, Australian observer Terry Lovejoy reported that the comet had undergone an outburst, lighting

▶ **FANNING OUT** On January 22nd, headless Comet ATLAS (C/2024 G3) displayed a 20°-long dust tail in addition to several other, fainter tails as it towered over one of the 6.5-meter Magellan Telescopes at Las Campanas Observatory in Chile.

(continued on page 18)

January 12 | January 13 (perihelion) | January 14 | January 15 | January 16

NORTHERN CHALLENGE Imager Chris Schur of Payson, Arizona, captured this series of images over five days as the comet rounded the Sun at perihelion. Each result was recorded at 10:30 a.m. local time.

YURI BELETSKY

▲ **NUCLEAR SHADOW** As ATLAS became visible in twilight following perihelion, it displayed a long, dark lane in its dust tail emanating from its nucleus. Astronomers thought the lane to be the shadow of the dense part of the coma blocking light along the tail. This image was recorded from the Tivoli Southern Sky Guest Farm in Namibia on January 17th.

▶ **SEASIDE DISPLAY** Low ocean clouds on January 24th parted sufficiently to reveal the comet above sea stacks at Mornington Peninsula in Victoria, Australia.

TWILIGHT CLOSEUP: GERALD RHEMANN / MICHAEL JÄGER; OCEANVIEW: ALEX CHERNEY

(continued from page 14)

up by a full magnitude to 3.7 in a single day. From that point, ATLAS continued to rapidly brighten. Just two days after his initial report, Lovejoy pegged it at magnitude 1.9. As it approached perihelion it remained visible in binoculars in the morning twilight. Observers began to note a dark "shadow" bisecting the comet's tail that was most pronounced near the nucleus. And by January 3rd, some were able to spot the comet without optical aid.

Another Daylight Display

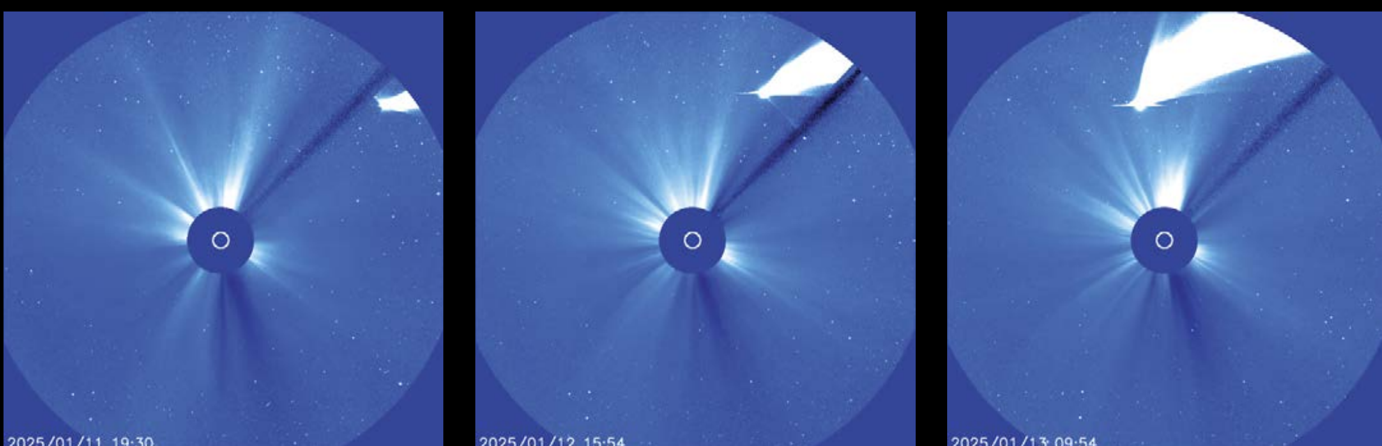
The comet entered the field of the SOHO spacecraft's LASCO C3 coronagraph on January 11th, when it lit up further due to the effect of forward scattering. Astronomers estimate the coma achieved a magnitude of –3.7 on the 13th, the day of perihelion, though it appeared to continue to intensify as it exited the LASCO field (seen below).

As the comet rounded the Sun, intrepid amateurs in the Northern Hemisphere had an opportunity to glimpse it during daylight hours. Chris Schur of Payson, Arizona, managed to image the comet daily from January 12th to the 16th at 10:30 a.m. local time. Northern observers were able to follow the comet with binoculars low on the southwestern horizon until about the 20th, just as the show was getting underway in the opposite hemisphere.

◀ **HEADLESS COMET** By February 1st, little if anything remained of Comet ATLAS's nucleus, producing strange images like this one showing the headless tails drifting off into space.

▼ **SOLAR SWING-BY** As the comet rounded the Sun it crossed the field of the SOHO spacecraft's LASCO C3 camera. Note the growing "blooming spikes" extending from the left and right of the comet's nucleus, particularly after January 13th — an early indication of the disruption of the comet's nucleus. (The white circle in the center of the frame represents the Sun's disk, while the dark silhouette is the telescope's occulting bar and support.)

HEAD SPLITTING: TARAS PRYSTAVSKI; SOLAR SWING-BY: ESA / NASA (6)



As Comet ATLAS emerged in the evening twilight for Southern Hemisphere observers, it appeared slightly brighter than Saturn and sported a 4°-long curved dust tail. The comet had survived perihelion! Or so it seemed. By January 17th it was high enough to see after evening twilight faded. Photographs revealed the comet's wide, curved dust tail extending some 15°. The striations visible within its tail recalled views of Comet McNaught some 18 years earlier. Deep images of ATLAS's tail revealed several additional, fainter tails located between the fan-like dust tail and the direction of the comet's orbital path.

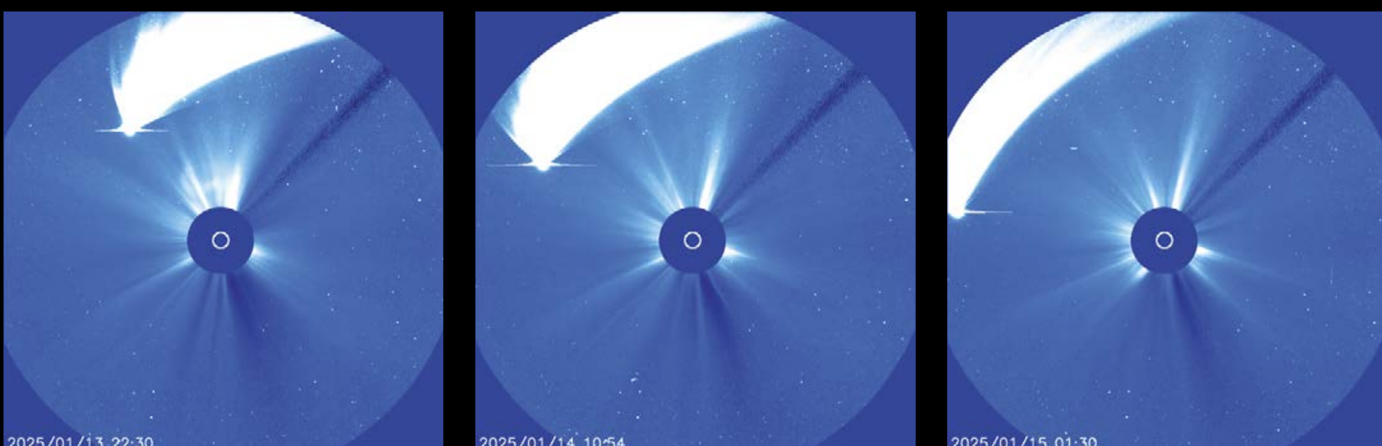
Rapid Changes

While the comet initially appeared to survive perihelion, that wasn't actually true. Hungarian astrophotographer Lionel Majzik was first to report dramatic changes in the appearance of the comet's head between January 18th and 20th while processing his images of it remotely acquired from Chile. On the 18th the head appeared sharp and bright, but by the next day it had morphed into a long, thin streak that dramatically faded on the 20th.

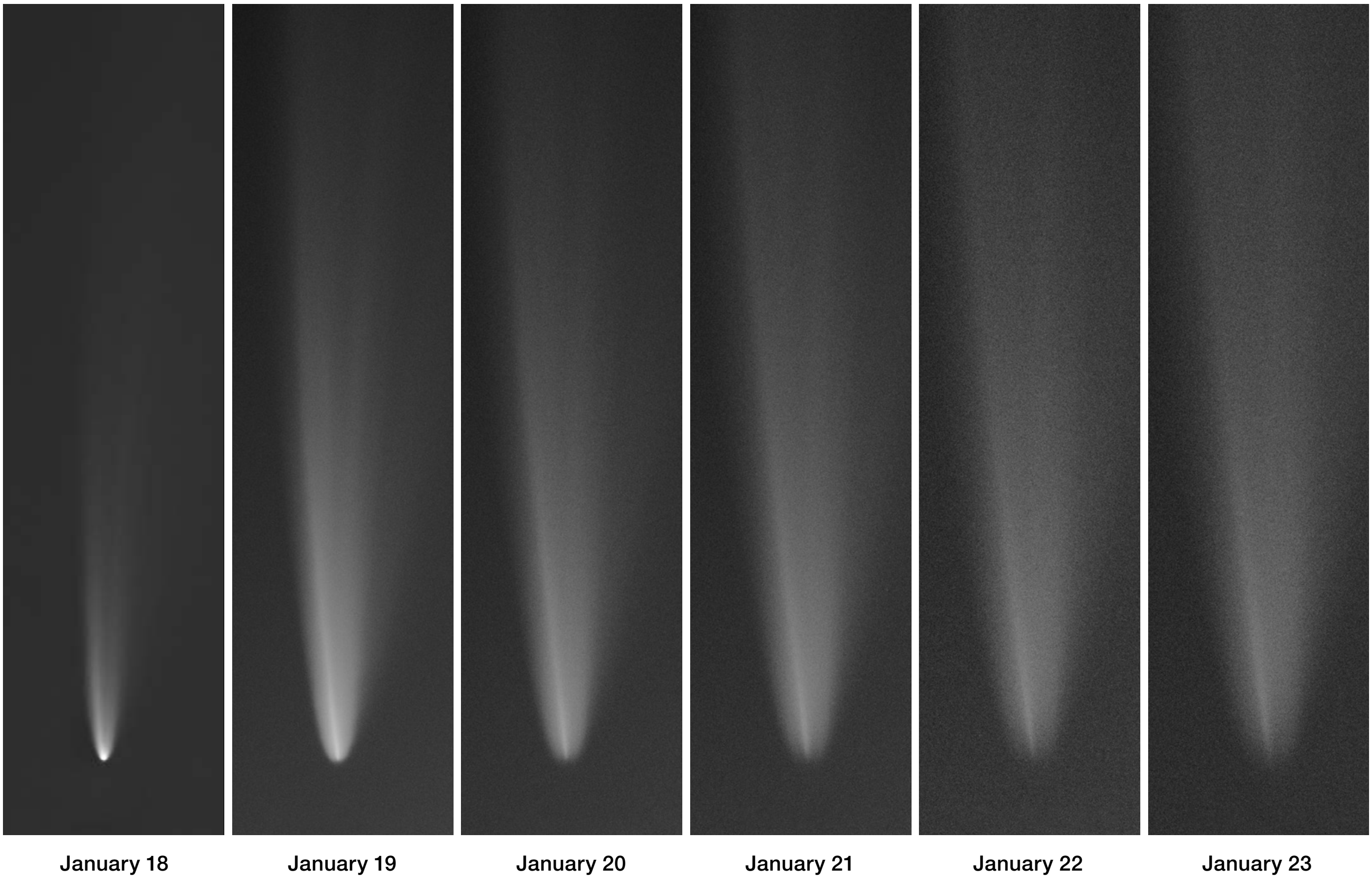
Evidently, immediately following perihelion, the comet began to break apart — the appearance of noticeably larger blooming spikes in the LASCO C3 images (due to excess light spilled onto adjacent pixels when CCD wells become saturated) on the 14th were a telltale sign that something was amiss. The thin "spike" seen for a few days after January 19th were larger dust particles released when the nucleus fragmented. Within days, the nucleus seemed to completely disappear, leaving behind a large, ghostly dust tail that continued to be visible for several weeks.

MARTIN MAŠEK / JAKUB KUŘÁK

▶ **A TALE OF MANY TAILS** Comet ATLAS displays at least six individual tails in this deep exposure recorded from Paranal Observatory in Chile on January 23rd.



LUC PERROT



▲ **RAPID CHANGES** In the days following perihelion, Hungarian astrophotographer Lionel Majzik was first to note major changes in the appearance of the comet. His images show how the head became elongated on the 19th and drastically faded each day thereafter.

Not Fade Away

Despite its apparent decapitation, Comet ATLAS continued to put on a fine display, slowly fading as its remaining dust and gas were carried downstream by the solar wind. *Sky & Telescope* Contributing Editor Stephen James O'Meara pegged its magnitude at 5.5 on February 4th while observing from his home in Maun, Botswana. He writes ". . . it is rising almost straight up from the horizon by about a degree a day while the stars are lowering by a degree a day, so the comet just sits in almost the exact same spot night after night, staying about 10° above the horizon in late astronomical twilight."

Astronomers believe some of the comet's nucleus survived, though it won't return to the inner solar system for some 600,000 years. By mid-February, the ghost of Comet ATLAS had fallen below naked-eye visibility, though it remained a fine target in binoculars as it drifted through Grus, the Crane.

So, for the second time in just three months, observers were treated to a bright comet. ATLAS was only the fifth daylight comet in the last 60 years, joining the ranks of Comet Ikea-Seki in 1965, Comet West in 1976, McNaught in 2007, and Tsuchinshan-ATLAS last October.

Comet enthusiasts are debating whether or not Comet ATLAS (C/2024 G3) should be considered a "great" comet. Although it achieved a peak magnitude about as bright as Venus, like Tsuchinshan-ATLAS it did so when it was close to the Sun and difficult to observe. By the time it was well placed, it had dimmed to 1st magnitude or fainter — still impressive, but "great"? Renowned comet observer John Bortle considers it the Great Comet of 2025, but others aren't so sure. O'Meara considers it a high achiever, but a little short of the title.

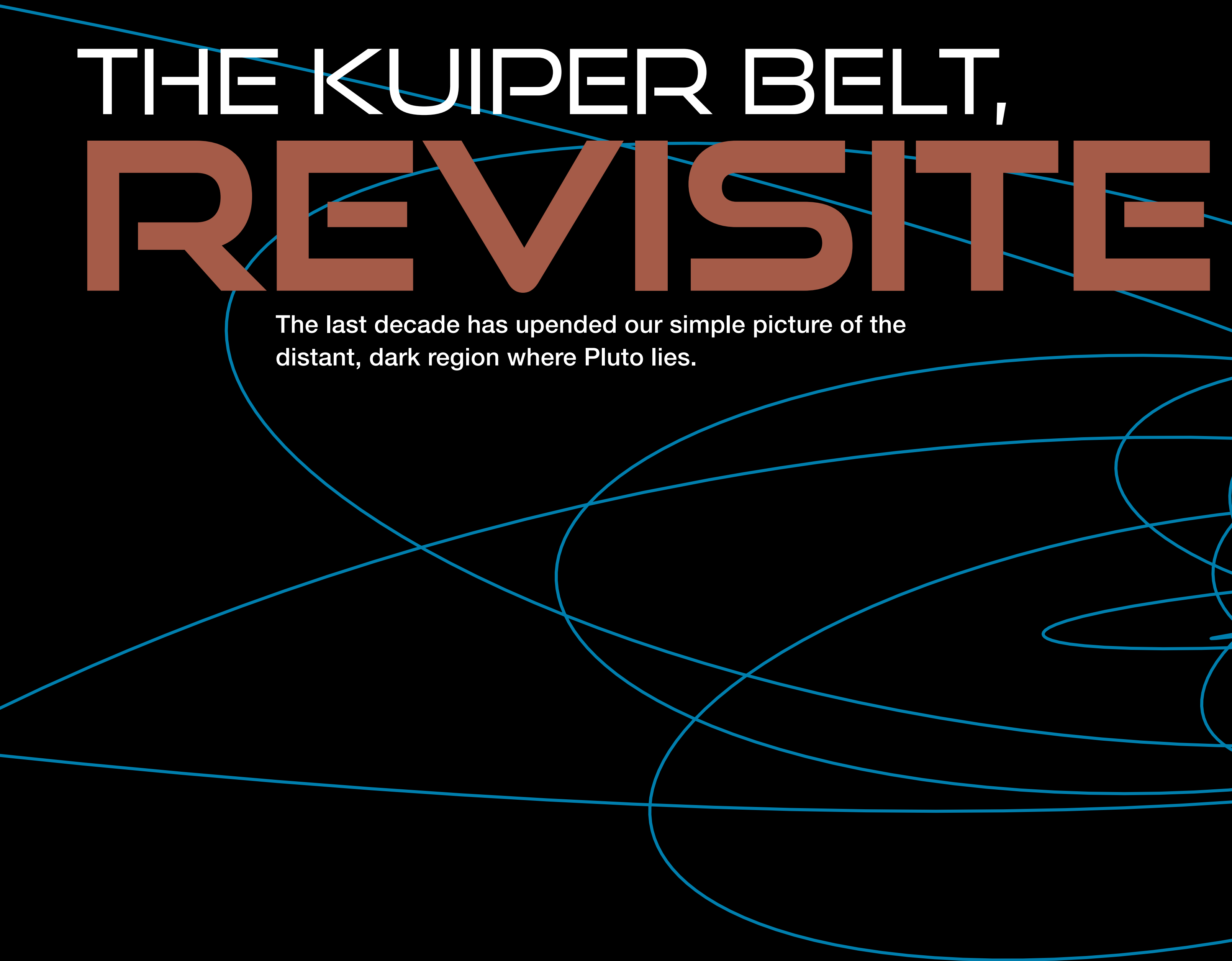
It may be that our definition of what constitutes a great comet is changing with the times, possibly due to the growing popularity of digital photography. It's so easy these days to take a photo that reveals far more than the eye can see, and with the ever-increasing problem of light pollution, observers spend more time behind a camera than they do at an eyepiece. We can ponder the question of greatness as we await the next bright visitor from the outer reaches of our solar system.

◀ **ABOVE THE FRAY** The comet's tails tower above a thunderstorm on January 25th, as photographed from Réunion Island in the Indian Ocean.

■ Associate Editor **SEAN WALKER** hopes to be in the right hemisphere when the next bright comet appears.

THE KUIPER BELT, REVISITE

The last decade has upended our simple picture of the distant, dark region where Pluto lies.



BEATRIZ INGLESSIS / S&T, SOURCE: KAT VOLK

When we imagine the solar system, we often picture the Sun at the center of a pattern of concentric circles of orbits. They come in sets: the four inner planets, the main belt of asteroids, then the four giant planets. Then beyond Neptune, we have the Kuiper belt, where Pluto lives.

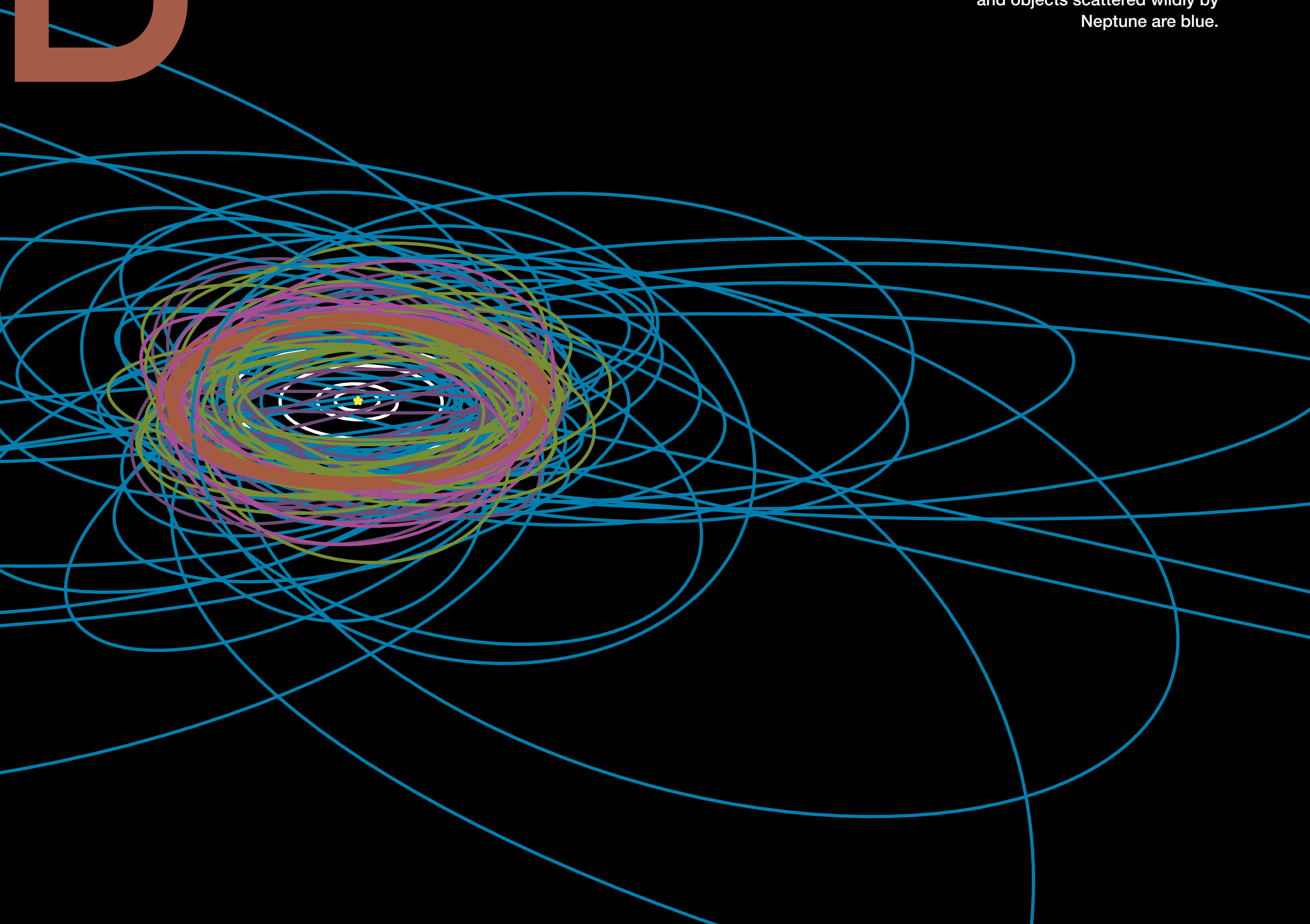
Many of us may imagine this belt — if we've thought about it at all, that is — as an icy cousin of the asteroid belt, its myriad little worlds circling the Sun in a fairly flat disk out beyond Neptune. For a long time, we had precious little to tell us otherwise. It's maddeningly difficult to study this region, because of the distance and darkness of its denizens: These objects are so far away that whatever light we can see from them takes several hours to reach us, and they're typically fainter than magnitude 18, requiring large telescopes to track them.

In the last decade, however, the formerly fuzzy picture of this region has come into focus. We've discovered that the orderly belt we once imagined is only part of the full picture, and that this frozen expanse is a jumble of worlds, many of which originally formed in different parts of the solar system. What we've learned has solved a major mystery about how our planetary system formed.

Not Just a Belt

Martin Duncan and others coined the term "Kuiper Belt" in 1988 to describe a proposed reservoir of tiny worlds beyond Neptune. That reservoir would explain the low inclinations

D



WHAT A MESS This diagram shows a selection of trans-Neptunian objects for which scientists have good orbits. The cold classicals' orbits are rusty red. Magenta orbits are hot classicals, green are two examples of resonant groups (including the one that Pluto occupies), and objects scattered wildly by Neptune are blue.

of short-period comets, which skim the ecliptic plane as they sail in and out of the inner solar system, they said.

The name was a nod to Gerard Kuiper, who had suggested in 1951 that the disk of dusty gas that coalesced into the planets must have contained solid material beyond the orbits of the four giant planets. (Never mind that Kuiper thought much of the material had long since disappeared; *S&T:* Sept. 2024, p. 20.)

Such a reservoir does exist, we now know. Thanks to several telescopic surveys, the count of small, icy worlds beyond Neptune currently stands at more than 5,000.

But only about 20% of these worlds occupy circular orbits in a flat belt, as Duncan imagined. (Pluto's not one of them.) Astronomers call this disk the *cold classical Kuiper Belt*. The belt stretches from about 42 to 47 astronomical units, well outside Neptune's orbit at 30 au.

You'd be forgiven for thinking that "cold" describes their temperature, because these objects certainly are that, with surfaces colder than 50 kelvin (–220°C, or –370°F). But this is a different kind of cold, one describing the objects' orbits.

A *dynamically cold body* has a (nearly) circular orbit that's only marginally inclined to the ecliptic plane, like the paths of the planets. The primordial disk of material orbiting the infant Sun would have naturally condensed into objects on dynamically cold orbits, as everything settled into place. To move bodies out of this state and set them traveling on orbits that are tilted, elongated, or both requires pumping energy into their trajectories, making them "hot."

Because some 80% of the worlds out there are dynamically hot and do not travel in anything like a belt, researchers have shifted away from using the term "Kuiper Belt object." *Trans-Neptunian object* (TNO) is now the term of art for all the worlds that travel past Neptune, whether of the cold or hot variety.

The hot objects come in many flavors, depending on how their orbits were energized. *Resonants* like Pluto travel around the Sun on elongated orbits at some cadence that's locked with Neptune's, having been boosted into these paths by the planet's repeated gravitational shoves. *Hot classicals* follow circular orbits that lie at the same solar distances as the cold classicals but are significantly tilted out of the plane of the solar system. Both resonant and classical orbits keep those TNOs at a safe distance from the ice giant, making their orbits stable over billions of years.

Other TNOs might stay on one tranquil path for thousands or millions of years, but eventually an encounter with Neptune sets them on a new course. Multiple encounters of this sort can scatter these worlds across the outer solar system, either toward or away from the Sun. In some cases, they can be forced into the giant planets' neighborhood, becoming objects called Centaurs (*S&T:* Jan. 2022, p. 14). In others, they're thrown onto orbits so long that they'll take thousands of years to return to Neptune's neighborhood. And there are yet other objects that don't fit into any of these categories, leaving scientists perplexed.

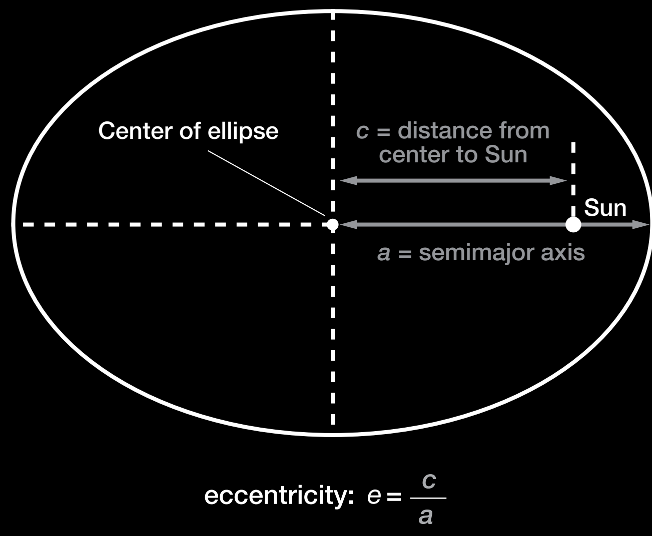
In the midst of this melee, the well-behaved ring of cold classical objects between 42 and 47 au is an anomaly, embedded in a snarl of tangled orbits that look like so many loops of yarn pulled from a ball. Neptune is responsible for the belt's boundaries: The belt is an orbital safe zone, protected from the ice giant's gravitational nudges. But Neptune is also largely responsible for the mess.

Nice Model You Have There . . .

According to our current theories, the planets moved around in the solar system's early years. Neptune probably formed at

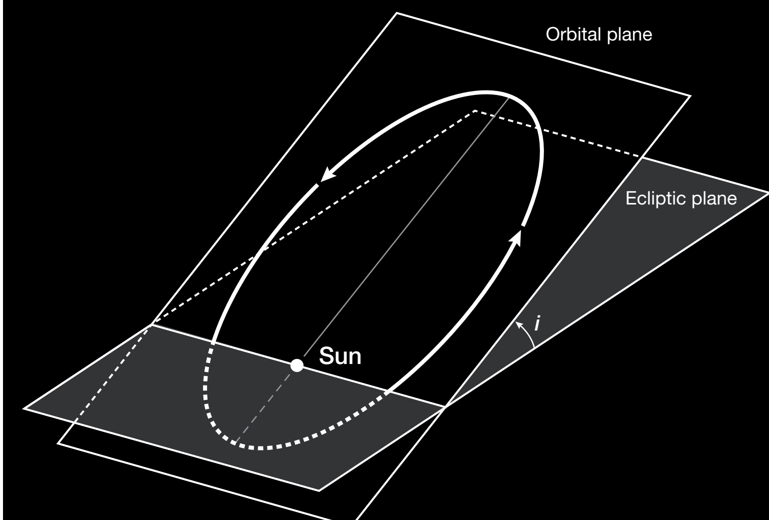
Orbital Eccentricity

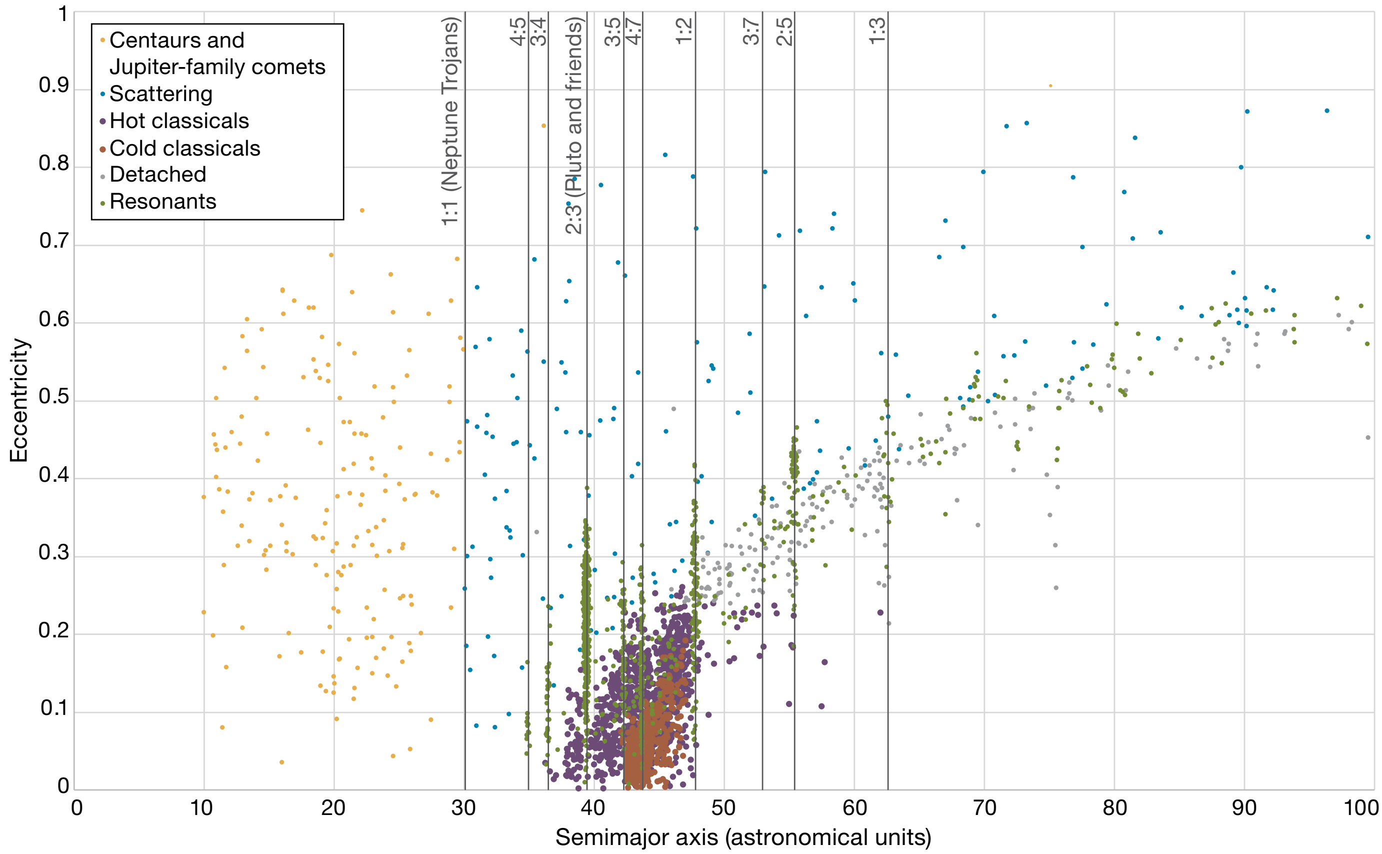
Eccentricity measures how much an orbit is squashed from a perfect circle. An eccentricity *e* of 0 is a perfect circle; for ellipses, *e* can be up to (but not including) 1. The plot on the right (page 25) shows the wide range of eccentricities that TNOs have.



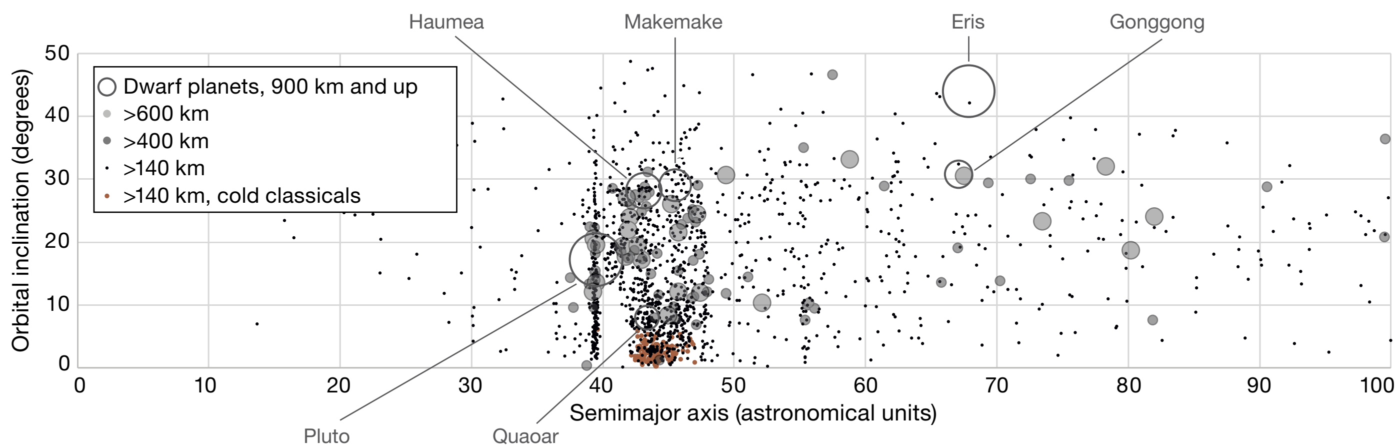
Orbital Inclination

Inclination, *i*, measures how tilted an orbit is from the plane of the solar system, called the ecliptic. An inclination of 0° means the orbit lies in the ecliptic plane; 90° would be perpendicular. Dynamically hot orbits have a wide range of inclinations and orientations.





▲ **NOT LIKE THE OTHERS** This plot shows trans-Neptunian objects and their cousins beyond 10 au, sorted by orbit size and eccentricity. The cold classicals (rusty red) have fairly circular orbits, whereas many other objects follow elongated paths that take them much closer and farther from the Sun than the average distance shown here. Neptune's gravity herds some objects into resonant orbits (vertical lines); resonances populated by at least 10 known objects are shown. Objects on the curve extending rightward have perihelia of 35 au. Beyond 50 au or so, information is limited.



▲ **SOME SOAR HIGH** This plot shows the subset of objects larger than about 140 meters. Dots are scaled based on objects' sizes, estimated from albedo. Dwarf planets' "dots" (large gray circles) are sized based on how the objects' real-life diameters compare to one another. Two dwarf planets also have large moons: Pluto's Charon (1,200 km wide) and Eris's Dysnomia (roughly 700 km), but we don't show those here. TNOs with sizes between 600 and 900 km are shown with a dot size equivalent to a 750-km object. The worlds are split into cold classicals (rusty red, clustered between 42 and 47 au) and the various hot populations (black and gray). The census is moderately complete out to about 50 au.

ECCENTRICITY DIAGRAM: BEATRIZ INGLESSIS / *S&T*, SOURCE: KAT VOLK; PLOTS: BEATRIZ INGLESSIS / *S&T* AND THE AUTHOR, SOURCES: KAT VOLK, Y. HUANG ET AL. / *ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES* 2022, JPL SMALL-BODY DATABASE, AND W. R. JOHNSTON (2)

TNOs' compositions support the picture that the cold classicals are distinct from everything else beyond Neptune.

a distance of around 15 au, much closer to the Sun than it is today. Beyond it, the protoplanetary disk originally contained 5 to 20 times the mass of Earth, caught up in a variety of mountain-size objects. As the giant planets migrated and Neptune moved outward, the ice giant elbowed these objects into their current orbits. When it reached the edge of the dense part of the protoplanetary disk at 30 au, Neptune stopped migrating. It's been there ever since.

When proposed in 2005, this model played well with a theory for how bodies coalesced in the early solar system known as *pebble accretion*. Tiny granules of condensed material called chondrules could stick together electrostatically in the dense early disk. These sticky clumps would glom onto each other until they were big enough to pull themselves together gravitationally and make pebbles. Under self-gravity, the pebbles stuck together to create potato-shaped planetesimals up to about 300 kilometers (200 miles) across, the size of large asteroids. After that, simulations have demonstrated, planetesimals very quickly assembled themselves into protoplanets.

In this picture, the dynamically hot TNOs could have formed between 15 and 35 au, where material was dense enough for protoplanets to form but not dense enough to build another giant planet. A very few grew large enough to become round and internally hot, not only separating into a rocky core and icy mantle but also sustaining active geology. On these worlds, ice melted to create internal oceans and icy goo erupted onto surfaces. These are the big, colorful trans-Neptunian dwarf planets, including Pluto, Eris, and oblong Haumea. Neptune's migration displaced these objects onto their present orbits. During the planetary dance, the ice giant also captured one dwarf planet, Triton, as its own moon.

But the dynamically cold TNOs presented a puzzle. Their sedate orbits suggest they haven't been disturbed since forming. Yet researchers were having trouble simulating the objects' formation with pebble accretion: Out beyond 30 au, there was much less material, and because the material also moved slowly, it stubbornly refused to condense into planetesimals. The only solution seemed to be that the cold TNOs had formed closer to the Sun and migrated outward — directly contradicting observations.

As astronomers discovered more TNOs, evidence mounted that the cold classicals were physically different than the rest. The hot population includes dozens of worlds larger than 500 km across, big enough to be round. But cold classicals are small: Based on their faint thermal radiation, we think only a handful are wider than 200 km. Most are much smaller, near the present detection limit of around 100 km. At that size, they're not big enough to gravitationally shape themselves to be round; they're all potatoes.

Cold classicals are also more gregarious than other TNOs. While binaries make up about 10% of the hot population, they comprise at least 30% of cold classicals. Many of these cold binaries are a type that's rare elsewhere in the solar system, with two components of nearly the same diameter that are widely separated, making them only barely gravitationally bound to each other. Any push from Neptune, or any significant collision, would have separated these wide binaries long ago.

Between their circular orbits, small sizes, and high binary fraction, it looked like the cold classicals were a truly primordial population, never disturbed since they condensed from the protoplanetary disk. But how did they form way out there?

Just a few years ago, theorists finally cracked the problem by incorporating another mechanism. The solution, called *streaming instability*, follows the interactions of primordial pebbles of dust and ice with the surrounding gases in the protoplanetary disk.

The protoplanetary nebula contained both gas and dust, all of it orbiting the center. As the nebula collapsed, shrinking into a rotating disk, the gas pressure increased. That pressure acted as an outward force, preventing the gaseous part of the nebula from collapsing inward as rapidly as the particles did. The gas, held up by its pressure, also didn't rotate as quickly as the particles.

Flying through the lagging gas, orbiting particles encountered a headwind and slowed down. But those particles also generated wakes in the gas as they moved. In these regions of lower gas pressure, particles in the wake felt less of a headwind and traveled faster. Those particles therefore caught up to the ones in front, creating pileups like accordion traffic on a freeway. As more particles arrived at the traffic jam, self-gravity took over, and the pileup collapsed into planetesimals. (Thank goodness gravity is too weak a force to make this happen on actual freeways.)

One important detail arose in the simulations: Collapsing clumps start out elongated rather than spherical. A stretched-out clump carries much more angular momentum than a spherical clump of the same size does. As elongated clumps collapse, they spin up so fast that they fission into two mutually orbiting, equal-mass clumps, eventually becoming widely separated, near-equal-mass binaries.

Just like the cold classical Kuiper Belt binaries.

Streaming instabilities also produce objects of a characteristic size of around 100 km. This prediction appears to agree with the uniformly small size of cold classicals. Closer to the Sun, many such bodies continued aggregating into dwarf planets, but the classical belt didn't have enough mass for that to happen.

Once theorists incorporated streaming instability theory into their models, everything came together. Theorists now think that every planetesimal formed as a binary pair. In the entire solar system, the cold classicals alone have been undisturbed since before the planets finished forming. Uniquely, they remain as they were born.

CHARON This enhanced-color view of Pluto's largest moon highlights surface variations, making the reddish north polar region stand out. Similar carbon compounds might explain the cold classicals' reddish look.

NASA / JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY / SOUTHWEST RESEARCH INSTITUTE

Fresh Frozen

Observations of TNOs' compositions support the picture that the cold classicals are distinct from everything else beyond Neptune. A body's composition can tell you if the world formed in the outer solar system and has stayed there, unheated by sunlight, or if it has moved around and experienced different temperatures.

Until recently, scientists could only detect specific compounds on the very largest TNOs. For smaller TNOs, they were limited to measuring color — specifically, the difference in an object's apparent brightness between two or more broadband filters.

The mid-size TNOs are not very colorful; we need only two colors to paint their pictures: one "gray" (of fairly uniform brightness across wavelengths) and the other "red" (notably brighter at long wavelengths). Astronomers spent many years trying to find correlations between the shapes of TNO orbits and their colors, with limited success. Only the cold classical objects are clearly distinct: They are all the reddest of red, with no hint of gray.

Work with the James Webb Space Telescope (JWST) suggests that this redness is due to widespread carbon dioxide. The largest TNO survey among JWST's first greenlit science programs was "Discovering the Composition of the Trans-Neptunian Objects, Icy Embryos for Planet Formation" (DISCO-TNOs), led by Noemí Pinilla-Alonso (University of Central Florida). The DISCO-TNOs program examined 59 TNOs and Centaurs, selected to represent the full range of diversity in orbital class, size, albedo, and color.

The first results, published in May 2024, focused on detecting two ices: carbon monoxide (CO) and carbon dioxide (CO_2). CO is quite volatile, with a freezing point of 68K (–205°C). It's unstable closer to the Sun than Neptune. On the other hand, CO_2 freezes at a relatively balmy 195K, and

◀ **ARROKOTH** This composite, enhanced-color image from the New Horizons spacecraft shows the cold classical 2014 MU_{69}, now named Arrokoth. It appears to be made of many smaller lumps.

its ice ought to be ubiquitous across the outer solar system. Yet it hadn't been detected on any TNO except Pluto before JWST.

The JWST spectra showed CO_2 on nearly all DISCO-TNO targets and CO on only about half of them — usually only those with a lot of CO_2. Objects from the hot population had a variety of compositions, some with ample CO_2, others with very little. But all five cold classicals studied by DISCO-TNO had abundant CO_2.

Abundant CO_2 explains why so many TNOs are red. Solar radiation and high-energy particles striking CO_2 ice can generate new molecules, including CO and heavier organic compounds that redden bright icy surfaces, like on the red north pole of Pluto's largest moon, Charon. The closer an icy world travels to the Sun, the more CO_2 and other light icy molecules it loses, leaving behind a carbon-black surface of organics and silicate dust — creating the darker, grayer colors of the hot population. The brighter cold classicals, conversely, have only been lightly toasted by the distant Sun.

Ancient Arrokoth

On New Year's Day 2019, New Horizons flew by the TNO called 486958 Arrokoth. The team, led by Alan Stern (Southwest Research Institute), had set a course for an unremarkable cold classical, in the hopes that it would bring the distant belt into focus.

The spacecraft's pictures revealed a contact binary, a double-lobed object that looked like two fat pancakes stuck together on a griddle. The pictures also made clear that Arrokoth was the most primitive body ever visited.

On close examination, the weird little world appeared to be built of a dozen or so distinct mounds of material. Simulations demonstrated that those mounds could be individual, 5-km-wide planetesimals that had grown from clumps of material formed by streaming instabilities. To retain their distinct moundy shapes, they must have come together in the gentlest of collisions, with speeds under 1 meter per second (2 mph).

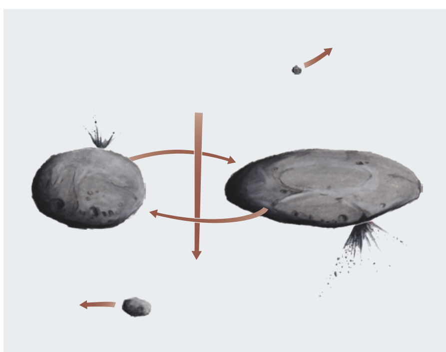
The Arrokoth flyby has delighted, and challenged, theorists. They don't know yet if simulations of streaming instabilities can make 5-km mounds, because they haven't progressed to such fine detail yet. The reason they haven't progressed to such detail yet is because we don't know which sizes the smallest cold classicals usually have.

Extensive survey work, done by Michele Bannister (now at University of Canterbury, New Zealand) and the Outer Solar System Origins Survey (OSSOS) team, among others, has efficiently detected objects in the cold classical belt down to about 100 km across. But the numbers of objects smaller than that are still a mystery. We don't even know if they're there.

Among asteroids and Centaurs, bodies smaller than 100 km tend to be smashed to bits by collisions. This process eventually erodes small objects into dust, leaving a dearth of the smallest bodies in the population. The New Horizons team estimated the abundance of very small TNOs — those with sizes in the 1- and 10-kilometer range — from the number of craters on Arrokoth and Pluto's largest moon, Charon. Based on how few craters they found, the researchers concluded there aren't many small objects flying around out there.

But do the low numbers mean that the primordial population of the smallest bodies has been ground away due to collisions? Or did the rapid growth of planetesimals due to streaming instability make all of the cold classicals a similar, characteristic size? We don't know — yet. Each of these scenarios should create a different distribution in the number of objects of a given size below 100 km. What we need is to determine which pattern the TNOs follow.

In the streaming instability model, a rotating, stretched-out cloud of small, icy bodies starts to coalesce in the outer solar system.

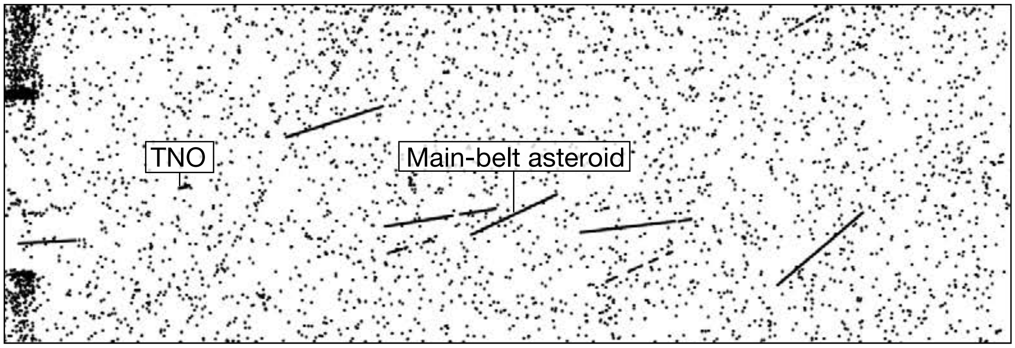


As the elongated clump collapses, it spins up and fissions into two larger bodies, which orbit their shared center of mass. (Downward arrow is the binary's spin axis.)

In cases like Arrokoth's, the two bodies slowly spiral closer until they touch, forming a bilobed object.

ARROKOTH: NASA / JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY / SOUTHWEST RESEARCH INSTITUTE / ROMAN TKACHENKO; STREAMING INSTABILITY: JAMES TUTTLE KEANE / NEW HORIZONS / NASA / JHU APL / SWRI

▶ **DEEP FIELD** Approximately 100 transient sources appear in this four-hour composite from the DEEP survey. Many are things like cosmic rays or satellites, but moving asteroids and TNOs appear as linear streaks. The image is centered at approximately RA 23h 22.3m, declination −5.5°, and spans about 0.3°. (The high number of detections on the left edge is an artifact of the observing strategy.)



Going DEEP

The DECam Ecliptic Exploration Project (DEEP) seeks to find out. DEEP's goal is to discover a large number of faint, low-inclination TNOs, in order to determine whether their sizes are controlled by active collisions or represent their birth sizes.

The DEEP team, led by David Trilling (Northern Arizona University), wants to push down to objects only 20 kilometers across, which means detecting objects as faint as 27th magnitude. That, in turn, requires a total exposure time of nearly four hours with their instrument, the wide-field Dark Energy Camera (DECam) on the four-meter Blanco telescope at Cerro Tololo Inter-American Observatory in Chile.

It's no problem for a telescope to track a faint star for four hours, or a moving target with a well-known orbit. But to *discover* such faint moving objects in four-hour exposures is normally impossible, because the accumulated light would be spread out across so many pixels that it would never be brighter than the noise.

To surmount this problem, DEEP astronomers took sets of about 100 two-minute exposures across a four-hour period. Then they use a "shift-and-stack" method, or digital tracking, in which they assume a trajectory for a faint TNO and then align images along that trajectory, co-add them, and search the resulting image for an object. Since the survey doesn't know which direction a TNO might be moving, scientists have to test a wide range of potential trajectories. As you might imagine, it's computationally intensive.

DEEP gathered data from 2019 to 2023, with significant interruptions due to the pandemic. The team published the first results in March 2024. Analysis is ongoing, but a fortuitous syzygy enabled early results on the cold classical population: Neptune was close to the survey field in 2019. Because objects in resonant orbits avoid Neptune, nearly all the TNOs found that year won't be resonants, and nearly all nonresonant TNOs are classicals. Furthermore, DEEP keeps its focus near the ecliptic. Searching along the ecliptic means the discoveries are most likely on low-inclination orbits, which would mean the objects belong to the cold classical belt.

Like the OSSOS results, DEEP's first look at the small-size end of the cold classical belt is consistent with the streaming instability theory. But there are other mechanisms that could still fit the observed size distribution.

DEEP's long exposures also permit something that no previous survey has been able to do: gather light curves on large numbers of TNOs. For space potatoes, light-curve variation is mostly a function of shape, because elongated bodies vary more in brightness as they rotate than spherical ones.

DEEP's early light-curve results suggest that the tiny worlds they're imaging are on average twice as wide as they are tall. Such extreme elongation on such tiny bodies isn't gravitationally stable; their spin would literally tear them apart. So it's quite likely that a large proportion of DEEP's detections are actually contact binaries, like Arrokoth, which are stable at higher rotation speeds.

Open Questions

While the DEEP team crunches their data, other groups are gearing up for future, more sensitive surveys. For example, the Classical and Large — A Distant Solar System Survey (CLASSY) project, led by Rosemary Pike (Center for Astrophysics, Harvard & Smithsonian), is currently searching for faint objects beyond the classical belt. OSSOS discovered several objects beyond 47 au that move like cold classicals, hinting that there's more to the primordial disk than we've yet been able to see. In fact, a recent survey for faint targets — reaching magnitudes fainter than 26 — has discovered a few members of what might be another classical belt beyond 70 au.

The real game changer for discovering small and/or distant TNOs will be the Vera C. Rubin Observatory, an 8.4-meter telescope under construction in Chile (*S&T:* June 2024, p. 34). Beginning in 2025, Rubin's Legacy Survey of Space and Time (LSST) will image the entire visible sky every three nights for a decade. Astronomers predict that it will detect more than 40,000 trans-Neptunian objects. With characteristics of thousands of TNOs in hand, researchers will be able to untangle the ball of yarn that Neptune has tied into knots.

Astronomers still have so many questions to answer, and the trans-Neptunian region is still dark and distant. But this frozen domain never seemed so close and clear as it does now.

■ Contributing Editor **EMILY LAKDAWALLA** is a planetary geologist, science writer, and space artist. Find her work at **lakdawalla.com/emily**.

 by Ken Croswell

Long-Distance Partners

Two stars can maintain a long-term relationship over surprisingly large distances.

Double stars exemplify the stunning diversity of the heavens: A red giant pairs up with a white dwarf; a yellow main-sequence star circles a blue giant; an orange dwarf whirls around a ravenous black hole.

But binaries also exhibit another kind of diversity. At one extreme, two stars can be so intimate they touch, the pair resembling a glowing peanut. At the other extreme, the stars can be so far apart they take millions of years to swing around each other.

Extremely wide binaries involve some of the brightest stars in the sky and probe a diverse array of astronomical issues. After an extremely wide binary forms, the pair must navigate a galaxy that's trying to split the duo apart. Furthermore, because the only thing holding one star to the other is gravity, and because gravity is so weak over such a great distance, the stars' orbital motion tests the validity of Newton's law of gravity at that limit.

Binary Basics

There's no official definition of an extremely wide binary. For binaries whose brighter member resembles the Sun, the most common separation between the two stars is about 50 times the Sun-Earth distance, or 50 astronomical units. But the most extreme few percent of all stellar pairs have members that lie some 10,000 au apart or more. This enormous distance is nearly one-sixth of a light-year and about 250 times

▲ **ALPHA CENTAURI** The nearby binary Alpha Centauri AB and its tag-along companion, Proxima Centauri, lie so far apart that their separation is clearly visible on the sky. The overlaid ellipse shows Proxima's most likely orbit, and the dot its location (the star is invisible in the image).

SKY IMAGE: E. SLAWIK / NOIRLAB / NSF / AURA / M. ZAMANI; ORBIT: PIERRE KERVELLA greater than the vast expanse from the Sun to frigid and far-off Pluto.

For a brilliant example, gaze at Capella in the constellation Auriga, the Charioteer. What you see with the naked eye is a pair of yellow *G* giants. At least 9,300 au away from the giants is a 10th-magnitude red dwarf binary that slowly revolves around them.

The study of extremely wide binaries received an enormous boost after the European Space Agency launched the Gaia spacecraft, which measured precise stellar distances and motions. If two stars truly constitute a binary, then their distances from us should be nearly identical, as should their velocities through space.

"It's been really transformative," says Kareem El-Badry (Caltech), "because before Gaia, if you saw two stars that were close to each other on the sky and might be a wide binary, it was very hard to tell whether they were actually physically bound or just two stars that are passing past each other at totally different distances."

Thanks to Gaia, we now know that most stars in extremely wide binaries have highly elliptical orbits around each other. As a result, the minimum distance between the two stars, known as *periastron*, is much smaller than their greatest distance, called *apastron*. Astronomers define the *mean separation* of the two stars as the average of the periastron and apastron distances.

The stars spend most of their lives farther apart than their mean separation, though, because they speed around each other fastest when closest together and most slowly when farthest apart. They therefore race through periastron and linger at apastron. In like fashion, Halley's Comet spends a lot more time near Neptune's orbit than Venus's. So two stars with a mean separation of 10,000 au can have nearly twice that separation for hundreds of thousands of years.

The greater the mean separation between the two stars and the less massive they are, the greater their orbital period, according to Kepler's third law. Thus, while no human being lives long enough to track a complete orbit for the widest binaries, it's straightforward to estimate their orbital period (see box at right).

To explore a star with a far-off partner, we don't need to travel far at all. The nearest example is right next door.

Alpha Centauri: Our Extreme Neighbor

Because of its proximity, we know Alpha Centauri's properties better than those of any other extremely wide binary. The system is triple, with two bright stars and a faint one currently located 12,000 au from them (*S&T:* Apr. 2019, p. 34). The bright stars are a yellow *G* and an orange *K* sun that orbit each other every 80 years. Their amber light blends together, making them the third-brightest nighttime star, after Sirius and Canopus.

Then there is little Proxima Centauri, a dim red dwarf also known as Alpha Centauri C. It is 4.25 light-years from Earth. That's slightly closer than the bright stars Alpha Centauri A and B, which are 4.34 light-years from Earth. All three stars are some 6 billion years old, which means they have plied the Milky Way together for longer than the Sun has shone.

Over the past decade, Pierre Kervella (Paris Observatory) and his colleagues have removed any doubt that Proxima Centauri orbits its bright partners by measuring the three stars' precise velocities through space. Because Proxima is so far from its mates, its escape velocity from them is a mere 550 meters per second (1,240 mph) — 1/20 of the escape velocity from Earth's surface. As a result, when evaluating the red- and blueshifts in the stars' light due to the stars' motions, Kervella's team had to worry about subtle effects astronomers usually ignore. For example, light climbing away from a star's surface suffers a slight redshift due to the star's gravitational pull. Proxima's estimated gravitational redshift is 500 m/s — nearly as great as its escape velocity from Alpha Centauri A and B.

Also, stellar convection induces a slight blueshift. Hot gas rises, gives off its heat at the star's surface, then sinks back down again. Because the rising gas moves toward us, the light it emits is blueshifted; because the sinking gas moves away from us, its light is redshifted. The two don't cancel out, though, because the hot, blueshifted gas outshines the cool.

In 2021, after taking all of these factors into account, the astronomers reported their latest results: Proxima Centauri's velocity through space differs from that of Alpha Centauri A and B by just 280 m/s, which is less than the system's escape velocity. Thus, Proxima Centauri is indeed gravitationally bound to Alpha Centauri A and B. Proxima Centauri revolves around them every 510,000 years, with a mean distance from the pair of 8,200 au.

Kepler's Third Law

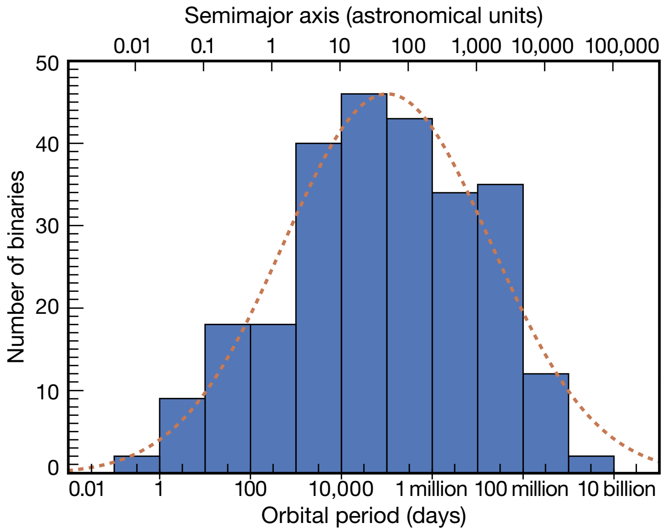
Kepler's third law relates a binary's mass, period, and mean separation. The equation is simple:

$$MP^2 = a^3,$$

where M is the total mass of all the stars in the system in solar masses, P is the orbital period in Earth years, and a is the mean separation in astronomical units. If you know two of these quantities, you can therefore calculate the third.

An extremely wide binary has such a long orbital period that you can't possibly observe it. But thanks to Kepler's third law, you can calculate this number from the masses of the two stars — estimated from their spectral types — and from their mean separation.

Ah, but what is the mean separation of stars that take thousands of human lifetimes to go from periastron to apastron? Fortunately, astronomers have calculated that this quantity is typically about equal to the *projected* separation — that is, the distance between the two stars if both are exactly the same distance from Earth.



▲ **BINARY PERIODS** This plot shows the distribution of orbital periods and separations for the companions of more than 250 Sun-like stars. The most common period is about 100,000 days, or 270 years, with an average separation of roughly 50 au. But a few percent of systems have companions that take at least hundreds of thousands of years to complete an orbit and lie many thousands of au apart.

Questions of Origin

But how does such an extremely wide system form? Stars are born with other stars in groups and clusters, and the cores of newborn star clusters are typically no more than 10,000 au across — smaller than the widest binaries. How do you bake a loaf of bread that's larger than the oven?

The answer lies in the clusters' evolution. The clouds of gas and dust in which clusters originate have their own gravity, which helps bind the newborn stars to one another. But as stellar winds and supernova explosions expel the gas and dust, most clusters break up. When this happens, two departing stars, though separated by an immense distance, may by chance be going the same way and link up via their gravitational attraction to each other, thereby creating an extremely wide binary. This process occurs most readily in sparse star-forming regions, such as the clouds of Taurus and Auriga, where other stars won't interfere. By contrast, in a dense region, such as the Orion Nebula Cluster, the gravitational tugs of other stars would quickly split a wide pair apart.

Another possibility is that some extremely wide binaries start out as compact triple stars. Two of the stars gang up on the third — usually but not always the lightest — and kick it away. In most cases, the ejected star escapes altogether, but in some cases, it remains loosely bound at a large distance. That sounds a lot like the Alpha Centauri system.

But this idea may not actually apply there. If Proxima Centauri was born close to Alpha Centauri A and B, the small star should be on an extremely elliptical orbit, one that carries the little red star from close to far, with an eccentricity exceeding 0.9. (Learn more about eccentricity on page 24.) But Kervella finds that Proxima Centauri's orbital eccentricity is only 0.5. This result suggests that Proxima Centauri was not born right next to its bright mates but instead latched onto them as the star cluster that spawned them all was disintegrating.

Far-off Friends for Fomalhaut

Six times farther from Earth than Alpha Centauri lies what is often called the loneliest star: white *A*-type Fomalhaut, a fixture of the southern sky in the constellation Piscis Austrinus, the Southern Fish. No other bright star shines near Fomalhaut.

But Fomalhaut does have company — of the long-distance sort. In 1938, American astronomer Willem Luyten discovered that an orange dwarf shares its motion through space. This star, Fomalhaut B, is 57,000 au from the main star, almost one full light-year away.

But that's nothing compared with a recent discovery. In 2010 Eric Mamajek (now Jet Propulsion Laboratory) found that a fainter star, a red dwarf on the other side of Fomalhaut A, also shares the bright star's motion. The red dwarf, named LP 876–10, is located a whopping 158,000 au away — 2.5 light-years, more than half the distance between the Sun and Alpha Centauri. It lies 5.7° from Fomalhaut A in our sky and even shines in a different constellation: Whereas Fomalhaut A is the beacon of Piscis Austrinus, Fomalhaut C (as Mamajek calls it) lies just over the border in dim Aquarius, the Water Bearer. All three Fomalhaut stars are almost exactly the same distance from Earth, 25 light-years.

If the red dwarf is orbiting Fomalhaut A, then one full revolution takes some 20 million years. Mamajek thinks a true pairing is likely because, if the two stars are not gravitationally bound, then even a slight difference in speed would have carried them far away from each other during the 440 million years they've been shining.

Nor is it likely that Fomalhaut C is just now escaping from the bright star. "It would be like meeting somebody for the first time, and you're meeting them on the day of their divorce," he says.

But not everyone accepts this conclusion. "It's not a binary," says Andrei Tokovinin (Cerro Tololo Inter-American Observatory, Chile). "This is a young star. It's normal that it is accompanied by some smaller brothers that were born together." He thinks the three stars constitute what's known as a *moving group*. Like the five central stars of the Big Dipper, they move through space together — but only because they were born together, not because they are gravitationally bound to one another.

Kervella, for his part, says the velocities of the Fomalhaut stars are too uncertain to make a definite statement one way or the other.

Surviving the Milky Way

An extremely wide binary faces several challenges as it sails through the galaxy. "The main threats are passing stars and passing giant molecular clouds — that is, dense concentrations of gas in the interstellar medium," says Scott Tremaine (Institute for Advanced Study). "Either of those can create

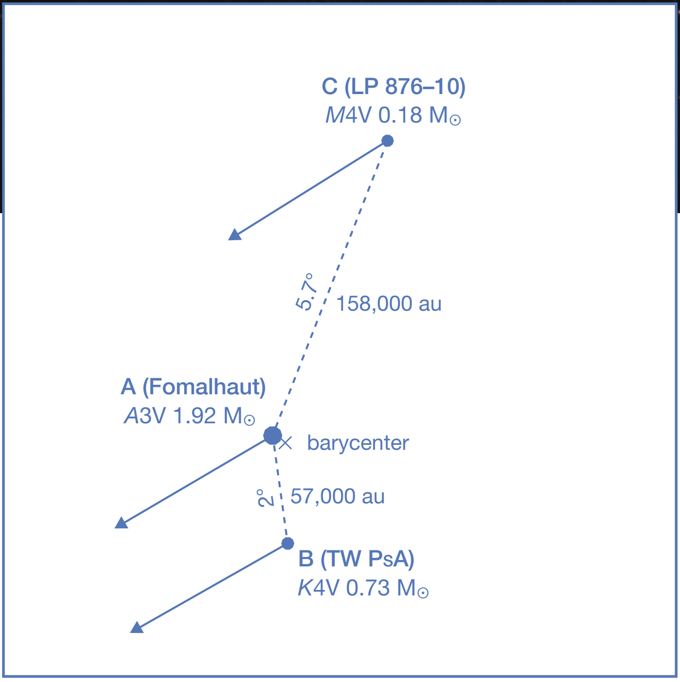
D. RAGHAVAN ET AL. / *ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES* 2010

▲ **NOT SO LONELY** The only bright star in its region of the sky, Fomalhaut is accompanied by two fellow travelers, which both lie at significant distances from the primary. The image spans roughly 30°. Star C is invisible here; the line points to its location.

gravitational pulls on the wide binaries that are sufficient to change the orbit from bound to unbound and thereby disrupt the binary."

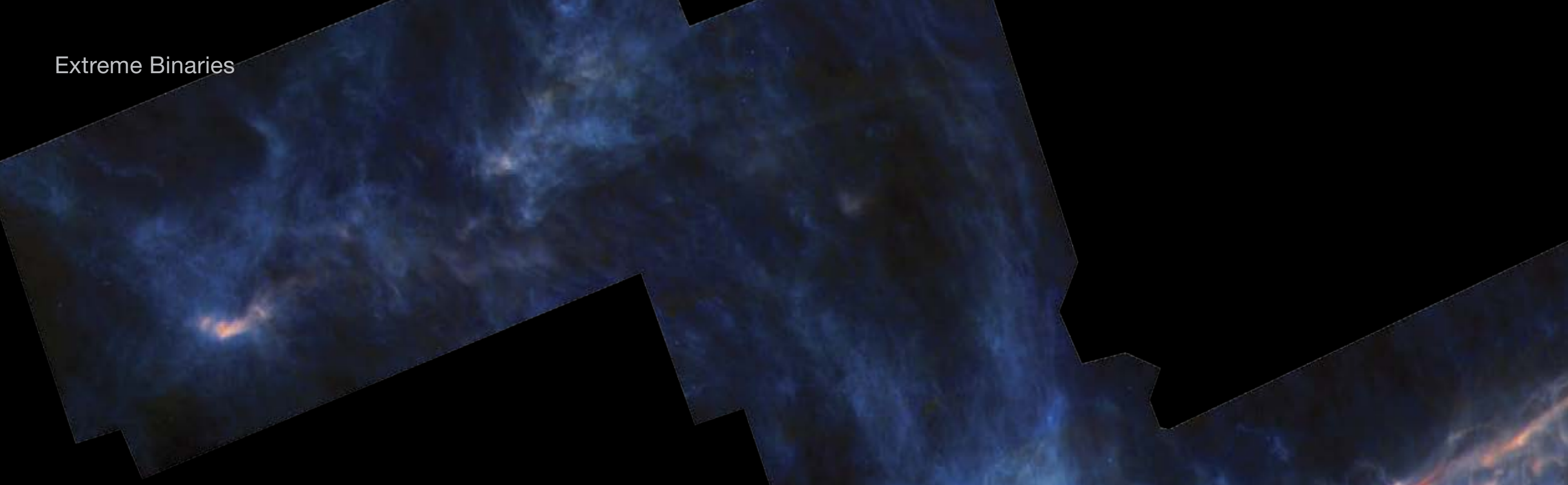
A passing star can gravitationally entice one member of an extremely wide binary away, since the two stars in the binary are so weakly bound to each other. Furthermore, the wider the binary, the greater the chance another star will slip between the two, rupturing their marriage.

Molecular clouds, meanwhile, can possess millions of solar masses of gas and dust, which exert their own gravitational pull. "The most dangerous encounters would be the ones where the binary passes through the molecular cloud," Tremaine says. Because the cloud is clumpy, its gravity can pull more on one star than the other, splitting the pair apart.



▲ **IN A PACK?** The proper motions (arrows) of the stars LP 876–10 and Fomalhaut A and B suggest that the three form a gravitationally bound system. The barycenter is the trio's estimated gravitational center. The angular distances are on the plane of the sky, but the separation distances are in three dimensions.

FOMALHAUT: AKIRA FUJII; FOMALHAUT TRIO'S MOVEMENT: BEATRIZ INGLESSIS / *S&T*, SOURCE: E. E. MAMAJEK ET AL. / *ASTRONOMICAL JOURNAL* 2013



An extremely wide binary also feels the galaxy's tide. Just as the Moon's gravity tugs harder on seas facing moonward than on those facing the other way, so the galaxy's gravity yanks more on whichever star in a binary is closer to the galactic plane, luring the star away from its distant mate.

Even a star's evolution can dissolve a long-distance stellar marriage. When a red giant sheds its atmosphere and becomes a white dwarf, the loss of mass can unbind an extremely wide binary. For this reason, extreme binaries rarely have white dwarf stars — as El-Badry and Hans-Walter Rix (Max Planck Institute for Astronomy) discovered after analyzing Gaia data.

Remarkably, despite all the dangers, extreme binaries can endure for more than 10 billion years. We know this because they exist in the Milky Way's halo, the population of ancient stars around the galactic disk (*S&T:* Aug. 2023, p. 34). For example, two 9th-magnitude orange *K* stars in Libra go around the galaxy backward, opposite the way our galaxy spins — a testament to their halo bona fides. The stars are 96 light-years from Earth, with the brighter, HD 134439, located 5 arcminutes north of the fainter, HD 134440. If both stars are equally distant from Earth, they are 8,800 au apart — and even farther apart if their distances from us differ.

Given the hazards posed by passing stars and the galactic tide, Yan-Fei Jiang (Flatiron Institute) and Tremaine have calculated how far out a star can hold on to its partners. The answer: surprisingly far. For a system with 3 solar masses — the approximate total of Fomalhaut A, B, and C — that distance is 6 light-years. All three Fomalhaut stars are safely within that limit.

For that matter, the Sun and Alpha Centauri also add up to about 3 solar masses, and we are less than 6 light-years from our neighbor. So if the Sun's velocity through space changed to match Alpha Centauri's, we would all become bound together, thanks to the gravitational attraction of the member stars on one another. In that case, our solar system would revolve around Alpha Centauri every 80 million years.

▲ **TAURUS MOLECULAR CLOUD** Stars form in clumpy filaments, as revealed in this infrared mosaic from the Herschel Space Observatory. The bright, reddish regions are the densest environments, with the most intense star formation.

ESA / HERSCHEL / NASA / JPL-CALTECH, ACKNOWLEDGEMENT: R. HURT (JPL-CALTECH) / CC BY-SA 3.0 IGO

Weighing the Law of Gravity

Extremely wide binaries could even threaten a cornerstone of physics: Newton's law of gravity. Thanks to Einstein, we already know that Newton's venerable law is incorrect when gravity is extremely strong. What if it's also wrong when gravity is extremely weak?

This question is more than idle speculation. Astronomers deduced decades ago that the Milky Way abounds with dark matter because of how fast our galaxy's stars revolve around the galactic center. In the solar system, planets move around the Sun more slowly the farther out they are: Pluto is 10 times slower than Mercury because it's 100 times farther out. Why? Nearly all the solar system's mass is in the central object, the Sun. By contrast, in a spiral galaxy, stars at the galaxy's visible edge move nearly as fast around the galactic center as those closer in. That means the galaxy possesses a huge halo of dark matter that exerts gravitational force — if Newton is right.

But what if he's wrong? It could be that at the edge of a galaxy, gravity is weak enough that Newtonian gravity breaks down — obviating the need for any dark matter at all.

The gravity between two widely separated stars is also weak. If Newton is wrong, the stars might revolve faster than Kepler's laws predict. By using Gaia data on extremely wide binaries, some astronomers have actually claimed to see this deviation, while others dispute it.

"I'm not that concerned for Newton," El-Badry says. "Newton has done pretty well for himself in the last 360 years, so the evidence needs to be pretty strong before you start to get worried."

Alpha Centauri could hold the key, Kervella says. Because we can measure its properties precisely, we might be able to see whether Proxima Centauri's velocity is changing in both magnitude and direction. If the star's acceleration differs from the Newtonian prediction, the little red star will spell big trouble for both Newton and the existence of dark matter.

Extremely wide binaries therefore do more than just demonstrate how gravity can tether two stars together over immense distances. These remarkable star systems could also lead to new discoveries about one of the fundamental forces of physics, a force that holds us to Earth, Earth to the Sun, and the entire solar system to the Milky Way Galaxy.

■ Contributing Editor KEN CROSWELL earned his PhD for studying the Milky Way. He is the author of *The Alchemy of the Heavens*, *Planet Quest*, and *Magnificent Universe*.

Kosovo's New Observatory

A young country inaugurates its first astronomical facility.

In the spring of 2024, I received an email from a graduate student enrolled at the University of California, Santa Cruz (UCSC). She invited me to the inauguration of her country's first observatory and planetarium, with a ceremony set for June 20th. I just knew that I had to go — so I cleared my calendar for that week and started making plans to travel to Europe.

That's how I found myself on a scorching June day standing on the edge of a cornfield in Kosovo, not far from the capital of Prishtina. Pranvera Hyseni, the student, was giving an impassioned speech on a dais to an eager crowd that had gathered. People were furiously fanning themselves in an attempt to keep cool, and the sound of balloons spontaneously popping in the stifling heat punctuated Pranvera's words. But all remained enthralled. We were witnessing history.

A Cornfield Outside the Capital

In the early 2010s, Pranvera Hyseni was enrolled as an undergraduate student at the University of Prishtina. Her wish had to been to study astronomy, but she enrolled in geography, because the university didn't offer astronomy as an option. But that didn't stop her from exercising her passion and engaging in astronomical activities. In fact, in 2015 she rallied some of her like-minded buddies and founded the nonprofit Astronomy Outreach of Kosovo, or AOK. Their mission was to bring the joy and science of astronomy to a wider audience, primarily through programs such as star parties and public lectures.

▲▼ **AN OBSERVATORY RISES OUT OF THE CORNFIELD** Astronomy Outreach of Kosovo built its facility just outside Kosovo's capital city of Prishtina. To date, more than 7,000 visitors have come to marvel at day- and nighttime sights.

Pranvera's and her fellow astrophiles' ambitions didn't stop there. They envisioned building their country's first-ever comprehensive astronomical facility, including a fully functioning observatory and a planetarium. To see their dream come true, they needed to raise funds. So, various AOK members got busy and began lobbying elected officials, visiting the Kosovo parliament on numerous occasions. Pranvera was already studying in the U.S. by this time, and those early years saw her traveling back and forth over the ocean as she and her colleagues set about persuading the government to recognize the importance of such a facility. Perseverance paid off, and the Kosovo government promised the AOK financial backing to begin construction of the country's first observatory.

But by then, it was election time. The people voted in new officials with their own plans and ideas for allocating resources, and the AOK found itself having to make its case for funding all over again. Ultimately, AOK members succeeded (again) in convincing the newly instated members of parliament that their mission was worthy, and funding was — again — granted.

Now, where to build such a facility? One of AOK's founders, physics teacher Milaim Rushiti, donated a plot of his family's farmland, which was some 32 kilometers (20 miles) southwest of Prishtina near a town called Shtime. Groundbreaking could commence!

Countdown to Opening

Building an observatory and planetarium from scratch is no mean feat — especially when one is half a world away, as Pranvera was, by then immersed in her postgraduate studies on planetary sciences at UCSC. But between them, Pranvera and her AOK colleagues started planning with architects and engineers. The blueprints for the observatory and planetarium domes started taking shape — electric cables had to be ordered, plumbing sorted, light fixtures decided on.

Finally, there was the crucial question of equipment. An astronomical observatory is not much use without telescopes. Nor is a planetarium without a projector.

At around the time of AOK's founding, Pranvera worked to build up a formidable social media presence. The international astronomical community — both amateur and professional — took note. Among the first to react to AOK's online traction was Stephen Ramsden of the nonprofit Charlie Bates Solar Astronomy Project. During the early days of AOK's efforts, Ramsden donated several of his own telescopes to the organization. For the inauguration, he endowed the observatory with a solar telescope — in fact, it's the largest of its kind in Eastern Europe.

◀ **IT'S SPEECH TIME** Pranvera Hyseni shares her passion and drive with the crowd, following several town and government officials who outlined the expected impact the observatory and planetarium would have on the country. Representatives from the equipment donors also gave emotional speeches.

Others swiftly followed, and equipment started rolling in. In the lead-up to the opening, telescope manufacturer Celestron supplied the 14-inch telescope that is currently mounted in the 6-meter observatory dome, as well as another telescope that can be taken out onto the roof when larger crowds visit. A few days before the inauguration, Celestron sent members of its team to install the telescope and step it through first-light procedures. Long-time planetarium guru Jack Dunn donated the equipment for shows within the 9-meter dome. In one way or another, in big ways and small, Pranvera and AOK inspired people all over to pitch in and ensure that Kosovo's first observatory and planetarium would be a resounding success.

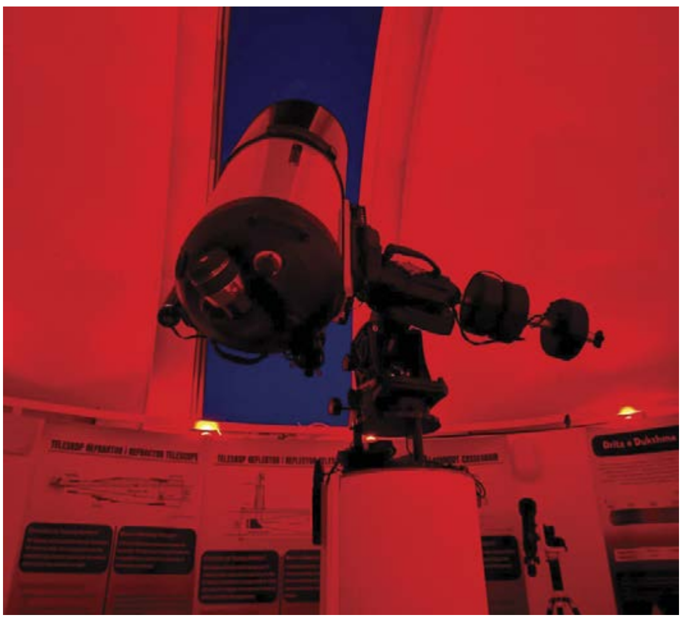
The Big Day Dawns

On the morning of the inauguration, I and several other visitors found AOK members as well as their friends and family in a flurry of preparations for the official guests due to arrive later that afternoon. Hammers were wielded, exhibits laid out, microphones checked.

At some point during the morning hours, we learned that the Speaker of the Assembly of Kosovo, Glauk Konjufca, wanted to meet those of us who had traveled from abroad. So, we piled into various cars and drove in the direction of

▼ **AND WE'RE OFFICIALLY OPEN!** Finally with the ribbon-cutting the observatory is fully inaugurated and celebrations can commence.

BUILDING: DIANA HANNIKAINEN; BUILDING SIGN, SPEECH, RIBBON-CUTTING: EURON ILIAZI (3)



Prishtina. After passing through metal detectors, we entered Kosovo's parliament building, greeted by a gigantic painting of Mother Theresa that adorned the facing wall. We were ushered into a magnificently formal room, where we were offered tea and coffee. The Speaker joined us, and we spent a good hour discussing all things astronomical. Konjufca was genuinely interested in astronomy and in AOK's activities, and asked all the pertinent questions as to what he and his colleagues could do to make the facility a success in its mission to bring science to the people.

By the time we got back to the observatory, a dais and chairs were in place, as were balloons that floated festively above the main entrance. Excited guests started taking their seats, the frisson of anticipation palpable despite the stifling air. Kosovo, like much of Europe, was experiencing a heat wave that week, and attendees sought out the shade of the dais or under scrawny trees.

It was finally time to begin the festivities.

The inauguration ceremony opened with the playing of three national anthems: Albania's, Kosovo's, and that of the United States of America. The mayor of Shtime, Qemalj Aliu, and the Minister for Education, Science and Technology, Arbërie Nagavci, gave speeches outlining the importance of the facility. Then several of the overseas guests gave emotional talks, reminiscing about how they first met Pranvera and how they'd followed AOK's journey to this historical moment. Finally, Pranvera herself took the stage and passionately shared her story with the riveted crowd. At the conclusion of the speeches, we all traipsed over to the main entrance (where the festive balloons were popping randomly), and Pranvera, flanked on both sides by the guests of honor, ceremoniously cut the ribbon.

With that, the country's first observatory and planetarium was officially opened!

A Successful First Year

Despite some niggling challenges, the facility nevertheless launched into full-scale operations shortly after that memorable day. The small staff of volunteers is kept busy conducting both nighttime and daytime activities.

Public stargazing is planned for three nights of every week. The second Celestron is lugged out onto the roof more often than not, as people line up to catch glimpses of the planets and deep-sky objects. Among the stargazers are both non-

◀ **GENEROUS DONORS** *Top:* Several telescope manufacturers shipped telescopes and other equipment ahead of opening day. Team Celestron sent Ben Hauck, Kevin Kawai, and Robert Reeves to install the 14-inch telescope on the mount in the 6-meter dome and step it through first-light procedures.

◀ **TRUE LOVE** *Middle:* Right after the Celestron team finished installing the telescope, emotion overcame Pranvera and she couldn't help herself but give the pier and all a big hug.

◀ **STARGAZING BEGINS** *Bottom:* The Celestron 14-inch telescope awaits eager stargazers on opening night.

EURON ILAZI (3)

Inspiring Future Generations

The facility runs both day- and nighttime observing sessions. The planetary line-ups earlier this year drew in large crowds. At right, schoolchildren ooh and aah at views of the Sun through the Charlie Bates Solar Astronomy Program telescope.

EURON ILAZI (3)

scientists and astronomy enthusiasts alike — major celestial events, such as the planetary line-ups earlier this year, are particularly popular.

On cloudless days, the public is treated to views of the Sun through the Charlie Bates Solar Astronomy Program telescope, as well as several Sky-Watcher USA scopes. The latter are outfitted with automatic tracking, making life somewhat easier for the volunteers as they juggle large crowds.

Besides the various observing programs, visitors can also explore the observatory's exhibits, some of which are interactive. Given Pranvera's PhD studies focusing on the solar system, it's perhaps unsurprising that the exhibits showcase various meteorite collections. The budding facility also features artifacts from space exploration and samples of astrophotography, besides other valuable educational resources. "Many visitors spend hours going through the displays, making the observatory a place for both hands-on learning and discovery," Pranvera says.

While nighttime stargazing is the biggest draw, schools focus on daytime visits. What better way to earn study credits than by enjoying inspiring views of the Sun and handling actual space rocks? The planetarium shows, covering topics such as asteroids, the solar system, and space exploration, are quite the hit with schoolchildren.

At the time of writing, more than 7,000 visitors have already visited Kosovo's first observatory, including from neighboring countries such as Albania and North Macedonia. The observatory has also piqued the curiosity of local officials: The country's prime minister, Albin Kurti, was among those who toured the facility recently, not only with his family but also with his whole cabinet! Kurti has apparently expressed strong support for the project, and that bodes well for its future.

▲ **SPACE ROCKS** The National Observatory and Planetarium of Kosovo already boasts a remarkable meteorite collection.

Pranvera notes that the country's first comprehensive astronomical facility has already had quite the impact: "The demand for visits continues to increase, highlighting the observatory's growing role as regional hub for science education and public engagement."

Casting my mind back to that hot, stifling day in the cornfields outside of Prishtina, witnessing with my own eyes the passion that drives the people who dreamt of their own observatory and the dedication of the AOK crew, I can only imagine that the National Observatory and Planetarium of Kosovo will continue to grow in relevance. Bravo, AOK. Brava, Pranvera. Keep looking up.

■ It would not be an understatement to say that the trip was a life-changer for Editor in Chief **DIANA HANNIKAINEN**.

The Missing

A brutal war in the 1990s ravaged Kosovo, during which more than 13,000 Kosovars, including military personnel and civilians, were killed. Many are still missing, a fact that is poignantly evident in the halls of its parliament. The corridor that connects the main entrance to the inner offices of parliament has walls and ceiling that are painted black. Quotes in stark white font adorn the walls, reflecting the words of those who witnessed the atrocities of the war in the 1990s, many of whom lost loved ones. Everyone who visits the building has to go through that hallway.

Hanging overhead are keys. Each key represents a Kosovar who is still missing. Keys that are joined together indicate members of the same family. Not one of us who visited Kosovo's parliament was left unmoved upon seeing this sight.

METEORITES: EURON ILAZI; HALLWAY: DIANA HANNIKAINEN

SKY AT A GLANCE
June 2025

1 DUSK: Turn to the west-southwest to see the waxing crescent Moon a bit more than 1° upper right of Leo's brightest star, Regulus. Mars gleams farther lower right of the pair — keep an eye on the Red Planet this month, as it approaches and then passes Regulus. Turn to page 46 to read more on this and other events listed here.

5 EVENING: In the south-southwest, the waxing gibbous Moon shines some 5° right of Spica. The gap between them shrinks as they sink toward the west-southwestern horizon.

9 EVENING: In the south-southeast, the Moon, a bit more than a day before full, is about 3½° upper right of the Scorpion's smoldering heart, Antares. The pair arcs above the southern horizon before setting at dawn in the southwest.

16,17 EVENING: On both dates, face west to see Mars a mere ¾° above or upper right of Regulus.

19 MORNING: Look low in the east to catch the waning crescent Moon and Saturn rising in tandem, with some 4° separating the duo.

20 THE LONGEST DAY OF THE YEAR in the Northern Hemisphere. Summer begins at the solstice, at 10:42 p.m. EDT (7:42 p.m. PDT).

21 DUSK: If you have an unobstructed view of the west-northwestern horizon you might glimpse Mercury less than 5° lower left of Pollux. You'll have to be quick to catch this sight before the pair sets.

22 MORNING: The waning crescent Moon and Venus rise above the east-northeastern horizon with around 6° between them.

26 DUSK: It would behoove you to seek a long and unobstructed northwestern horizon so as to behold the sight of the slender lunar crescent 3½° right of Mercury. Pollux and Castor complete a neat line to the right.

29 DUSK: After sunset, the waxing crescent Moon hangs less than ½° lower left of Mars. Some parts of the world will see the Moon eclipse Mars. Regulus completes the scene, shining about 7° lower right of the pair.
—DIANA HANNIKAINEN

▼ This photo was taken at five minutes past midnight at the summer solstice in 2019 on the shores of Lake Ruovesi in Central Finland (latitude 62° north). At those latitudes, June nights never get dark. MARKUS HOTAKAINEN

JUNE 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					

FIRST QUARTER

June 3
03:41 UT

FULL MOON

June 11
07:44 UT

LAST QUARTER

June 18
19:19 UT

NEW MOON

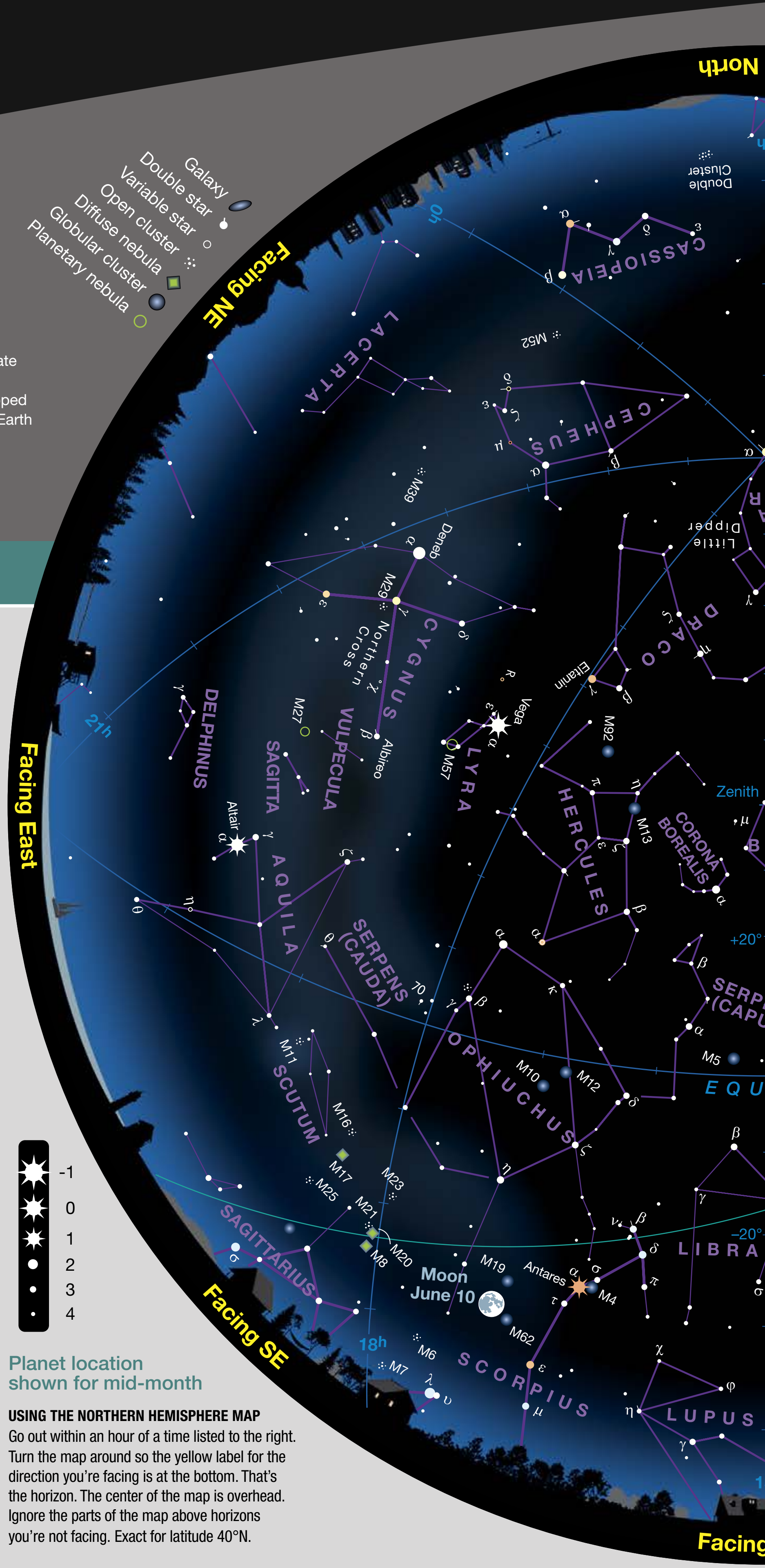
June 25
10:32 UT

DISTANCES

Apogee	June 7, 11^h UT
405,553 km	Diameter 29′ 28″
Perigee	June 23, 5^h UT
363,179 km	Diameter 32′ 54″

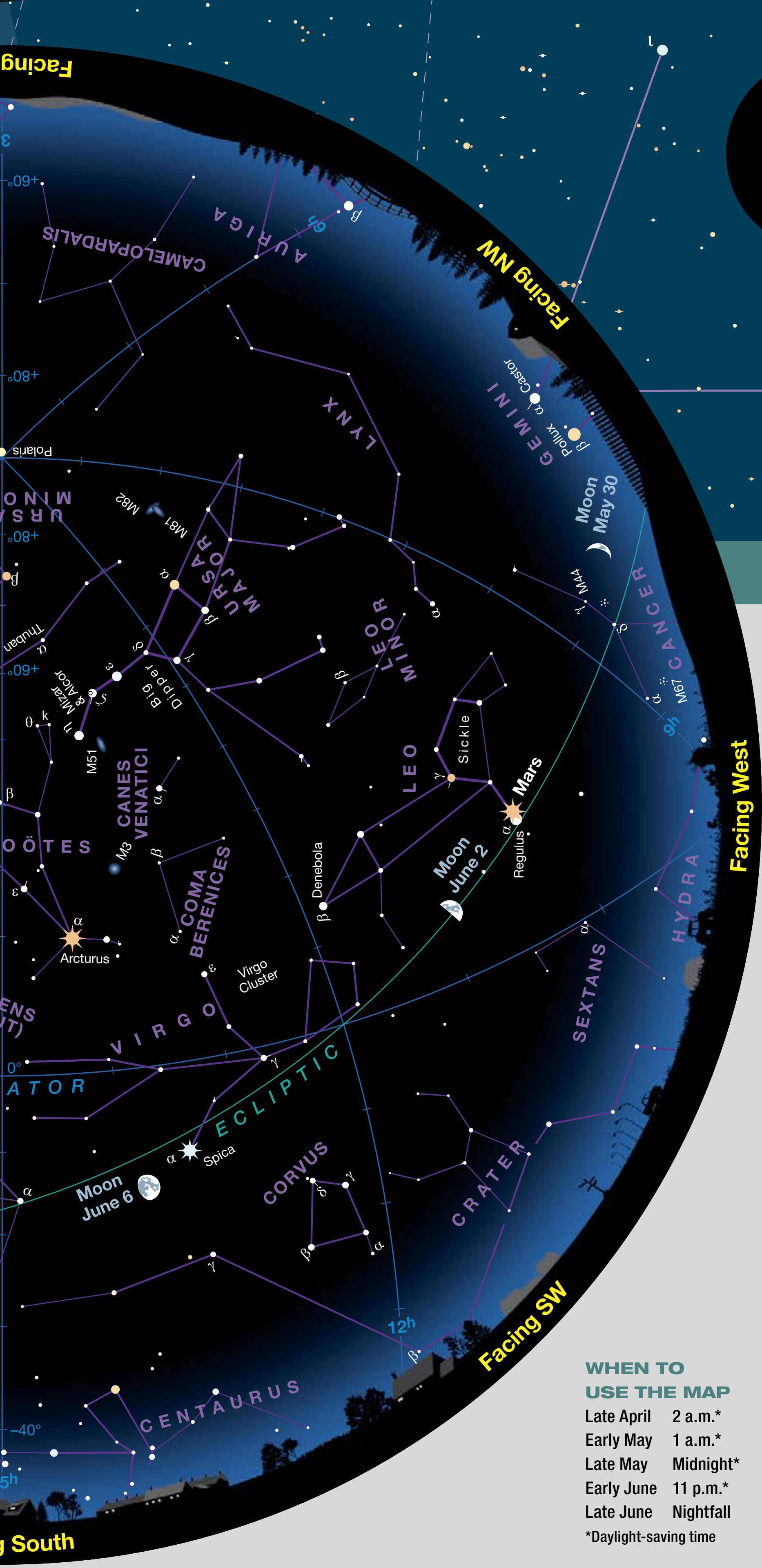
FAVORABLE LIBRATIONS

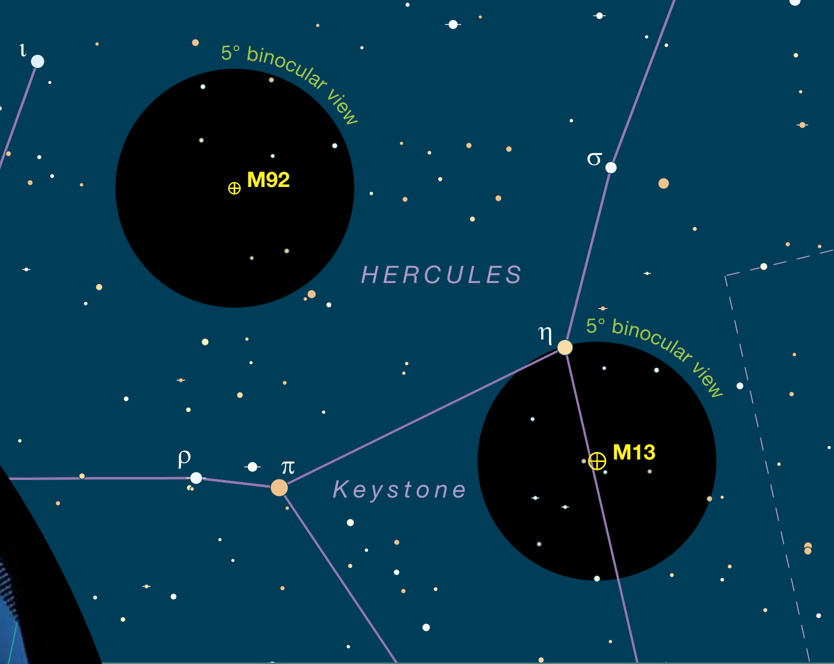
• Humboldt Crater	June 1
• Mare Smythii	June 4
• Poczobutt Crater	June 12
• Lacus Autumni	June 19



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

Comparing Hercules Globulars

Despite their modest binocular appearance, I have a fondness for globular clusters. Two of the finest for observers in the Northern Hemisphere are found in Hercules: **M13** and **M92**. Most deep-sky guidebooks wax eloquent about the charms of M13 and then continue with some version of ". . . and by the way, M92 is nearby and would be considered pretty great if it wasn't overshadowed by M13." Well, challenge accepted. Let's break with convention and try observing M92 first.

There's no denying that M92 is more work to get to than the so-called Great Hercules Cluster. Scan about 5° southwest of 3.8-magnitude Iota (ι) Herculis for M92's fuzzy, 6.5-magnitude glow. I often attempt a spring Messier Marathon, so at this time of year I have fresh memories of the zillion or so globulars near the galactic center in Sagittarius. This Hercules cluster looks pretty darned good by comparison.

But there's no question that at magnitude 5.8, M13 is the showier object. Under good conditions it's an easy naked-eye find, about 2½° south of 3.5-magnitude Eta (η) Herculis, the star marking the northwestern corner of the Keystone asterism. Spend some time on M13 and see if you can tease out any detail. In my 10×50 binoculars it's a fairly uniform glow, but my 15×70s start to show some concentration at the center.

To really appreciate the personalities of these two Hercules clusters, try rapidly going back and forth between them. Most of the visible differences are down to physical size, with M13 being almost twice as massive as M92. Regardless, each is worthy of the title "showpiece object."

■ **MATT WEDEL** has a real weakness for underdogs, including celestial objects with more famous neighbors, and stargazing with handheld optics.

WHEN TO USE THE MAP

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

*Daylight-saving time

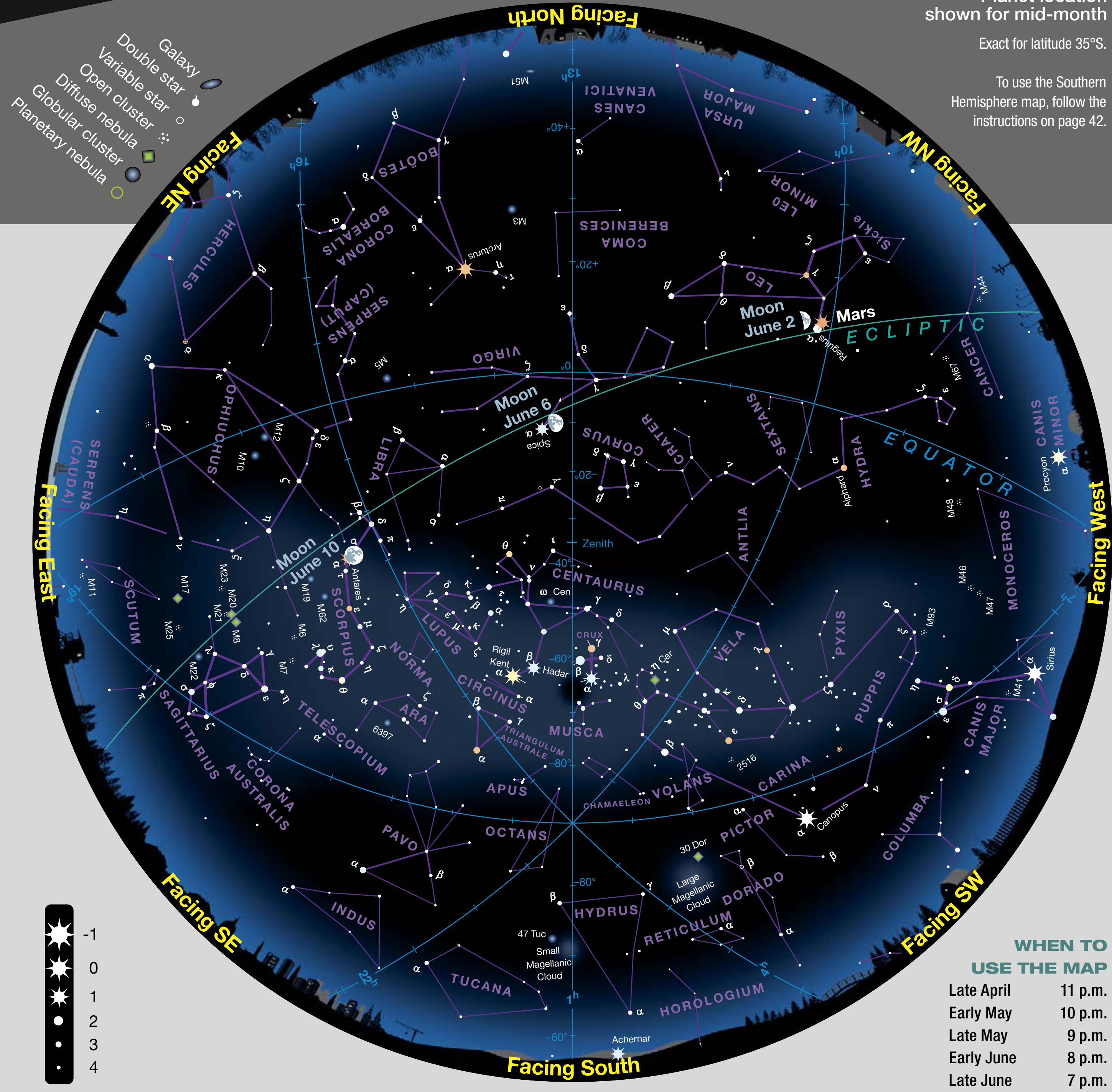
Southern Hemisphere Sky Chart

by Jonathan Nally

Planet location shown for mid-month

Exact for latitude 35°S.

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



WHEN TO USE THE MAP

Late April	11 p.m.
Early May	10 p.m.
Late May	9 p.m.
Early June	8 p.m.
Late June	7 p.m.

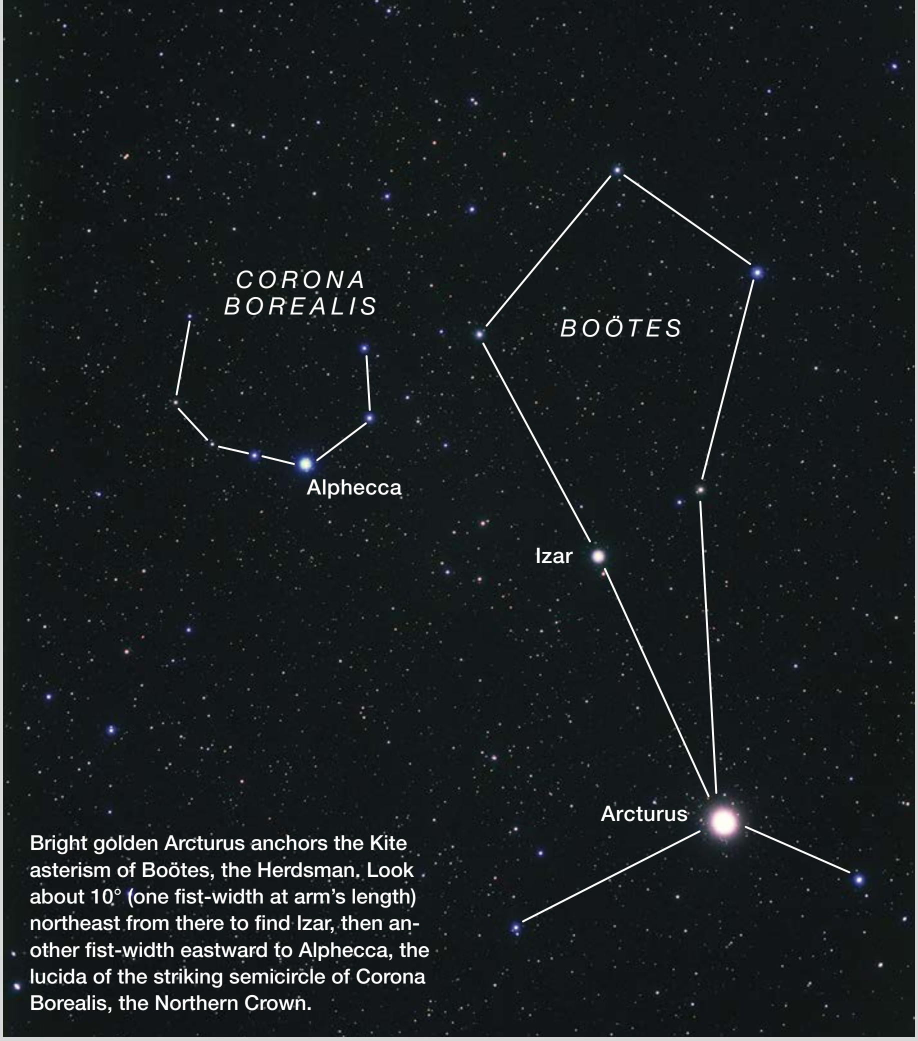
THE CONSTELLATION Circinus is named after the Drafting Compass, not the compass used for finding directions. Indeed, its depiction on the chart above makes that much clear — the instrument's two arms are easy to trace. We can also see that Circinus is tiny. By area it's the fourth smallest of the 88 official constellations. As it happens, it lies near the smallest constellation of all, Crux, the Southern Cross.

Of Circinus's three main stars, the brightest is Alpha (α) Circini. It's relatively nearby at a distance of 53 light-years and is variable, though its brightness changes by only a tiny amount centered on magnitude 3.2. Compared to our Sun, the star is twice as big and about 10 times more luminous. It also rotates relatively quickly, spinning on its axis once every 4.5 days — roughly six times faster than the Sun. ■

Stories in the Stars
by Stephen James O'Meara

Corona Borealis: A Castle in the Sky

See if this tale of Corona Borealis doesn't leave your head spinning.



Bright golden Arcturus anchors the Kite asterism of Boötes, the Herdsman. Look about 10° (one fist-width at arm's length) northeast from there to find Izar, then another fist-width eastward to Alphecca, the lucida of the striking semicircle of Corona Borealis, the Northern Crown.

AKIRA FUJII

Look high overhead after dark this month for the garland of seven stars representing Corona Borealis, the Northern Crown. You'll find this tight semicircle of modest stars hugging the zenith, just northeast of golden Arcturus, the Alpha (α) star of Boötes, the Herdsman. To the Celts of old, however, this stellar gathering was not the crown one wears but a magical realm in a medieval Welsh tale.

As with the ancient Greeks and Romans, the ancient Celts looked to the stars and envisioned their own mythologies. For the Welsh Celts, Corona Borealis was Caer Arianrhod, the Castle of the Silver Wheel, inhabited by the sky goddess Arianrhod, whose name means "Silver Wheel."

In one aspect, the goddess's name refers to how the silvery stars of Corona Borealis wheel around the North Star as Earth turns on its axis. In another aspect, the "silver wheel" refers to the annual cycle of the seasons as marked by the successive arrivals and departures of the zodiacal constellations.

In the *Mabinogion,* a collection of Welsh tales composed in the early 14th century, as translated by Lady Charlotte Guest (later Schreiber, 1812–1895) we learn that Arianrhod lives on the island of Caer Sidi, a disputed Welsh term likely meaning "revolving castle," in the far north surrounded by maidens. A renowned beauty, Arianrhod is a powerful and independent female figure who professes to live her life as a virgin, yet she secretly romances her brother Gwydion.

When mythical Welsh king Math fab Mathonwy is in need of a foot-holder — as the king's life strangely depended upon his feet always resting in a virgin's lap when he was not at war — Arianrhod applies for the office. Math, however, tests Arianrhod's purity by having her step over his magic wand. The test is a trick, and she finds herself giving premature birth to twin sons — Dylan (Darkness) and Lleu (Light) — of whose conception she had been unaware.

The names of Arianrhod's children are important, as the Celtic year is divided into two parts: darkness and light. The Celts placed great importance in the agricultural cycles brought on by seasonal change. In Welsh mythology, they mirror the cycles of life, death, and rebirth, as symbolized by Arianrhod's wheel of the year. With this in mind, let's see how Math's magic wand can symbolize the sky's *meridian* — the imaginary line running north to south while passing directly overhead — and how it relates to the seasons.

In the mid-14th century, Caer Arianrhod lay slightly east of the meridian just after sunset around the summer solstice — a time of extended light in the Northern Hemisphere. A few days later at dusk, the constellation crossed the meridian, and for the next half year the days gradually became shorter and the nights longer. Around the autumn equinox — a time that heralds the coming long dark nights of winter — Caer Arianrhod was near setting in the west. The constellation did not reappear in the early evening sky again until the spring equinox, when Caer Arianrhod was rising in the east, trumpeting the return of light to the land as Arianrhod's wheel completed its seasonal cycle.

■ 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.

Regulus Welcomes the Moon and Mars

Leo's brightest star has a pair of evening conjunctions.

SUNDAY, JUNE 1

June kicks off with the closest conjunction between the **Moon** and a star this month. Look toward the west-southwest in fading twilight to see the waxing lunar crescent (a little more than one day shy of first quarter) sitting above Regulus, the brightest star in Leo, the Lion. At magnitude 1.4, Regulus qualifies as a member of the first-magnitude club, but only just. That's why its best pairings with the Moon occur when the lunar phase is less than first quarter so that the star isn't completely overwhelmed by moonlight.

The Moon closes in on Regulus throughout the evening until about 12:30 a.m. EDT on June 2nd, when the gap between them shrinks to just 32′. Try using binoculars to get the most out of the scene — a little extra magnification makes the star stand out much better.

SATURDAY, JUNE 7

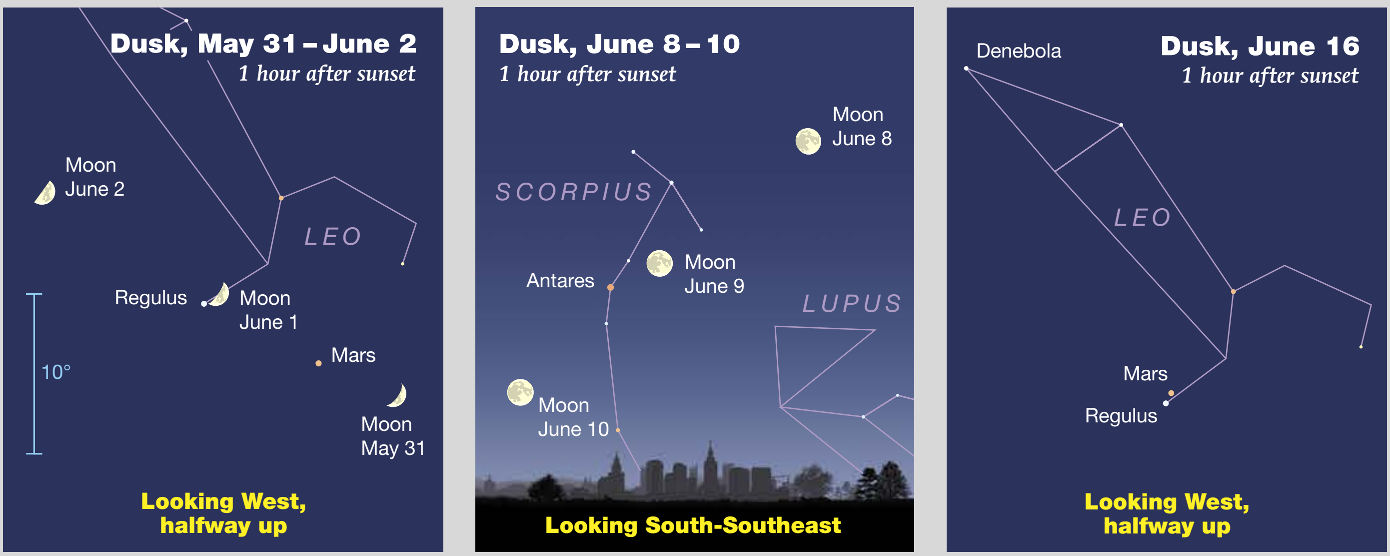
Here's one that falls into the category of maybe/maybe not. It's a noteworthy conjunction featuring two planets, but I'm not exactly going out on a limb when I say that your chances of seeing it aren't great — unless you view the sky from a location on the West Coast that looks out over water. And the farther south you are, the better. With those caveats out of the way, this evening presents an opportunity to catch **Mercury** and **Jupiter** side by side, separated by a bit less than 2½°.

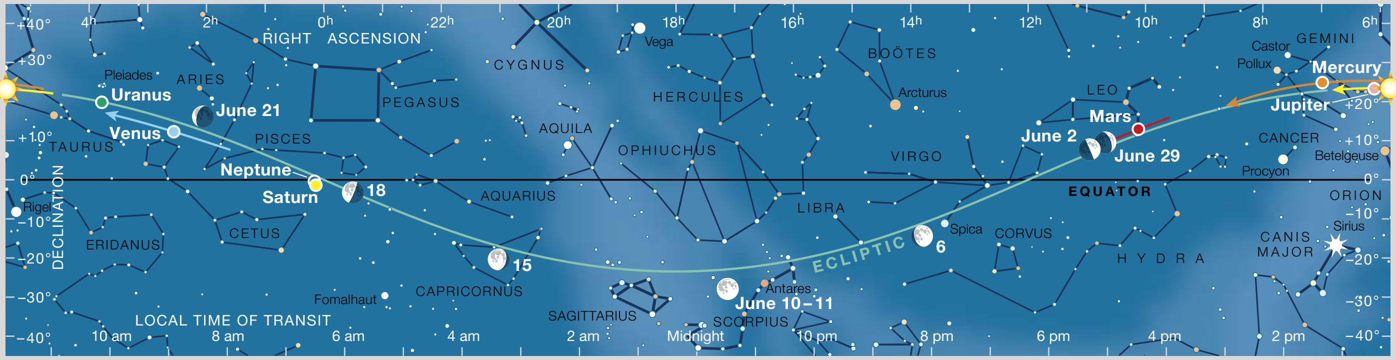
Both planets are reasonably bright, with Jupiter at magnitude –1.9 and Mercury a bit fainter at –1.2. The difficulty lies in the fact that they're both very low in the west-northwest and awash in bright twilight. Even from Los Angeles, California, the duo are only 3° above the horizon half an hour after sunset. Binoculars are a must. On the following evening (the 8th) the planetary pair are slightly closer with Mercury positioned about 2° upper right of Jupiter. Over the following days, Mercury continues to climb while Jupiter sinks sunward on its way to its June 24th conjunction with the Sun.

TUESDAY, JUNE 17

Our friend **Regulus** entertains a second guest this month when **Mars** visits this evening. Together they'll look like a wonderfully attractive, equal-brightness double star — something akin to a brighter and wider version of Albireo, the beautiful color-contrasting binary in Cygnus. At their closest, the planet and star are separated by about 46′. Both shine at magnitude 1.4, but their hues are distinctly different. Mars is famously known as the Red Planet,

▼▶ 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.





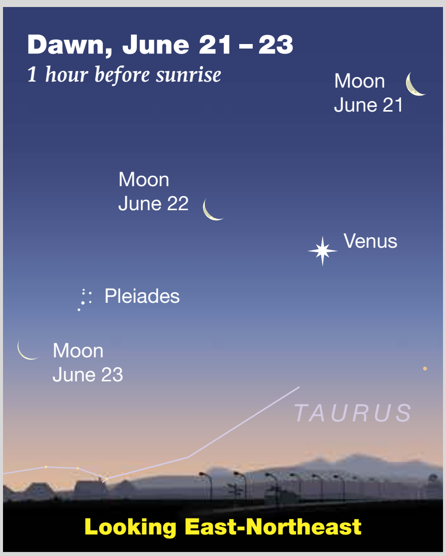
▲ The Sun and planets are positioned for mid-June; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

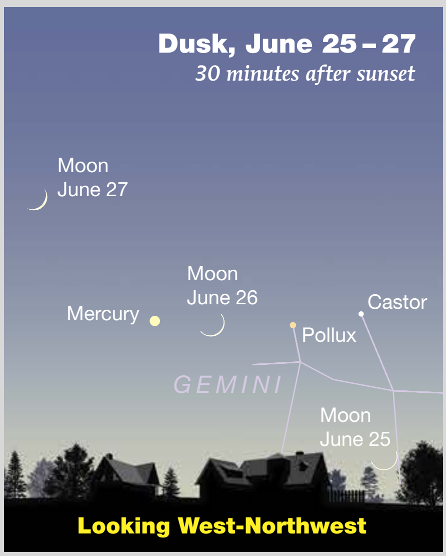
though its really more orange than red. Regulus, on the other hand, is bluish-white. Their proximity to each other helps emphasize their respective tints. Use binoculars to enhance your view — the extra light-gathering optics provide helps bring out the colors. To make the orange/blue contrast even more distinct, defocus your binoculars slightly so that the two objects appear as tiny disks instead of sharp points. Spreading out a star or planet's light makes its dominant hues more obvious. Try it — you might be surprised by how well this trick works.

Mars is presently trekking eastward through Leo and is close to Regulus for several nights, including both the previous and following evenings (the 16th and 18th). Although the planet is now several months removed from its January opposition, its current apparition still has seven months left to go.

THURSDAY, JUNE 26

In all likelihood, you didn't get to see **Mercury** earlier when it was next to Jupiter. Thankfully, this evening you have a much better chance to catch the innermost planet as it reaches its greatest altitude for the current apparition. Although Mercury is now slightly fainter than it was at the start of June, it sets more than 90 minutes after the Sun. You'll still need an unobstructed west-northwestern horizon to catch it, though. Mercury's greatest elongation doesn't occur until July 4th, but owing to the shallow angle the ecliptic makes with the western horizon at this time of year, the planet is better positioned now for observers at mid-northern latitudes.





Tonight isn't just about Mercury, however. Sitting 3½° to the planet's right is a thin, earthlit crescent **Moon**. It's about 3.5% illuminated and roughly 1.8 days old. And to the right of the lunar crescent, you can find the brightest stars of Gemini, **Pollux** and **Castor**. Together, the foursome makes a neatly curved, 13°-long line. Castor anchors the righthand end of the line, but at magnitude 1.9, it's the faintest of the quartet and the most difficult to claim.

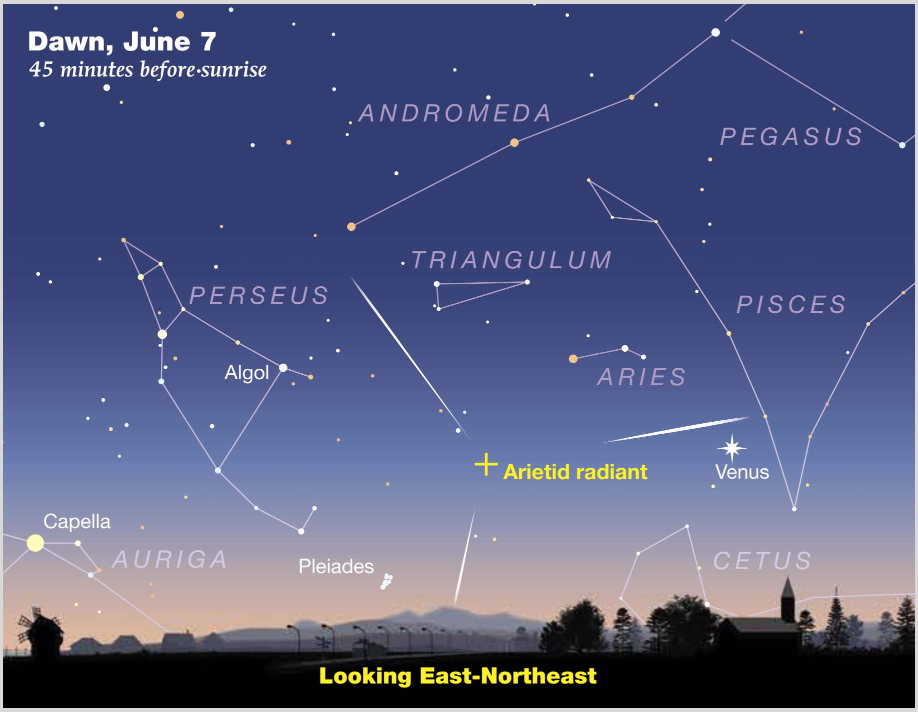
SUNDAY, JUNE 29

The **Moon** has its second close planetary encounter of the month tonight when it passes south of **Mars**. And this passage is close indeed! The gap between the two is at its smallest early in the evening, when roughly 17′ separates the Red Planet from the Moon's northern limb. But the exact amount depends on where you're located — the farther south and west you are, the tighter the gap. From Los Angeles, for example, the space between them shrinks to less than 2′ wide! Unfortunately, that's *before* sunset — by the time twilight begins, the Moon has moved eastward to ½° left of the planet. In some places, the Moon actually occults the planet. That's the case for observers in Hawai'i, where the event takes place in daylight hours, but in Ecuador and northwestern Peru, it occurs after sunset.

■ Consulting Editor **GARY SERONIK** generally overlooks Regulus unless the Moon or a bright planet is nearby.

Observe the Daytime Arietids

Some meteor showers are best enjoyed indoors.



◀ You can start watching for Arietid earthgrazers around 3 a.m. local daylight time on the morning of June 7th. The radiant lies in eastern Aries approximately 20° left of brilliant Venus. Get comfortable in a lounge chair, face east, and cross your fingers!

All the best-known meteor showers — the Perseids, Orionids, and Geminids — share their bounty at night. But there are others that peak only during daylight hours. The strongest and richest of these is the Daytime Arietid stream, which reaches maximum each year on or about June 7th. Others include the Zeta Perseids (which overlap with the Arietids) and the Beta Taurids, which peak on June 28th. Arietid shower members strike the atmosphere at 38 kilometers per second (137,000 mph), about the same speed as December's Geminids. As for the Arietid parent body, possible candidates include the large, near-Earth asteroid 1566 Icarus and sungrazing Comet 96P/Machholz.

All three of these daylight showers were initially detected by radar at England's Jodrell Bank Observatory in 1947. During World War II, radar operators discovered that meteor ionization trails reflected radio waves beamed from their tracking systems. At the time, the resulting "pings" and "bursts" were merely considered a nuisance. But after the war, scientists were quick to adapt and utilize radar technology to study meteors.

The Arietid radiant lies just 32° west of the Sun, so it's very low in the eastern sky at the start of morning astronomical twilight. Even under ideal circumstances, observers have at most an hour or two for meteor watching before the sky becomes hopelessly bright. If the Arietids weren't smothered by daylight we'd see around 60 per hour zipping from an area lower left of the three stars that outline the distinctive, flat-triangle shape of Aries, as shown in the chart at left. As it is, the rate is closer to a dismal 1 or 2 per hour!

I've never knowingly seen a single Arietid, but then again, I've never looked. When I hear "daytime" in combination with "meteor shower," it becomes an event to easily write off. In hindsight, I may have been too hasty — there are accounts of at least a handful of observers spotting a few Arietids just before dawn. And experienced meteor-watchers know that the radiant doesn't always need to be above the horizon. In the case of the Arietids, many blaze out of view below the horizon, but a few shoot straight up into the eastern sky. Known as *earthgrazers*, such particles skim nearly horizontally across the atmosphere and often streak for long distances in the sky.

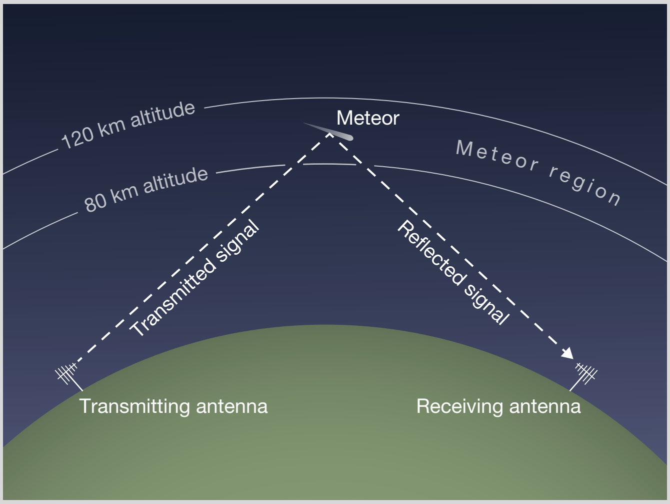
Thanks to these earthgrazers we can hope to see a few Arietids. The shower is active from May 14th to June 24th, but according to the International Meteor Organization (IMO), the visual maximum occurs around 9:30 a.m. EDT on June 7th, but with caveats.

Given the event's challenging viewing circumstances, astronomers employ additional tools, including radar and video networks, to record the shower. Radar registers meteoroids too small to leave visible trails, and taking these into account shifts the shower's peak to June 8th around 1 p.m. EDT. Video taken from multiple locations around the globe over the past 10 to 15 years point to an additional peak on June 10th at around 8 a.m. EDT. Unlike visual observers, video cameras are able to capture meteors even in bright moonlight, not to mention that these networks never sleep. The spread in times means "that the maximum for visual observers could occur on any morning from June 7th through June 10th," says meteor expert Robert Lunsford, Secretary-General of the IMO.

On the morning of June 7th, the Moon will be waxing gibbous and sets shortly before the start of astronomical twilight. Observers in the southern U.S., and particularly in the tropics, are favored because twilight is shorter and begins later than it does from more northern locations. Given how few (if any) images of the shower exist, a photographic vigil is highly recommended.

Admittedly, seeing an Arietid or capturing a portrait of one is a long shot, but there is one more option: Listening to the Arietids at **livemeteors.com**. At the site, click the play button on the bottom of the graphic display. After a few minutes you'll likely hear the low, metallic whistle of a random meteor. Rates vary day and night but are noticeably higher during meteor showers.

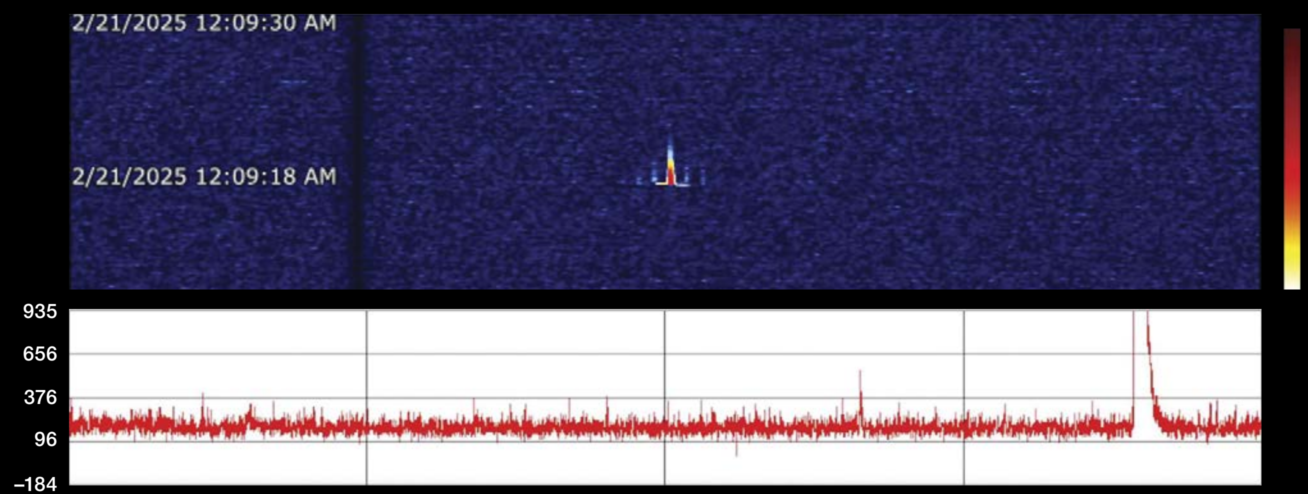
▶ When a meteoroid enters the atmosphere at high velocity it leaves behind a trail of ionized gas and particles that reflect radio waves for up to several seconds. A radio receiver converts these reflected waves into audible pings. These trails are also used for *meteor burst communications* that allow brief contact between two stations separated by up to 2,250 kilometers (1,400 miles).



Often, when a shower coincides with cloudy weather, I'll sit at the computer and listen to meteors instead. It makes for great background music. The meteor pings and echoes are displayed on a moving chart as bright blips for short-duration reflections and trails for longer-lasting ones. Ionization trails can be as brief as a second or, on rare occasions, persist for several minutes. Listening to radio echoes is a unique way to observe meteors, whether the Daytime Arietids or any other shower.

The site's meteor-detector antenna is located in the Washington, DC, metropolitan area and points at a TV tower in Ontario, Canada, broadcasting at a frequency of around 55.24 or 61.26 MHz. A meteoroid entering the atmosphere 80 to 120 km overhead leaves a trail of ionized air molecules and atoms that acts like a radio mirror. The TV signal bounces off the trail and reflects to the receiver, which converts the signal to audio.

Try listening to the Arietids during one of its predicted peaks. Of course, you have no way of knowing if a given ping is from a specific meteor stream, but if you keep an hourly tally, you can compare your results to what you've heard on days when no showers were active and get a real sense of having experienced the Arietids.



▲ This screenshot from the strip chart display at **livemeteors.com** records a meteor ping on February 21, 2025. The color gradient of the meteor signals in the top graphic indicates the amplitude (strength) of the signal, from blue (weak) to dark orange (strong). The numbers on the vertical axis of the strip chart show the relative amplitude of the signal strength.

BEATRIZ INGLESSIS / *S&T*

The Moon and Sun Stand Apart

ON THE NIGHT OF June 10–11, the full Strawberry Moon spreads its pale-yellow light over the nighttime landscape. I'm confident about the color because the Moon stands only about 20° high when it crosses the meridian for observers at mid-northern latitudes that night. Dense air present at lower altitudes scatter a fair portion of the Moon's blue and purple light and warm its gray countenance.

Thanks to the current lunar standstill (*S&T:* Apr. 2025, p. 49), that night the Moon has a declination of nearly –29°, in Ophiuchus between the distinctive forms of Scorpius and the Sagittarius Teapot. That's about as far south as it can ever get. For many of us, the Moon will spend much of the night partially hidden by trees, hills, and buildings. The farther north you are, the closer the lunar disk skims the southern horizon. For example, from Anchorage, Alaska (latitude 61° north), the Moon barely clears the horizon even as it culminates during the season's all-night twilight and remains in view for less than two hours. For locations farther north, it doesn't rise at all!

While the Moon visits the ecliptic's deep south, the Sun ascends to its most northerly position during the summer solstice, which officially occurs on June 20th at 10:42 p.m. EDT. At that time the Sun arrives at declination +23.5°. On the 11th, when the Moon is full, the Sun is nearly as high and 52° farther north than the Moon. That's only about ½° shy of the maximum possible declination spread.

▲ The full Moon rises orange and distorted over Lake Superior, as photographed from Duluth, Minnesota, on August 30, 2023. Its pumpkin-like shape results from strong atmospheric refraction near the horizon. Light from the Moon's lower edge is more strongly bent (refracted) than light from the top. The difference squeezes the bottom half of the lunar disk into the upper half and warps its outline.

Of course, you can't actually see the full Moon and Sun cross the meridian at the same time, but you can observe their disparate declinations. Simply pound a stake into the ground and use it to gauge the lengths of their shadows. Make your measurements when each reaches its greatest altitude, at around 1 p.m. local daylight time for the Sun and 1 a.m. for the Moon. (Use an astronomy app or software to refine these times down to the minute for your specific location.) Knowing the height of the stake and shadow length, the mathematically inclined can calculate the altitude of each body using basic trigonometry.

I'll be picking wild strawberries around the time of the Strawberry Moon. Most traditional full Moon names were passed down to us from the Algonquin tribes who lived in regions from New England to Lake Superior. The names refer to important weather indicators, hunting and harvesting traditions, and the behavior of animals and plants. Many, such as the Flower Moon of May or December's Cold Moon, still ring true in the 21st century. But they also offer a glimpse of life lived closer to the land before the advent of artificial lighting, satellites, and leaf blowers.

Saturn Meets Neptune Under the Great Square

ON THE MORNING OF June 29th, Neptune and Saturn share the same right ascension with the distant blue planet sitting just 1° above the ringed wonder. Locating Neptune doesn't get much easier. In binoculars they'll make a snug pair with plenty of room to spare. And you'll have no problem squeezing them into the field of view of a telescope used at low magnification.

Saturn's rings are inclined 3.7° with their south face in view. Would that we could also glimpse Neptune's bare-bones ring system, too! Sadly, it's composed of radiation-darkened organic ices which are both too faint and far away to discern except with sophisticated instruments observing in infrared wavelengths.

BOB KING

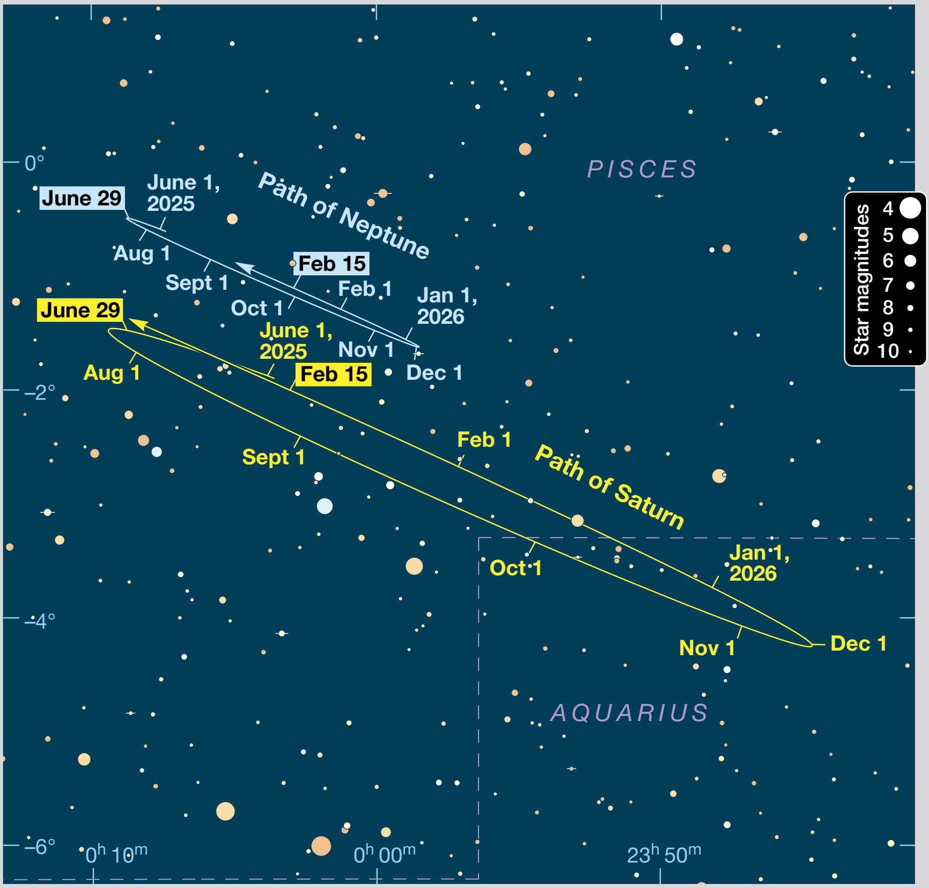
JUPITER IS IN CONJUNCTION with the Sun on June 24th and effectively out of view the entire month. The planet will return at dawn in July, when it becomes visible to the naked eye around the 9th. For observers at mid-northern latitudes hoping to enjoy good telescopic views of the giant planet, the wait is even longer. Jupiter won't attain an altitude of 30° or greater (necessary for steady seeing conditions) at sunrise until August 11th.

Our regular tables showing the transit times of the Great Red Spot and Jovian satellite events will be presented as usual in the July issue.

This detailed Jupiter portrait includes the Galilean moons (from left to right) Ganymede, Callisto, and Io, with Ganymede casting its shadow on the gas giant's south polar region.

The duo are in southern Pisces, south of the Great Square in Pegasus, where they're well-placed for viewing in the hours before dawn. When two planets get this close it's fun to compare their colors and moon systems. Saturn's brightest satellite is Titan, which shines at magnitude 8.5 and is near greatest elongation east of the planet. Triton, on the other hand, glows meekly at magnitude 13.5, about 11″ northeast of Neptune's tiny disk.

Although both planets plod slowly along and remain within 1° of each other until mid-July, you might want to make the effort to see them together this time. The next conjunction occurs at dusk on February 15, 2026, when they're separated by 55′. But after that, we won't see the duo together in a dark sky until February 2132!

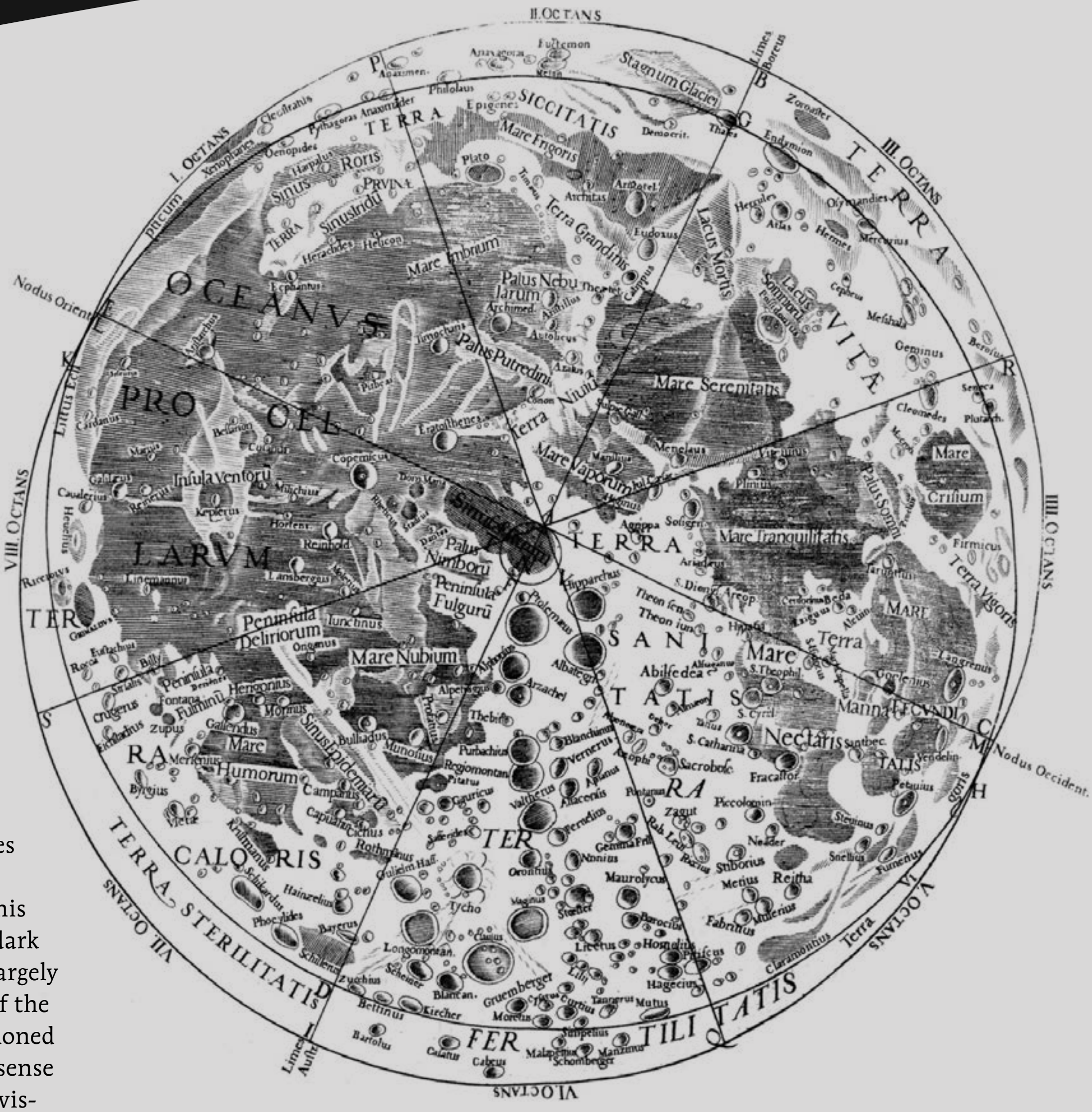


▶ Saturn's path across the sky brings it to within 1° of Neptune twice: on June 29th this year and once again on February 15, 2026. On both occasions you can locate Neptune by keying off Saturn. Enjoy observing these close conjunctions while you can — your next opportunity lies more than 100 years in the future.

SEAN WALKER

Long-Lost Terrae

Revisit lunar regions whose names have been abandoned.



▲ Riccioli's lunar map, published in his *Almagestum Novum* in 1651, contains names for many bright terrae that are no longer recognized today.

G. B. RICCIOLI

When Flemish astronomer Michel Florent van Langren made the first major lunar maps in the mid-17th century, he named conspicuous dark areas *maria* and bright areas *terrae*, for what he respectively thought were seas and landforms. His contemporaries Johannes Hevelius and Giovanni Battista Riccioli quickly adopted this scheme. Riccioli's choices for the dark features — like Mare Imbrium — largely remain in use today, whereas all of the names for bright areas were abandoned some 200 years later. That makes sense because the Moon is full of easily visible, well-defined craters, mountains, and maria, while the bright regions with their often-indistinct boundaries are less useful as geographic locators.

Even though Galileo had previously speculated that the maria were *not* seas of water, Hevelius specifically considered them to be such, as was the general belief at the time. If seas were to be named, so should the extended lands that rise above them. Hence these early selenographers bestowed titles on the most conspicuous bright areas. Van LLangren named eight of them, each of which he called a Terra (land), while Hevelius created designations for 12, which he called Regio (region); and Riccioli named 11, keeping the term Terra. Like the maria, these names are in Latin. The ones Roccioli chose often expressed weather conditions, while van Langren's reflected virtuous feelings, and Hevelius's names were inspired by supposedly similar landscapes on Earth.

The abandoned names of these lunar bright areas are of little interest to lunar scientists. However, they provide casual observers with connections to the interpretations those pioneering observers made when the physical natures of the Moon, Sun, planets, and stars were unknown. So let's explore some of the designations applied by Riccioli and the other early mappers to large, non-dark spaces.

One of the most conspicuous and best defined of these is the elliptical zone between the north shore of **Mare Frigoris** and the northern limb. Riccioli named this area *Terra Siccitatis* (Land of Dryness) and the south polar area *Terra Sterilitatis* (Land of Sterility). Perhaps Riccioli knew Earth's polar regions were bad for agriculture and assumed the same for the Moon. Not to be outdone, Hevelius named the north polar limb area *Hyperborea* (Beyond the North Wind) after the Greek mythical kingdom that marked the northern boundary of the known world in antiquity. For some reason van Langren denoted the zone north of Mare Frigoris as *Terra Honoris*, but I think of people, not locations, as having honor. Contrary to the idea that polar regions are bad for farming, Riccioli placed *Terra Fertilitatis* (Land of Fertility) from the lunar south pole to **Mare Australe** along the northeastern limb. But presumably the richest land for agricultural use, perhaps even heavenly blessed, was the cratered zone between **Mare Nectaris** and **Mare Fecunditatis** that Riccioli named *Terra Mannae* (Land of Manna).

Riccioli continued bestowing names to limb regions, calling the area between **Mare Serenitatis**, **Mare Crisium**, and the eastern limb *Terra Vitae* (Land of Life). Many, including William Herschel a century later, speculated that Earth-like life existed throughout the solar system and on the stars. But why did Riccioli think that Terra Vitae deserved such a title? Who knows.

The bright borders of **Mare Imbrium** also attracted Riccioli's attention. In this region he named the rugged **Montes Apenninus** chain *Terra Nivium* (Land of Snows), the area from craters **Plato** to **Calippus** as *Terra Grandinis* (Land of Hail), and the region surrounding **Montes Jura**, whose ejecta added to that from the Imbrium Basin to form *Terra Pruinae* (Land of Frost). Perhaps the bright terrain and the Apennines led Riccioli to interpret these terrains as snow.

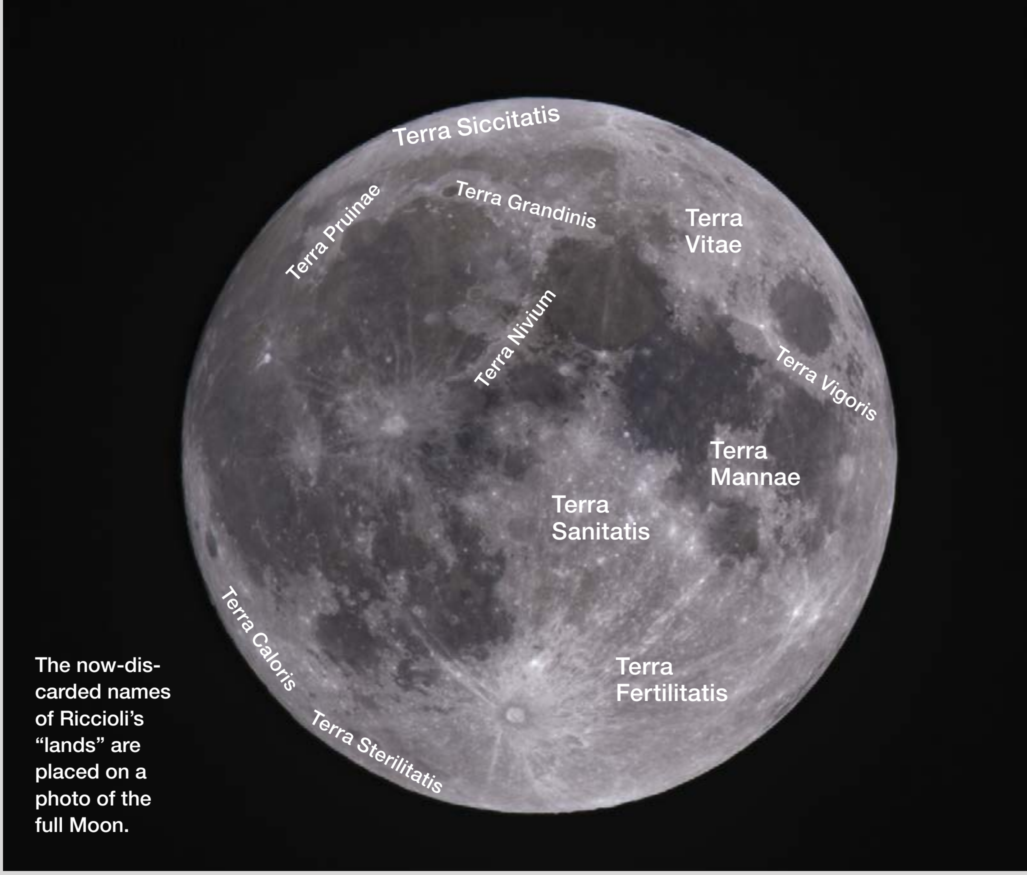
Meanwhile, van Langren honored the area around Sinus Iridium and the Jura Mountains by bestowing *Terra Laboris* (Land of Labor) to the region. Oddly, he named **Montes Archimedes** *Terra Virtutis* (Land of Virtue). Hevelius named this area *Italia*, though it doesn't look much like the boot-shaped peninsula on Earth.

The main bright area of the Earth-facing side of the Moon is the crater-dense region that stretches south from **Sinus Medii** to the south pole area, which Riccioli called *Terra Sanitatis*. Van Langren was more of a lumper and simply called the bright highlands from Sinus Medii to the limb *Terra Dignitatis* (Land of Dignity), though I don't know how much dignity is left on this oldest and highly battered lunar terrain.

Riccioli's lunar names are related to agriculture. The bright lands weren't plowed up in furrows but instead at random spots by impact events that widely spread the highlands' light-toned crust and pulverized ejecta. Unknown to Riccioli and his contemporaries, they weren't mapping farmlands or noble thoughts, but instead, their borders denote fundamental compositional differences between dark, dense basaltic maria and light anorthositic crust.

As you observe the Moon, try to recognize these broad, continental-scale bright regions before their ancient names are forgotten to future generations of astronomers.

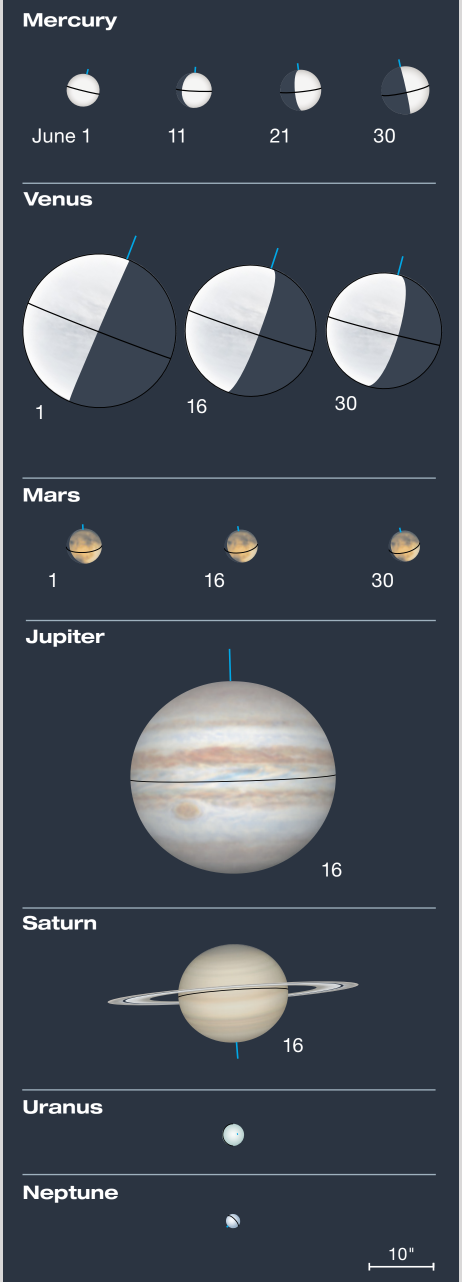
■ Contributing Editor **CHUCK WOOD** with Maurice Collins are authors of *Extreme Illumination Atlas of the Moon*, available through Amazon.



The now-discarded names of Riccioli's "lands" are placed on a photo of the full Moon.

▲ This close-up of the Imbrium region ("Mare Austriacum") of van Langren's 1645 lunar map shows Terra Laboris and Terra Virtutis.

MOON WITH RICCIOLI LABELS: SEAN WALKER; DETAIL OF LANGRENUS MOON MAP: MICHEL VAN LANGREN

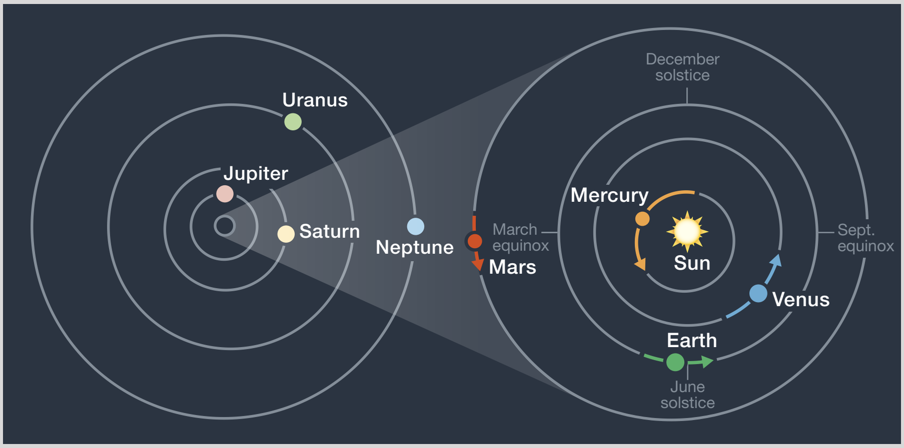


PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dusk starting on the 7th • **Venus** visible at dawn all month • **Mars** visible at dusk and sets around midnight • **Jupiter** lost in the Sun's glare after the 8th • **Saturn** rises in the early morning and visible to dawn.

June Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	4^h 35.2^m	+22° 00′	—	–26.8	31′ 33″	—	1.014
	30	6^h 35.4^m	+23° 11′	—	–26.8	31′ 28″	—	1.017
Mercury	1	4^h 44.4^m	+23° 10′	2° Ev	–2.2	5.1″	100%	1.318
	11	6^h 16.5^m	+25° 19′	14° Ev	–1.0	5.5″	85%	1.221
	21	7^h 33.4^m	+23° 32′	22° Ev	–0.3	6.4″	64%	1.056
	30	8^h 24.4^m	+20° 04′	25° Ev	+0.2	7.5″	48%	0.901
Venus	1	1^h 34.2^m	+7° 31′	46° Mo	–4.4	23.9″	50%	0.699
	11	2^h 12.3^m	+10° 37′	46° Mo	–4.3	21.4″	55%	0.779
	21	2^h 52.9^m	+13° 44′	45° Mo	–4.3	19.4″	59%	0.859
	30	3^h 31.5^m	+16° 21′	44° Mo	–4.2	18.0″	63%	0.929
Mars	1	9^h 34.3^m	+15° 58′	70° Ev	+1.3	5.5″	91%	1.695
	16	10^h 05.8^m	+13° 00′	64° Ev	+1.4	5.2″	92%	1.815
	30	10^h 35.8^m	+9° 57′	59° Ev	+1.5	4.9″	92%	1.918
Jupiter	1	5^h 49.8^m	+23° 14′	17° Ev	–1.9	32.3″	100%	6.094
	30	6^h 18.4^m	+23° 14′	4° Mo	–1.9	32.0″	100%	6.159
Saturn	1	0^h 03.8^m	–1° 53′	70° Mo	+1.1	16.8″	100%	9.879
	30	0^h 08.8^m	–1° 29′	97° Mo	+1.0	17.7″	100%	9.404
Uranus	16	3^h 45.6^m	+19° 38′	26° Mo	+5.8	3.4″	100%	20.431
Neptune	16	0^h 08.4^m	–0° 31′	83° Mo	+7.9	2.3″	100%	29.996

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**.



▲ **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 June. The outer planets don't change position enough in a month to notice at this scale.

Making a Connection

There are many ways to add a camera to your telescope to create pleasing astrophotos.

◀ **DISTANT SPLENDOR** This image of the Triangulum Galaxy (M33) was captured using the prime-focus method — one of several different ways to combine a camera and telescope. In prime-focus astrophotography, the scope essentially functions as a powerful telephoto lens. This photo of M33 combines a total of 20 hours of 5-minute exposures recorded with a dedicated astrocamera paired with an equatorially mounted 110-mm f/7 refractor.

Just about everyone who has experienced the wonders of the night sky with a telescope has at one time or another wished to preserve the view or share it with others. Today, thanks to modern digital cameras, photographing celestial objects has never been easier. Even a small telescope combined with a smartphone can record the Moon and numerous additional celestial sights. More sophisticated setups allow you to image everything from impressive lunar and planetary detail to the faint glow of remote galaxies. Astrophotography also reveals wonders that the human eye alone can't see. It's not an exaggeration to say that modern backyard equipment is capable of results that were once possible only at professional mountaintop observatories.

Remarkably, having this capability needn't be expensive or especially complicated. If you already have some kind of camera and even a basic telescope, you can at least make a start. But how exactly do the various puzzle pieces fit together? Combining a camera and a scope can be as simple as pointing your smartphone at the eyepiece. Other methods use dedicated adapters and specialized imagers. Each approach offers its own advantages, limitations, and creative potential for revealing the universe's grandeur. Which method you choose depends on your equipment as well as your goals and expectations.

A Simple Start

As I mentioned, one of the easiest ways to begin capturing what's in your telescope is to hold a smartphone or point-and-shoot camera to your scope's eyepiece. This technique, known as *afocal projection*, is as straightforward as it gets. You simply substitute your eye for a camera and lens. The telescope gathers and focuses light, and the camera's lens transfers the image to the sensor. It sounds basic, but it often produces surprisingly good images of the Moon and even reveals Saturn's rings.

The method's simplicity makes it ideal for newcomers. Afocal projection works with just about any camera and any telescope design — and you don't *need* a special adapter to get started, however, you probably will *want* one. Holding your camera steady and in the right position behind the scope's eyepiece isn't as easy as it sounds. Even slight movements will cause misaligned shots, dark corners, or blurred details. A digiscoping bracket or smartphone adapter solves this problem by securely attaching the camera to the eyepiece, keeping everything correctly positioned and steady. Such an adapter is a small investment that makes a big difference in getting sharp, well-framed shots.

The procedure for afocal-projection photography is straightforward: Start by focusing the telescope through the eyepiece as you would for visual observing. Once the image is crisp, align the camera lens with the eyepiece's exit pupil and fine-tune the focus. You may need to

▶ **GETTING SMART** The author's iPhone is secured to the telescope's eyepiece with a Celestron smartphone adapter. This setup enables afocal imaging to capture the Moon, planets, and bright deep-sky objects with ease.

ALL IMAGES COURTESY OF THE AUTHOR

adjust the spacing between the camera and the eyepiece to find the best position. If you're using a smartphone, tap the screen to adjust focus and exposure, then lock the settings for consistent results. Using a self-timer or a Bluetooth shutter remote minimizes vibrations, helping keep your images sharp.

This afocal method excels with bright targets. The Moon is especially rewarding — it's easy to focus on and only requires short exposures that minimize motion blur arising from Earth's rotation. Planets, double stars, and bright star clusters are also within reach. However, the limitations of a typical smartphone's sensor and circuitry means that most large, faint targets aren't suited to this approach.

A Direct Connection

Ready to move beyond afocal projection? The next step is *prime-focus* photography. With this arrangement, your telescope effectively becomes a powerful camera lens. The payoff? Sharper images that reveal faint details in galaxies and nebulae and clearer images of the Moon and planets. This is the technique used for most of the astrophotos you see in this magazine.

Prime-focus photography works with any camera that allows for interchangeable lenses, such as DSLRs, mirrorless cameras, video cameras, or dedicated astronomy cameras. The field of view (how much sky fits in your frame) depends on two factors: your telescope's focal length and your camera's sensor size. Longer focal lengths work nicely for smaller targets such as planetary nebulae or for capturing lunar and planetary detail, while shorter focal lengths are perfect for big objects like the Andromeda Galaxy, M31. And larger camera sensors take in more of the night sky than smaller ones.

◀ **POWER MAD** This 5-inch Newtonian reflector telescope is equipped with an eyepiece-projection adapter that houses a telescope eyepiece, which projects a magnified image onto the sensor of a Canon T7 DSLR. This method enables high-magnification imaging of the Moon and planets but requires a sturdy mount to minimize vibrations.

To use a DSLR or mirrorless camera with your scope, you'll need two additional items: a T-ring and a T-adapter. The first of these attaches to your camera's lens mount. You have to make sure to purchase one that works with your camera's specific make and model. The T-ring's opening is threaded to accept a T-adapter, which has either a 2-inch or 1¼-inch fitting at its other end to insert into your scope's focuser. If you have a camera with a so-called full-frame sensor, a 2-inch adapter is the best choice. Some telescope focusers actually have built-in T-threads for a more direct connection, while dedicated astrocameras might require additional spacers.

Getting sharp focus requires positioning your camera's sensor at the telescope's focal plane, where light rays converge from the objective lens or mirror to form an image. To reach focus with your camera, you typically need to rack the focuser inward so that the telescope's focal plane lands on the camera's sensor. The distance between the innermost position of the focuser and where the telescope comes to focus is often referred to as its *back focus distance*. DSLRs typically require more back focus than mirrorless cameras. This makes focusing tricky with some Newtonian reflectors, which typically have less focus range than refractors or Schmidt-Cassegrain scopes.

Once everything's set up and working, prime-focus photography reveals levels of detail that afocal projection can't touch. Add an equatorial mount and you can start capturing long-exposure images that bring out the subtle features in star clusters, galaxies, and nebulae. Really, the sky's the limit!

▼ **DETAILS GALORE** The northern half of the waning gibbous Moon recorded using the afocal method with an iPhone and a Celestron EdgeHD 11-inch telescope fitted with a Tele Vue 18mm DeLite eyepiece. Precise alignment of the eyepiece and camera's lens is essential for a clear image. This lunar portrait illustrates the technique's strengths and limitations — fine detail is present, but so are some color fringing artifacts.

Power and More Power

But what if you want to capture fine lunar and planetary detail, or if you can't quite reach focus with your camera? You have two similar methods to choose from: *eyepiece projection* and *negative projection*. These methods involve placing either a Barlow lens or a telescope eyepiece between your camera and your telescope's objective. This shifts the focal plane outward, solving focus issues with reflectors while increasing the system's effective focal length to magnify your target.

Adding a Barlow is straightforward. Insert it into your focuser and attach your camera using the same T-ring and adapter setup as for prime-focus photography. A 2× Barlow doubles your telescope's focal length, but at the expense of halving the amount of light reaching the camera's sensor. In other words, a 1,000-mm f/8 telescope effectively becomes a 2,000-mm f/16. This extra reach reveals fine planetary details like Jupiter's cloud bands or Saturn's ring divisions. You can also fine-tune the magnification by varying the distance between the Barlow and camera sensor and then refocusing.

If you're looking to create high-resolution lunar or planetary images, eyepiece projection offers a route to even greater magnification. As the name implies, in this setup your scope's eyepiece projects an image onto your camera's sensor. One of its great strengths is that you can cover a wide range of image scales by using different eyepieces.

An eyepiece-projection setup requires specific hardware. In addition to a T-ring, you'll need an eyepiece projection adapter. The design matters. Premium adapters offer precise adjustment and minimal flexure — both crucial for high-magnification work. In this configuration, your choice of eyepiece becomes a creative tool. A 25-mm Plössl delivers moderate magnification with sharp edge-to-edge performance, while a 10-mm eyepiece dramatically increases image scale, but at the cost of some field flatness.

Both projection methods demand attention to fundamentals. The extended light path means longer exposures or higher ISO values. Mechanical stability becomes critical. Any flexure in the imaging train will degrade sharpness at these magnifications. Success requires careful polar alignment, stable tracking, and patience while focusing. This is why I suggest honing your technique with the Moon before tackling smaller, dimmer, and more difficult targets.

▲ **MOON AND SUN TOGETHER** The author used the prime-focus method to photograph the diamond ring during the April 8, 2024, total solar eclipse. She used a Canon EOS Ra DSLR fitted to a 103-mm f/7 refractor via a T-ring. Precise tracking on an equatorial mount ensured sharp detail at the critical moment when the Sun's photosphere emerged from behind the Moon's limb.

Wide-Field Freedom

If your goal is to include as much sky as possible, a completely different approach is required. This time, the telescope plays a supporting role. Literally. When you want to capture the grandeur of the Milky Way stretching across the sky, or frame multiple deep-sky objects in a single shot, *piggyback astrophotography* offers an elegant solution. Instead of shooting through your telescope, you attach your camera and lens on the scope's tube to take advantage of the mount's tracking capability. The only extra piece of gear you need is a piggyback bracket.

The beauty of this method lies in its flexibility — you can use any of your camera lenses, from an ultra-wide 14-mm for sweeping star fields, to a 200-mm telephoto for framing specific nebulae, galaxies, or star clusters. These relatively shorter focal lengths are more forgiving of tracking errors, making exposures of up to a minute or two achievable even with basic polar alignment. And your scope can perform double duty, either as a second imaging platform (with a prime-focus setup) or as a means of keeping an eye on how well the mount is tracking.

Keep an eye on weight distribution, though. Heavier camera setups can affect tracking performance, so check your mount's payload capacity and ensure it can handle your entire imaging setup. You'll likely need to adjust (or, add) counterweights to maintain balance, but the effort is worth it for the stability you'll gain.

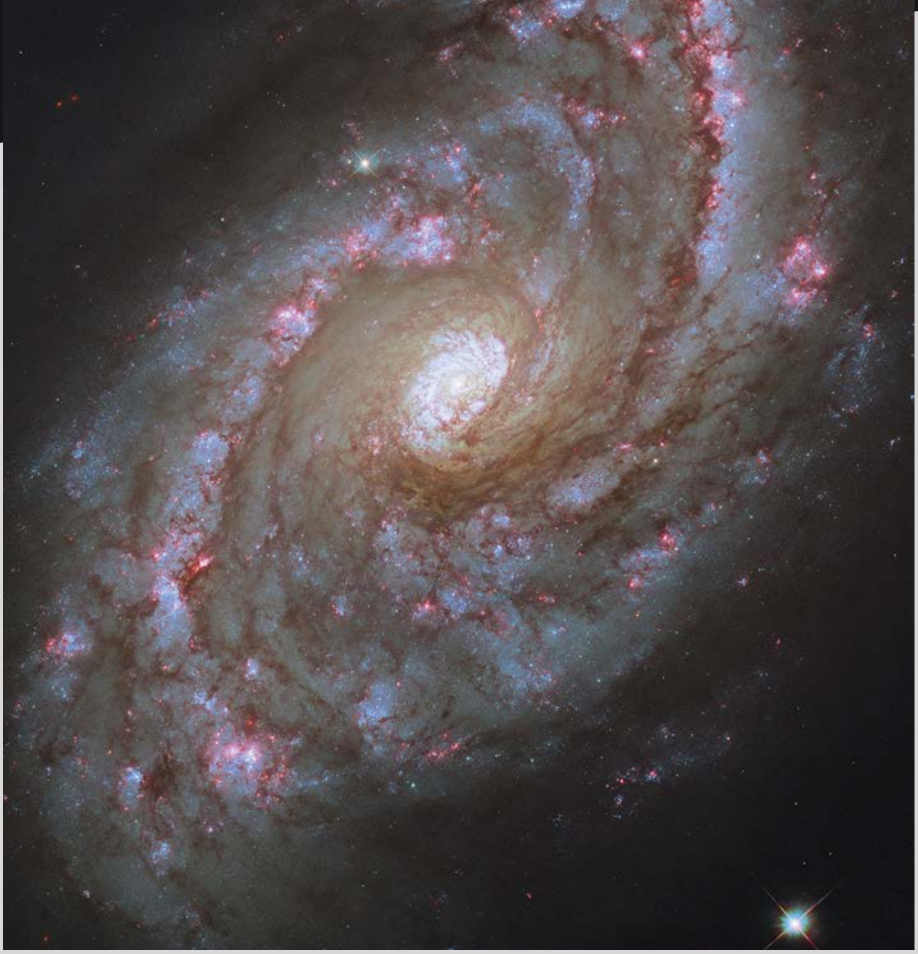
Start with familiar wide-angle views to capture the glowing band of the summer Milky Way or to frame your favorite constellations. As your skills grow, experiment with longer focal lengths to zoom in on larger deep-sky objects. The possibilities are as vast as the sky itself.

Whether you choose afocal projection for quick lunar shots, prime focus for deep-sky imaging, projection methods for high magnification, or piggyback mounting for wide-field views, each technique opens new windows to the cosmos. The key is to match the method to your target. With practice and patience, you'll discover which approach works best for your specific imaging goals.

■ SARAH MATHEWS is an astrophotographer who blends her curiosity for the cosmos with her background in the space industry. She shares her knowledge and experiences on her YouTube channel (**www.youtube.com/@SarahMathsAstro**).

A Galaxy-Hop in Boötes

The celestial Herdsman offers a fertile hunting ground for spotting galaxies.



▲ **GRAND DESIGN SPIRAL** NGC 5248 has a lot going on, besides its marvelous spiral arms. The galaxy has not one but two rings of starburst regions encircling its nucleus. This level of detail might not be visible in your scope, but keep this Hubble Space Telescope image in mind when you've located NGC 5248 in your eyepiece.

ESA / HUBBLE / NASA / F. BELFIORE / J. LEE / PHANGS-HST TEAM

There are many varied myths from ancient cultures involving the stars that make up the modern constellation Boötes. The current manifestation, that of the Herdsman, is just one of them. If you're like me, you simply see a kite-shaped asterism extending northeast from the constellation's brightest beacon, Alpha (α) Boötis, or Arcturus.

Regardless of what the stars of Boötes represent to you, there's no denying that the constellation is a rich hunting ground for galaxy aficionados. Within its boundaries there are more than 32,000 cataloged galaxies — and about 100 are brighter than 14th magnitude. I've selected some objects that I think provide a good sampling that should at least be detectable in a 10-inch telescope. I conducted my observations described here with an 18-inch f/4.5 Dobsonian and a 30-inch f/4.45 Dobsonian in Bortle 4 (brighter rural) skies.

In the Southwestern Corner

Our first target, **NGC 5248**, lies about 14° southwest of Arcturus. To find it, locate 3rd-magnitude Eta (η) Boötis, west of Arcturus and from there star-hop to the southwest along a roughly straight line via 4th-magnitude Upsilon (υ) Boötis, a farther 5.6° to the 5.6-magnitude star HD 118889, and from there another 1.9° to the galaxy. In my 30-inch at 300×, this 10.3-magnitude, grand-design spiral shows just a hint of its two sweeping arms that wrap around a bright core. The arms appear somewhat knotty. In the early 2000s, researchers determined that what was once assumed to be an inclined disk is actually an extended stellar bar. In addition, the bar is home to a spiral structure that drives a ring of starburst regions. This "spiral within a spiral" is fascinating to contemplate, but alas, not apparent in the eyepiece.

Moving about 6° east-northeast of NGC 5248, we encounter 12.4-magnitude **NGC 5414**. It lies 16′ north-northwest of the 6.2-magnitude star (HD 122563). This small, oval-shaped galaxy so far escapes firm classification and could be either an elliptical or an face-on spiral — in fact, it's listed as "peculiar" in catalogs. Its high surface brightness makes it rather easy to detect in my 18-inch at 197×.

From NGC 5414, we'll slew east-northeast some 3.8° and focus instead on 11.9-magnitude **NGC 5532**. The galaxy lies 52′ northeast of the 5.3-magnitude star 15 Boötis. In my 18-inch at 263×, this lenticular galaxy is moderately bright and presents a slightly elongated, more conspicuous core that sharpens to an almost stellar center. I can sometimes glimpse a 14.8-magnitude starlike smudge about 36″ south-southeast of NGC 5532's center, which is a companion galaxy. A second lenticular, 13.5-magnitude **NGC 5531** is 5′ to the north-northwest and is a member of the same group of galaxies as NGC 5532.

The Western Side of the Kite

The 4th-magnitude star Rho (ρ) Boötis is the jumping-off place for our next target. Scan some 55′ north-northwest of Rho to land at **NGC 5653**. In my 18-inch at 263× I note this 12th-magnitude spiral as moderately bright and a little elongated northwest-southeast. William Herschel discovered this galaxy on March 13, 1785. Eighty-one years later, mathematical prodigy (and later director of Hopkins Observatory at Williams College, Massachusetts) Truman Henry Safford reported it as a new object, which he cataloged as IC 1026.

From Gamma (γ) Boötis, the 3rd-magnitude star that marks the northwestern corner of the kite asterism, drop 2.3° south-southwest to locate the 6.2-magnitude star HD 127065. Next, jump slightly less than 1° southeast to find **NGC 5656**. In my 18-inch at 197× the 11.8-magnitude spiral appears oval with a bright center and mottled outer edges.

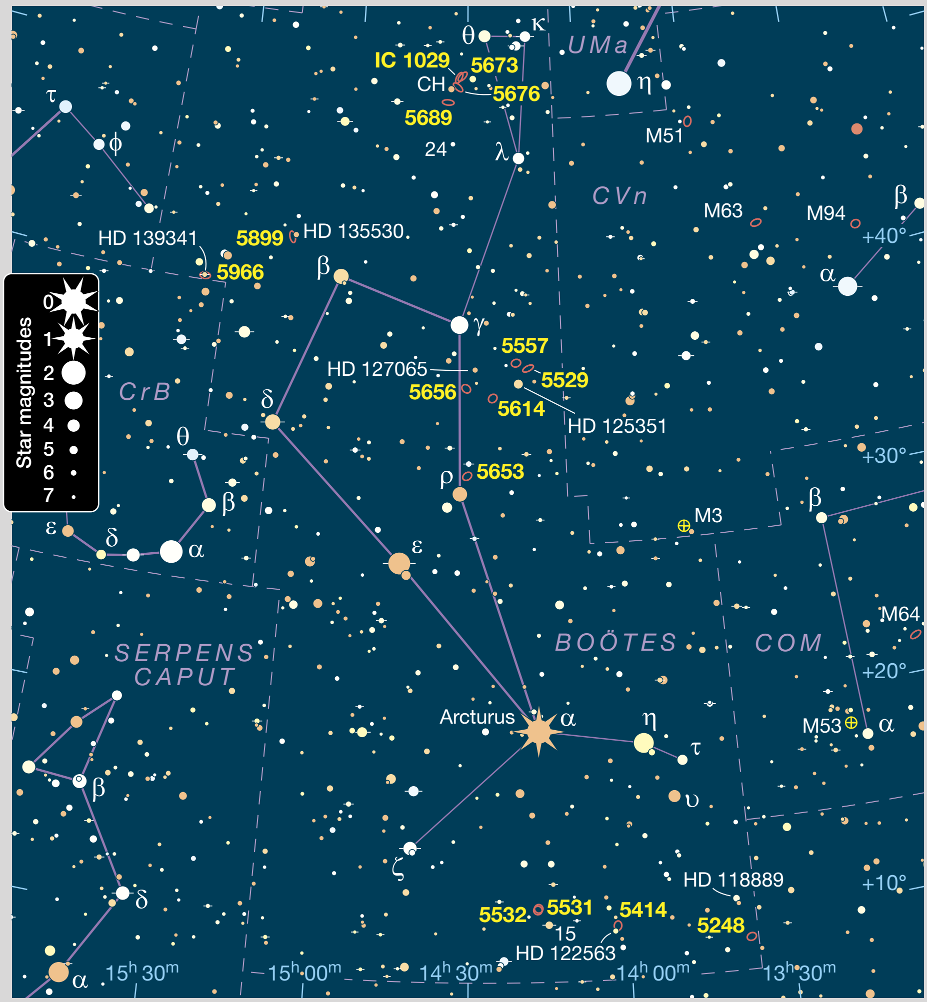
Moving 1.4° west-southwest of NGC 5656, we come to the 11.7-magnitude spiral **NGC 5614**, also known as Arp 178. In fact, this peculiar object consists of a pair of galaxies: NGC 5614 is interacting with NGC 5615, likely contributing to the ring- and tail-like features. In my 30-inch at 300×, the two galaxies appear as a single object, with NGC 5615 no more than a knot 26″ northwest of NGC 5614's core. The duo appear elongated in the direction of a fainter, nearly stellar companion 2′ to the north, 15th-magnitude NGC 5613.

A convenient reference star for our next object is 4.8-magnitude HD 125351, which is 1.4° northwest of NGC 5614. Continue another 52′ north-northwest of the star to spy the slender sliver that is **NGC 5529**. This is a very nice edge-on galaxy that in my 18-inch at 229× appears large and bright, sporting a considerably brighter central region. Move 38′ northeast of NGC 5529 to land on the elliptical **NGC 5557**. Switching to 197× in my 18-inch, this 11th-magnitude oval has a bright core that sharpens to an almost stellar nucleus. This object is a good target for smaller apertures as it shows up fairly well in my 10-inch Dob at 133×.

◀ **COSMIC CONNECTIONS** NGC 5614 and NGC 5615 are also cataloged as Arp 178, which hints at their interacting nature. The gravitational influence of NGC 5613, the object to the pair's north, might be responsible for the ring feature and the tail swooping up from NGC 5614 to the upper right.

Navigating North

Our next group of targets lies in the northern reaches of the constellation. Not quite 7° east of 2nd-magnitude Eta Ursae Majoris, or Alkaid, the star marking the end of the Big Dipper's handle, are a pair of 6th-magnitude stars that we'll use as guides. The more northern of the pair is 5.6-magnitude 24 Boötis, with 5.7-magnitude CH Boötis lying a bit more than 1° to its southeast. About 20′ north of a line connecting the pair of stars, we come upon two nice, edge-on galaxies (see the article on page 62 for more on multiple galaxies in the same field). As with quite a few NGC/IC targets, the duo's discovery history is a bit muddled. **NGC 5673** is the more westerly of the pair and, at magnitude 12.1, marginally brighter than 12.4-magnitude **IC 1029** located 10′ to the east-southeast. William Herschel discovered the object we recognize today as IC 1029 on



▶ **BEAUTIES IN BOÖTES** You'll need a large-aperture scope to see detail in these galaxies in the celestial Herdsman, but it's well worth the effort hunting them down. Use this finder chart to plan the itinerary of your galaxy-hop — the constellation's brighter stars serve as jumping-off points, and you can refer to the text for more detailed star-hop instructions.

May 15, 1787. When his son John viewed the area in May of 1830, he observed NGC 5673 — which William had missed — and assumed it was his father's object. John recorded it in the *General Catalogue of Nebulae and Clusters of Stars* (published in 1864) using William's designation, and in 1888 John Dreyer copied the error into the *New General Catalogue of Nebulae and Clusters of Stars*.

Observers who appreciate the beauty of edge-on galaxies will find the field quite rewarding. The pair are nearly the same size and angled in almost the same orientation, but IC 1029's higher surface brightness and brighter core makes it much more apparent. NGC 5673 is crowned by a 13th-magnitude star located about 1′ northwest of the core.

NGC 5676 is a moderately large 11th-magnitude spiral situated about 27′ south of IC 1029. The star CH Boötis is in the same 40′-wide field of view about 19′ to the east-southeast. In my 30-inch at 300×, the galaxy appears fairly bright, very elongated, and has a dusty outer halo surrounding a conspicuous core.

Moving 38′ south-southeast from CH Boötis will put **NGC 5689** in your eyepiece. This 12th-magnitude barred spiral has a moderately bright center with a very faint outer halo elongated almost exactly east-west. My 30-inch at 300× reveals an almost stellar nucleus.

Last But Not Least

The 4th-magnitude star Beta (β) Boötis shines as the tip of the kite asterism.

◀ **SLIVER IN SPACE** Boötes holds several edge-on galaxies, and the spiral NGC 5529 might be one of the finest specimens.

KPNO / NOIRLAB / NSF / AURA / BILL AND SEAN KELLY / ADAM BLOCK

From there, we jump 3° northeast to the 6.1-magnitude star HD 135530, which is in the field of our next target. **NGC 5899** is an 11.7-magnitude barred spiral 12′ southeast of the star. In my 30-inch at 300×, it's elongated with an abruptly brighter, nearly stellar core. NGC 5899 is angled parallel to a row of three dim stars to its west and is the brightest in a group of much fainter galaxies.

Swing about 4.5° southeast for our last stop, the 12.2-magnitude elliptical **NGC 5966**. It shares the field with a bright multiple-star system that will certainly draw your attention. The 6.9-magnitude HD 139341 and 7.8-magnitude HD 139323 make a 2′-wide pairing. HD 139341 is itself a close double that I found impossible to split at in my 18-inch at 295× — this requires better seeing than what I typically get at my observatory. Our galaxy is located a bit less than 3′ southwest of HD 139341 and appears fairly faint with a brighter center and a diffuse outer halo. I also note it to be somewhat elongated east-west.

We have just scratched the surface of this galaxy-rich constellation. Because Boötes is devoid of well-known deep-sky showpieces and Messier objects, many observers might ignore the roughly 900 square degrees of the Herdsman. However, within its boundaries there are more than enough targets to enrich your observing lists, including 37 Arp peculiar galaxies, four Hickson Compact Galaxy Groups, and hundreds of NGC and IC galaxies within reach of backyard telescopes. I've spent many hours enjoying the constellation's splendors. I hope I've inspired you to do the same.

The Herdsman's Galaxies

Object	Type	Surface Brightness	Mag(v)	Size	RA	Dec.
NGC 5248	Barred spiral	13.8	10.3	6.2′ × 4.5′	13^h 37.5^m	+08° 53′
NGC 5414	Peculiar	12.0	12.4	1.0′ × 0.8′	14^h 02.1^m	+09° 56′
NGC 5532	Lenticular	12.8	11.9	1.6′ × 1.6′	14^h 16.9^m	+10° 48′
NGC 5531	Lenticular	13.1	13.5	0.9′ × 0.9′	14^h 16.7^m	+10° 53′
NGC 5653	Spiral	12.9	12.2	1.7′ × 1.3′	14^h 30.2^m	+31° 13′
NGC 5656	Spiral	12.8	11.8	1.9′ × 1.5′	14^h 30.4^m	+35° 19′
NGC 5614	Spiral	13.3	11.7	2.4′ × 2.0′	14^h 24.1^m	+34° 52′
NGC 5529	Spiral	13.5	11.9	6.0′ × 0.7′	14^h 15.6^m	+36° 14′
NGC 5557	Elliptical	12.6	11.0	2.4′ × 1.9′	14^h 18.4^m	+36° 30′
NGC 5673	Barred spiral	12.5	12.1	2.4′ × 0.6′	14^h 31.5^m	+49° 58′
IC 1029	Spiral	12.5	12.4	2.6′ × 0.5′	14^h 32.5^m	+49° 54′
NGC 5676	Spiral	13.2	11.2	3.9′ × 1.8′	14^h 32.8^m	+49° 27′
NGC 5689	Barred spiral	13.0	11.9	3.3′ × 1.0′	14^h 35.5^m	+48° 44′
NGC 5899	Barred spiral	13.0	11.7	3.3′ × 1.4′	15^h 15.1^m	+42° 03′
NGC 5966	Elliptical	13.0	12.2	1.8′ × 1.1′	15^h 35.9^m	+39° 46′

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.

■ Contributing Editor **TED FORTE** enjoys seeking lesser-known celestial sights from his backyard observatory near Sierra Vista, Arizona.

FURTHER READING: For more on the discovery history of NGC and IC objects, see Contributing Editor Steve Gottlieb's website: **https://is.gd/astronomy_mall**.


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

Viewing Galaxies by the Bunch

THE EYES HAVE IT The Virgo galaxy pair NGC 4438 (left) and NGC 4435 (above) are also known as Markarian's Eyes. NGC 4438 is thought to have originally been a normal spiral galaxy, but its shape has become badly distorted through gravitational interactions with its neighbor. Both objects lie at a distance of roughly 52 million light-years and are members of the Virgo Cluster. The Eyes are among the region's most popular targets for backyard telescopes.

ESO

Few sights are more exciting than an eyepiece field containing multiple "island universes."

I've always been attracted to galaxies and really enjoy viewing and imaging these distant deep-sky wonders. I take special pleasure in seeing groups of two or more in a single eyepiece field. Many of these collections feature interacting galaxies with interesting shapes distorted by gravitational effects. While any size telescope can show you several galaxies grouped together, the finest details are reserved for large instruments or best appreciated in photos. Still, there's an undeniable thrill in observing galaxy groups even in smaller scopes.

Lone galaxies are actually the exception — most "island universes" (to use an apt phrase coined by German philosopher Immanuel Kant) occur in groupings of various sizes. It's certainly true that if you use low magnification, it's easy to have a field of view expansive enough to hold several galaxies, but low power also means minimal detail. For this article, I'm going to stick to multi-galaxy fields no greater than ½° wide so that the objects can be viewed together with magnifications in the range of 80× to 300×. Of course, this means some well-known galaxy groups — such as the Leo Triplet (M65, M66, and NGC 3628) and the fine Ursa Major pair, M81 and M82 — won't make the cut. Instead, I want to highlight what I consider the best tight galaxy bunches.

I observe and image with my homemade 32-inch f/6 telescope (*S&T:* May 2011, p. 32) from Gloucester, Massachusetts, where I have Bortle 4.5 (rural/suburban) skies. However, most of the objects described in this article can be viewed with an 8-inch telescope. Of course, the greater the aperture and the darker your skies, the more detail you'll see. I also expect imagers will agree that many of these galaxy groups are wonderfully photogenic.

In Northern Hemisphere springtime and early summer, we are blessed with rich galaxy fields in Leo, Coma Berenices, and Virgo. Let your imagination soar with the realization that in each view you're eyeing the combined light of trillions of stars!

Lurking in Leo

Let's begin our tour with one of my favorite galaxy groupings, located in the mane of Leo, the Lion. Spiral galaxy **NGC 3190** and its companions are members of Hickson Compact Group (HCG) 44. NGC 3190 is a nearly edge-on galaxy 4.4′ across with a distinct warp in its dusty disk. This feature results from its close interaction with **NGC 3187**, a neighboring spiral that displays an iconic S shape — a result of the gravitational tug-of-war with its neighbor. The lovely pair are only 8′ apart. At magnitude 11.2, NGC 3190 is easily seen, while NGC 3187 is distinctly dimmer at magnitude 13.4. If you have good, dark skies, try to trace out its spiral arms. As a bonus, the same field of view includes 10.9-magnitude elliptical galaxy **NGC 3193** and 13.0-magnitude **NGC 3185**. This impressive collection lies some 60 million light-years away and makes a great imaging target.

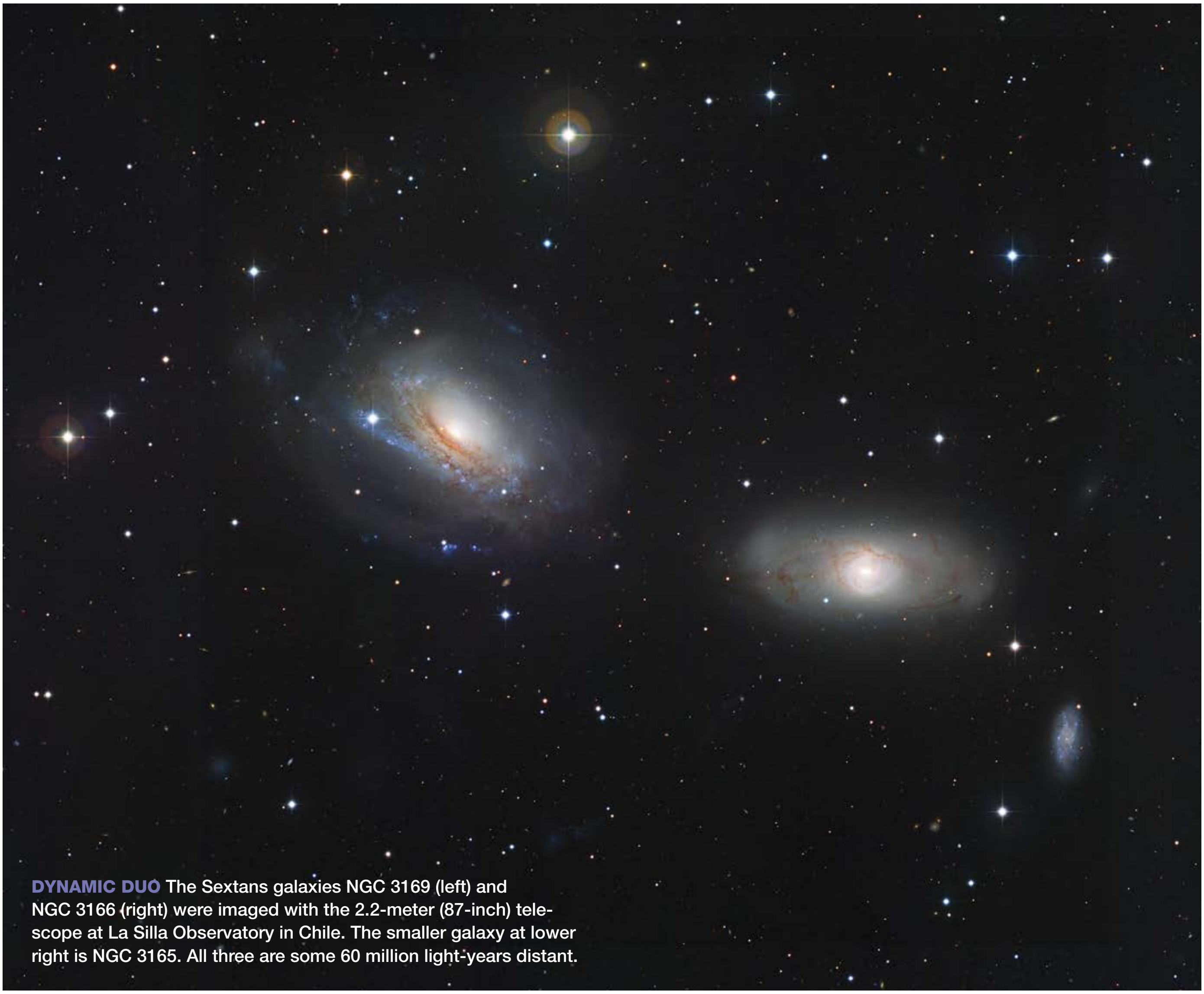
Riding on the back of Leo and 50′ east of the superb double star Algieba, or Gamma (γ) Leonis, is the interacting pair **NGC 3226** and **NGC 3227**. Together known as Arp 94, they're separated by only 2′ and shine at magnitudes 11.4 and 10.3, respectively, which makes them relatively easy to see. The pair are in the process of merging as dwarf elliptical NGC 3226 disrupts the stately spiral NGC 3227. NGC 3226 has an active galactic nucleus emitting energy in radio and X-ray wavelengths and probably harbors a supermassive black hole at its center. Astrophotographers may note a large halo of faint gas surrounding both galaxies — material likely flung out by their tidal interactions. Be careful not to dismiss this feature as a gradient artifact when processing your images!

Now look south to the belly of the Lion for elliptical galaxy **M105** and its companions, **NGC 3384**, and **NGC 3389**. M105 is easily seen at magnitude 9.3, while neighboring elliptical NGC 3384 glows at magnitude 9.9. The third member of the bunch, spiral galaxy NGC 3389, is the faintest at magnitude 11.9. They make a fine sight as a tight trio separated by only a few arcminutes. NGC 3384 is unusual for an elliptical: It has a bar at its center, a feature normally seen only in some spiral galaxies.

Moving south from Regulus, or Alpha (α) Leonis, we cross the border into Sextans to locate 10.4-magnitude **NGC 3166** and 10.2-magnitude **NGC 3169**, separated by 8′. The field includes additional galaxies, the brightest of which is 13.9-magnitude **NGC 3165**, located about 5′ southwest of NGC 3166. Images reveal distinct features resulting from the galaxies' gravitational

▼ **GALAXIES BELOW THE BOWL** The severely distorted spiral NGC 3718 (center right) is among the author's favorite galaxies. Also visible in this field, located south of the Big Dipper's Bowl, are NGC 3729 to the east (image left) and the tight grouping of distant galaxies cataloged as Hickson Compact Group 56 directly south of NGC 3718. The author captured this image and those that follow (except where noted) with the 32-inch telescope he built at his home observatory located north of Boston, Massachusetts.

MARIO MOTTA



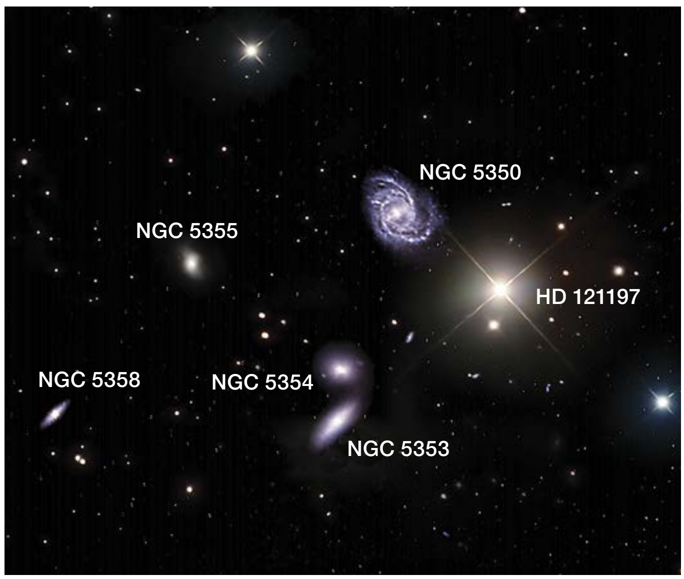
DYNAMIC DUO The Sextans galaxies NGC 3169 (left) and NGC 3166 (right) were imaged with the 2.2-meter (87-inch) telescope at La Silla Observatory in Chile. The smaller galaxy at lower right is NGC 3165. All three are some 60 million light-years distant.

dance — the most conspicuous being NGC 3166's warped disk. The grouping is thought to be trapped in a "death spiral" of tidal interactions that will eventually result in their merger.

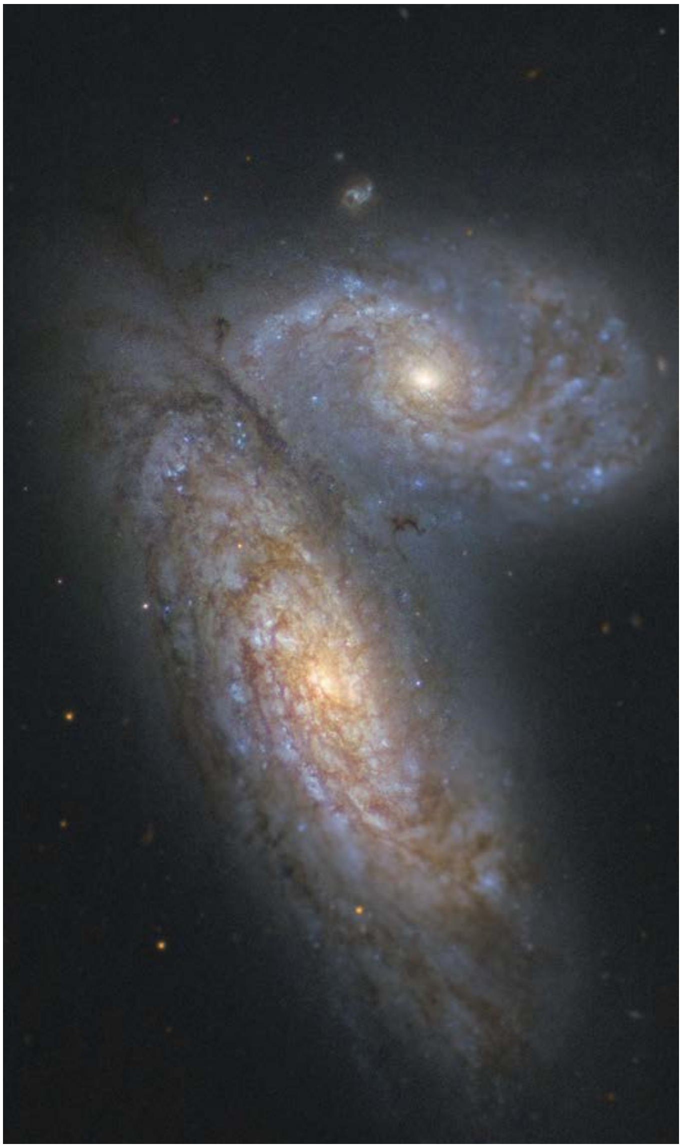
Polar Pleasures

Leaving Sextans behind, let's shift our attention to the far north. In Cepheus, only 4° from the celestial pole, we can sweep up a pair of rarely viewed 11th-magnitude galaxies: **NGC 2300** and **NGC 2276.** The latter is a small spiral galaxy that's difficult to see because it's positioned just northeast of the 8th-magnitude star SAO 1148. Thankfully, lenticular galaxy NGC 2300 is farther from the star and thus easier to observe. Together the pair are known as Arp 114 and lie at a distance of some 90 million light-years. Interestingly, ROSAT X-ray data show that NGC 2300 is bathed in an enormous cloud of hot gas — potentially indicating a concentration of unseen dark matter.

To visit one of my favorite galaxy groups, let's skip over



NGC 3169 GROUP: ESO / IGOR CHEKALIN; NGC 5350: MARIO MOTTA

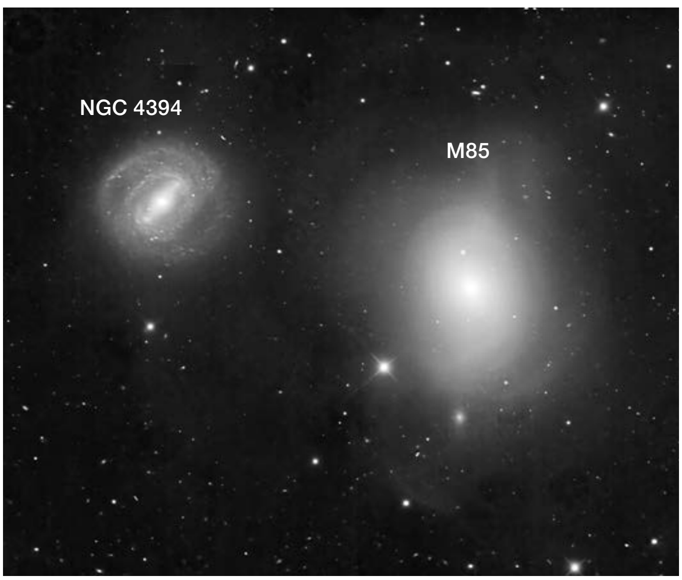


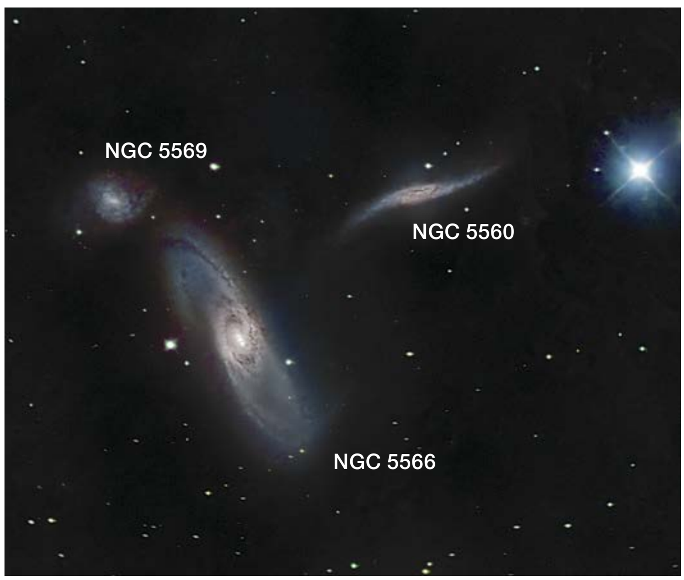
◀ **GALACTIC BUTTERFLIES.** Lying around 60 million light-years away in the constellation Virgo are the striking pair of spiral galaxies NGC 4567 (top) and NGC 4568 (bottom), poetically known as the Butterfly Galaxies. Shining at magnitudes 11.3 and 9.5, respectively, both are within easy reach of backyard scopes. But enjoy the view while you can — 500 million years from now the two objects will merge into a single elliptical galaxy.

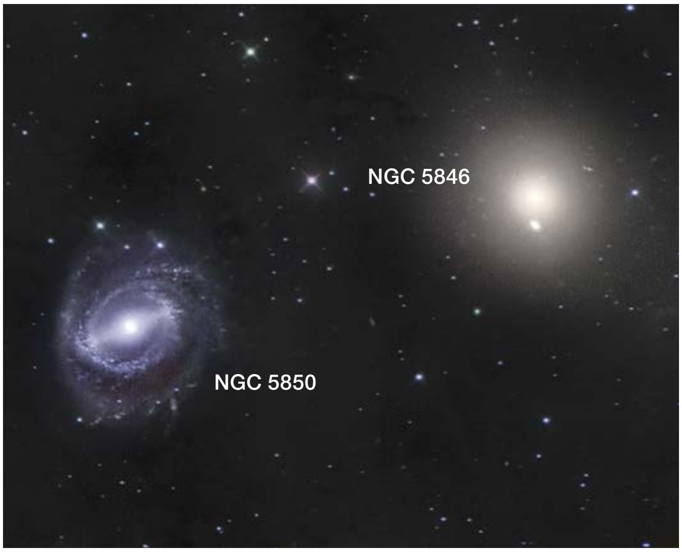
to Ursa Major. South of the Bowl of the Big Dipper you'll find **NGC 3718** shining at magnitude 10.8. It lies some 60 million light-years away and is a member of the Ursa Major Cluster of galaxies, a collection that is in turn part of the Virgo Supercluster. NGC 3718 is a fascinating object with warped S-shaped spiral arms probably resulting from interaction with 11.4-magnitude **NGC 3729**, positioned 12′ east-northeast. Although it looks like a face-on galaxy, NGC 3718 is in fact an edge-on barred spiral. Its "face" is a large central bulge, but the dark dust lane bisecting it gives away the galaxy's edge-on orientation, and what appears to be a pair of spiral arms is really the galaxy's severely warped outer disk. The dust lane that bisects the galaxy's core is warped, too. Visually you need a dark sky to see this detail well, but capturing it in an image is easy.

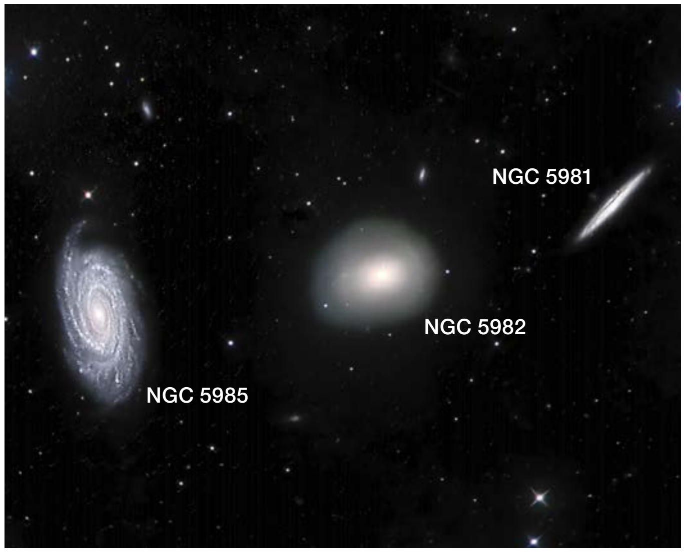
While we're in the area, I have an additional challenge for imagers and those with larger scopes. Look directly south of NGC 3718 to find **HCG 56**. It's comprised of five galaxies that appear to be merging. They're also much farther away than our two NGCs, at a distance of some 370 million light-years. (Both spirals and HCG 56 are pictured on page 63.) Despite their remoteness and small apparent size, the group can be glimpsed in a large scope. As you appreciate the eyepiece view of the two main spirals and HCG 56 together, consider how many trillions of stars are present in this single 20′-wide field.

After plumbing the depths with HCG 56, let's take a break and visit a target closer to home. Shift your gaze about 20° east to locate the famous Whirlpool Galaxy, **M51**, in Canes Venatici. At 22 million light-years distant, the Whirlpool is a spectacular face-on, grand-design spiral that you've likely









viewed many times before. But let's not forget this is a double act — M51 is paired with **NGC 5195**, a galaxy that has lost its spiral structure after interacting with its bigger brother. Ironically, this same interaction may have enhanced the Whirlpool's conspicuous spiral arms, the features that make M51 a telescopic crowd pleaser. NGC 5195 is thought to have passed through M51 hundreds of million years ago and is now positioned behind the big spiral.

Staying in Canes Venatici and heading some 8° south-southeastward we come to **NGC 5353** and **NGC 5354**. They're a close pairing with ends that appear to touch, reminiscent of the Butterfly Galaxies in Virgo (described later). Three more galaxies lie in close proximity, the most noteworthy of which is the open spiral **NGC 5350** north of the pair. Although it's an 11.3-magnitude object, it's visually challenging thanks to the 6.5-magnitude star HD 121197 shining a mere 3′ southwest. Your optics need to be spotlessly clean to glimpse the galaxy.

Realm of the Galaxies

Let's carry on with a deep plunge into the heart of the Virgo Cluster. Here you'll find some 2,000 galaxies scattered like dust within a 6° circle of sky. Without question, this is my favorite place in the universe.

The center of the Virgo Cluster is about 54 million light-years away and anchored by M86 and M84 — two ellipticals surrounded by a veritable zoo of galaxies, many of which are arranged in striking groups. I'll highlight just a handful of the most notable here, but you could productively spend many evenings exploring this remarkable region.

M84 and M86 are the brightest members of Markarian's Chain, which is part of the Virgo Cluster. Following the Chain eastward, you immediately encounter a startling pair of interacting elliptical galaxies dubbed Markarian's Eyes: **NGC 4438** and **NGC 4435**. In the eyepiece you should easily see both "eyes" staring back at you at magnitudes 10.2 and 10.8. Deep images (like the on presented on page 62) record the tenuous, disrupted outer spiral structure of NGC 4438.

Continuing northeast along Markarian's Chain we reach the close pair **NGC 4477** and **NGC 4473**. The former is a barred spiral with a compact structure that displays fine detail in astrophotos. Just 7′ to its south is NGC 4473, a spindle-type galaxy. Together they make a striking visual pair. Images usually add **NGC 4479** — another spindle galaxy lying 5′ southeast of NGC 4477.

Jumping north about 5° from the Chain you'll find another huge elliptical, **M85**, and its close companion, barred spiral **NGC 4394**. In photos, M85 is far from being a "boring elliptical." As the image on page 65 shows, it has a complex structure with several intricate outer shells. The shells are evidence of mergers thought to have occurred within the past 5 to 7 million years. NGC 4394 is a stunning object with a central bar surrounded by an inner ring that merges into a pair of outer spiral arms. These arms wrap completely around the galaxy's core, giving the appearance of a double-ring structure.

Sliding back to the Chain and proceeding roughly 3° farther southeast brings us to the pair of galaxies nicknamed the Butterfly Galaxies, **NGC 4567** and **NGC 4568**. Their proximity isn't an illusion — the two spirals are in the process of merging and may become a single galaxy in roughly a half billion years or so. In smaller scopes they look like a single, hazy check mark, but larger instruments show two glows in contact. As a bonus, see if you can pick up 11.1-magnitude **NGC 4564** just 11′ north-northwest of the main pair.

Lying less than 2° east-northeast of the Butterflies are **M60** and **NGC 4647** — another elliptical and spiral duo. While M60 is easy at magnitude 8.8, its companion is much fainter at magnitude 11.3 and a challenge object for smaller scopes.

Eastern Virgo and Beyond

Moving on into eastern Virgo, our next stop is a visually appealing triple-galaxy system known as Arp 286. **NGC 5566** is the dominant large spiral and is clearly interacting with neighboring **NGC 5560** and **NGC 5569**. NGC 5560 is a beautifully disturbed spiral with a warped disk, and NGC 5569

MARIO MOTTA (2)

is markedly disrupted — likely from its close association with NGC 5566. This grouping offers great visual detail in a moderate-sized scope and is a rewarding imaging target.

Shifting our gaze about 8½° farther east across Virgo to we come to the interacting pair **NGC 5774** and **NGC 5775**. The duo consists of face-on and edge-on galaxies, both of which are challenging in smaller scopes but attractive in moderate and large instruments. Images show a faint bridge of gas being transferred from NGC 5774 to its neighbor.

Let's finish up the Virgo leg of our tour by shifting 4° south-southeast to visit to **NGC 5850** and **NGC 5846**. The two galaxies are visually distinct — NGC 5846 is a 10.0-magnitude spherical elliptical that's easy to see, while NGC 5850 is a fainter, beautiful barred spiral glowing at magnitude 10.8. Images present a wealth of detail. Although they appear only 10′ apart, NGC 5846 is 80 million light-years away while NGC 5850 is quite a bit farther off, at a distance of about 120 million light-years.

Moving northwest, let's briefly jump into the galaxy-rich constellation of Coma Berenices to scope the striking pair **NGC 4302** and **NGC 4298**. Very nice detail is visible in both objects with moderate to large scopes — NGC 4302 is a lovely edge-on galaxy with a dusky lane evident, and NGC 4298, lying only 2′ to the west, displays a tilt of about 30°. Tidal interactions between the two galaxies may have created a tenuous bridge between them.

A Northern Conclusion

Let's wrap up our survey with a personal favorite. Indulge me by heading north once again all the way to Draco. There, near the middle of the long and winding constellation, we find one of the greatest galaxy trios in the sky: **NGC 5981**, **NGC 5982**, and **NGC 5985**, collectively known as the Draco Triplet. This string of galaxies spans 14′ and has it all: an edge-on spiral, an elliptical, and a face-on spiral. Visually they are a treat in telescopes of any size. NGC 5985 has tight spiral structure that's apparent in photos, whereas images of the elliptical, NGC 5982, show hints of some prior galaxy merger. NGC 5981 has a thin dust lane but shows no evidence of interaction with its neighbors. Likely it's just along the same line of sight. Astrophotographers can also record several PGC galaxies in the same field. The Draco Triplet is a fine sight that serves as an excellent introduction to galaxy groups.

Cloudy skies aren't uncommon at this time of year, but perseverance pays off for those wishing to take advantage of the season's rich galaxy fields. I hope that you'll add some of the wonderful groupings I've highlighted to your late-spring/early-summer observing list.

■ MARIO MOTTA is a past president of the Amateur Telescope Makers of Boston. He enjoys introducing visitors to the wonders of the deep sky at his home observatory north of Boston and is a long-time advocate for light-pollution abatement.

Multi-Galaxy Groups

Brightest galaxy	Constellation	Mag(v)	RA	Dec.	Additional galaxies	Other designation
NGC 3190	Leo	11.2	10^h 18.1^m	+21° 50′	NGC 3185, 3187, 3193	HCG 44
NGC 3227	Leo	10.3	10^h 23.5^m	+19° 52′	NGC 3226	Arp 94
M105	Leo	9.3	10^h 47.8^m	+12° 35′	NGC 3384, 3389	
NGC 3169	Sextans	10.2	10^h 14.2^m	+03° 28′	NGC 3165, 3166	
NGC 2300	Cepheus	11.0	07^h 32.3^m	+85° 43′	NGC 2276	Arp 114
NGC 3718	Ursa Major	10.8	11^h 32.6^m	+53° 04′	NGC 3729, HCG 56	
M51	Canes Venatici	8.4	13^h 29.9^m	+47° 12′	NGC 5195	Whirlpool Galaxy
NGC 5353	Canes Venatici	11.0	13^h 53.4^m	+40° 17′	NGC 5350, 5354	
NGC 4438	Virgo	10.2	12^h 27.8^m	+13° 01′	NGC 4435	Markarian's Eyes
NGC 4473	Coma Berenices	10.2	12^h 29.8^m	+13° 26′	NGC 4477, 4479	
M85	Coma Berenices	9.1	12^h 25.4^m	+18° 11′	NGC 4394	
NGC 4568	Virgo	10.8	12^h 36.6^m	+11° 14′	NGC 4564, 4567	Butterfly Galaxies
M60	Virgo	8.8	12^h 43.7^m	+11° 33′	NGC 4647	Arp 116
NGC 5566	Virgo	10.6	14^h 20.3^m	+03° 56′	NGC 5560, 5569	Arp 286
NGC 5774	Virgo	12.4	14^h 20.9^m	+03° 14′	NGC 5775	
NGC 5846	Virgo	10.0	15^h 06.5^m	+01° 36′	NGC 5850	
NGC 4298	Coma Berenices	11.3	14^h 36.4^m	+14° 36′	NGC 4302	
NGC 5985	Draco	11.1	15^h 39.6^m	+59° 20′	NGC 5981, 5982	Draco Triplet

Right ascension and declination are for equinox 2000.0.

The ZWO Seestar S30 Telescope

This pintsized powerhouse takes images of the night sky that will surprise even seasoned astrophotographers.

◀ The Seestar S30 is a tiny "observing station" built around a 30-mm apochromatic refracting telescope and integrated CMOS sensor. The scope comes with a table-top tripod, solar filter, USB charging cable, quick-start guide booklet, and a custom-fitted carry case (not pictured).

ALL IMAGES COURTESY OF THE AUTHOR

Seestar S30 Telescope

U.S. Price: $349
zwoastro.com

What We Like

Produces decent deep-sky images

Powerful control and processing app

What We Don't Like

Image noise caused by field rotation

Wide-angle camera cannot be used for deep-sky imaging

THE SMART-TELESCOPE revolution rolls on with the latest entry in this growing market, ZWO's Seestar S30. Unless you've been on a desert island and don't know what a smart telescope is, they're small robotic instruments that point at and take images of sky objects with little or no human intervention. These devices make obtaining astrophotos of surprising quality easy for just about anyone.

The Seestar S30 is a sleek, modern-looking device with a shiny, white plastic body and black trim that looks more like a security camera than it does an astronomical telescope. That's what it is though, a 30-mm aperture apochromatic refracting telescope. Its three-element objective lens has a focal length of 150 mm, resulting in a focal ratio of f/5. In addition, the S30 sports a second objective separate from the main telescope, a wide-angle lens with a 23.2° field of view.

The optics are only part of the story, however. The heart of the S30 is an integrated one-shot color camera built around a Sony IMX662 CMOS sensor with an array of 1,920 × 1,080 pixels (2.1 megapixels). Together the system produces a 1.2° × 2.4° field of view. In addition, the scope is equipped with dual-axis drive motors, internal computer, on-board Wi-Fi, a rechargeable battery, an internal dew heater, and a dual-band light-pollution filter that can be switched in and out automatically or through the control app. The S30 is an amazingly small and compact package weighing a mere 1.65 kilograms (3.64 pounds) and measuring just 21 × 14 × 8 centimeters (8.3 × 5.5 × 3.1 inches) excluding its tabletop tripod.

In the Box

In addition to the S30 itself, opening the box reveals a custom-fitted carry case, a solar filter, and a USB charging cable as well as the tiny tripod and a short instruction brochure. What you won't find in the box is a hand controller. The S30, like most other smartscopes, is controlled wirelessly with an Apple or Android device such as a smartphone or tablet using the *Seestar* app (available on the Apple App Store or the Android Play Store). You connect your device to the scope via the S30's onboard Wi-Fi. Images are displayed and saved on your phone or tablet. There is no printed manual, but the app includes setup and operation tutorials.

The *Seestar* app is primarily designed for use on smartphones and tablets, though if you are the owner of a recent Apple Macintosh with an M2 processor or better, the iPhone app works just as well on your computer. While the display is vertically oriented like on a tablet, it doesn't take up the entire Mac screen.

Getting Connected

I've had problems pairing my smart devices to some Wi-Fi-enabled telescopes in the past, but I had no trouble connecting to the S30, which operates on both 4G and 5G networks. To turn on the telescope, press and hold the power button until it beeps twice, then wait until the S30 says "Power on, ready to connect!" Next, start the *Seestar* app and follow the prompts. The only quirk is you'll be asked to allow the S30 to connect via Bluetooth during initial setup (the only time Bluetooth is used). Your device will then be paired directly to the telescope.

Direct connection is helpful in the field away from Wi-Fi networks, but at home it's better to pair with the telescope through your local network. That allows the phone to remain connected to the internet while using the scope. To do this, select ***Station Mode*** in setup and enter the Wi-Fi password. One important benefit of Station Mode is your phone or tablet doesn't have to remain near the telescope while imaging. All that's necessary is for the S30 to be within range of the network router some 15 meters or so (50 feet).

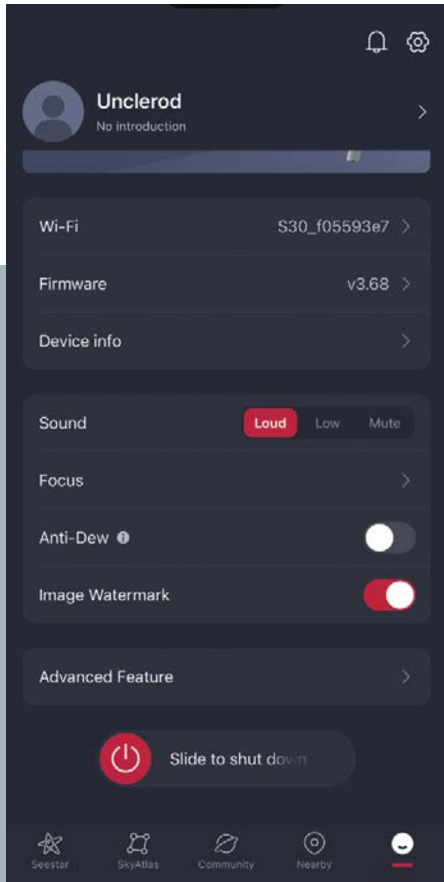
I was anxious to get the S30 into my backyard and see what it could do. One thing was obvious: The tabletop tripod wouldn't work for my needs. I didn't have a table or other flat, level surface on which to place it. Luckily, the S30 connects to any photo tripod via a standard ⅜ × 16 threaded socket on its base, and I was able to use a telescope tripod I own. Before heading out to the backyard, I made sure the battery was fully charged, which took several hours. The telescope runs about 6 hours on a charge with normal use, and 3½ hours when the dew heater is enabled.

It's important to level the S30's tripod to ensure adequate star tracking with this alt-azimuth telescope. The app features a clever ***Adjust Level*** function. Touch the picture of the telescope at the top of the screen, then tap ***Advanced Feature*** followed by Calibrate, then tap the ***Adjust*** button. A window with two circles opens, and the S30 says "Please level your Seestar." To do so, simply adjust the tripod legs until the circles overlap and the displayed number is as low as possible (I usually tried for 0.2). Once you're satisfied with your efforts, close the window and return to the main screen.

Basic Operation

To begin using the S30, select a target from the app's main screen. The first categories are ***Stargazing, Solar System***,

▲ Controlling the S30 (and its big brother, the Seestar S50) is done with the *Seestar* iOS/Android app. The app contains several video tutorials to help users quickly get acquainted with the scope. Begin by connecting to the device via its built-in Wi-Fi and Bluetooth receivers. The app also permits connection via a local area network (LAN) if one is available.



▲ Opening the ***Me*** icon at bottom right of the screen brings up information about the S30. Here you can adjust a few settings including focus, activating the Anti-Dew heater, and watermark images with the name of the object and total exposure time. The shortcut for the ***Advanced Feature*** menu is also found here.

▲ The *Seestar* app includes a planetarium feature called ***SkyAtlas*** (the second icon from left at the bottom of the main screen). In it, you can scroll around the sky to select and frame your targets. Zooming is performed by moving two fingers apart at your area of interest.

and ***Scenery***. The last option allows you to shoot photos and videos of terrestrial objects as close as 6 meters (20 feet) away. It was fun to plop the scope down and scan around the neighborhood, using the scope as a 150-mm zoom lens to look at the bird feeder or objects farther afield.

As noted earlier, the S30 also includes a separate, wide-angle objective paired to a smaller detector (ZWO doesn't give any additional details about the lens or its sensor). I was hoping to see how it performed on the night sky, but unfortunately it's only operational in either ***Scenery*** and ***Solar System*** mode. It produces interesting low-resolution views of the Moon, and landscapes that were inferior to photos taken with most any smartphone. If at some point the wide-angle objective becomes available for deep-sky imaging in a future update, I could see using it for images of the Milky Way and other large vistas. For now, it's pretty much a novelty.

In ***Solar System*** mode, the main optics and camera of the S30 take pleasing images of the Moon, Sun (when fitted with the included filter), and bright comets. In this mode, it can record still images as well as videos you can later stack to produce even sharper results. It also offers 2× and 4× digital zoom. While the zoom feature works, it doesn't provide enough additional magnification to help much with planets. Saturn's rings are detectable, and Jupiter's moons are visible, but if the planets are your major interest, this is not the scope for you.

The Little Scope That Could

Where the S30 really shines is with its deep-sky imaging capabilities. You can choose your targets from ***Tonight's Best, Deep Sky***, or ***Solar System*** categories. You can also locate objects with the search bar at the top of the screen. I couldn't find a specification for the number of objects in its database, but the ***SkyAtlas*** (found on the bottom of the main screen) includes the Messier and NGC/IC catalogs. You can also slew directly to any position in the sky by using right ascension and declination coordinates.

Once you've made your selection, tap ***Locate Target Position***. This centers the object on the SkyAtlas. Tapping the ***GoTo*** button slews the S30 to the object and use *plate solving* (taking short exposures of the field and comparing the star patterns to those stored in the S30's internal memory) to precisely match the framing seen in the SkyAtlas. After the object is centered, the app presents a live video display of the field. This is where you can focus and touch-up centering if necessary. Focus is performed via the ***Autofocus*** icon. In about a minute, the S30 was focused and delivering sharp stars.

On one of my first nights with the S30, I decided to try an "impossible" (at least from my yard) target: a 2½° stretch of faint emission nebulosity in Perseus known as the California Nebula, NGC 1499. I've never been able to produce a good photo of it from my bright Bortle 6 sky and didn't expect to with this tiny, inexpensive telescope. When the S30 stopped slewing, though,

◀ *Left:* Selecting the ***Objects*** icon within the SkyAtlas opens a new screen providing several ways to find targets. At the top is a general search function followed by tonight's best. You can also select objects by type (Deep Sky or Solar System).

◀ *Right:* After acquiring your target, the *Seestar* app offers several options along the right of the screen before you begin accumulating more exposures. Here you can activate the light-pollution (LP) filter, adjust the brightness of the image, or apply the Intelligent Denoising process to the image. The app can also identify objects in the field.

▶ *Facing page, near right:* The S30's field of view is adequate for capturing most deep-sky objects, though large galaxies like M31 don't quite fit in the frame unless oriented just right. *Middle right:* A recent update to the Seestar app enabled a new mosaicking feature. Activated by clicking Framing at the right of the screen. This lets you expand the field to plan mosaics. *Far right:* The mosaic frame can also be rotated to permit any composition you desire.

to my surprise I could see a trace of something on the live view.

The S30 had automatically engaged its light pollution filter (it detects when the filter can improve an object), and all I had to do was tap the button at the bottom of the display to start imaging. The scope began recording and stacking 10-second exposures, updating the screen with each additional image. After a couple of minutes, there was a recognizable view of the nebula displayed on my phone. An hour's exposure (during which I did nothing but sit on the couch and watch TV) rendered a picture of the California Nebula better than I've achieved from bright or dark sites. Finished photos are watermarked with the object's name, date and time of exposure, and telescope operator, but that can be disabled in the main menu.

Shortly after I received the S30, ZWO issued a major update to the app which, among other things, added an ***Intelligent Denoising*** function that's applied while the image is accumulating exposures. Using that for my picture improved it even further. I also found that the Denoising feature sometimes made light pollution gradients and other artifacts in my pictures more apparent, but in general the feature works well.

◀ The S30 produced this 1-hour exposure of The California Nebula (NGC 1499) while imaging through its built-in light-pollution filter. The only additional processing was application of the ***Intelligent Denoising*** to clean up any residual noise.

The story was the same with other challenging deep-sky objects. Nebulae so dim I've never had any success imaging them from home, like IC 405, the Flaming Star Nebula in Auriga, or B33, the Horsehead Nebula in Orion were easy to capture with this pintsized powerhouse. Given the telescope's short focal length, large nebulae, galaxies, open clusters, and the rare bright comet are its prime targets. It does a passable job on smaller galaxies and globular clusters, but they aren't large enough to reveal much detail other than looking distinctly nonstellar.

Expanding the Field with Mosaics

The Seestar's 1.2° × 2.4° field of view is adequate for most large objects, but

what about really big ones like M31, the Andromeda Galaxy? The S30 fit it into the frame when the galaxy is properly orientated with respect to the scope's rectangular field. It would be nice to place some dark sky around it, though. Shortly after I began testing, there was an update to the app which added a feature called ***Framing*** to the SkyMap.

Framing lets you expand and rotate the field-of-view indicator in the Sky-Map to accommodate larger fields than a single pointing can achieve. After you adjust the frame size and rotation to your liking, the S30 reports the time required for the exposure. In the case of my new framing for M31 the app indicated the S30 would take 2½ hours to move to and expose the sky at various positions on and around M31.

The Framing mode worked, but filling in all the area would have required twice the estimated time, about 4 hours. With the galaxy heading into trees, I stopped after 2 hours. This mode is best if you're under an open sky and can devote an entire night to one or two targets. However, even though I cut the exposure short, the S30 still delivered a larger field than I'd have gotten without Framing.

◀ This image shows progress on the galaxy M31 in ***Framing*** mode as the S30 slowly expanded the field with each additional exposure.

I was more than satisfied with the JPEG pictures the S30 sent to my iPhone. More advanced imagers will be pleased to learn that you can set the device to save the individual subframe exposures and corresponding dark calibration frames in FITS format to the telescope's 64-gigabyte internal memory. These can be retrieved by connecting the scope to a computer with a USB cable or by downloading the images over your local network. You can then stack them yourself using your preferred image-processing software. Tweaking images manually takes time and skill, but results are often better than the pictures the S30 processes automatically.

▲ Applying the ***Intelligent Denoising*** function can greatly improve your pictures, as it did to this 1-hour exposure of the Horsehead Nebula. The version on the left shows the 61-minute exposure as it was automatically processed by the app. The version on the right has Denoising applied.

Final Thoughts

No telescope is perfect, including this impressive little device. One minor issue I experienced was image noise resulting from field rotation. Unless you live at the North or South Pole, stars move in arcs across the sky. An equatorially mounted telescope can follow these arcs, but an alt-azimuth one like the S30 cannot. Instead, it must take short exposures and rotate each frame electronically as it stacks them together so stars don't trail. This works, but in longer exposures it causes noise to appear at the corners of the image, where there is little or no overlap between sub-exposures. The easiest cure for this is cropping combined with the Intelligent Denoise feature. ZWO recently announced that an equatorial mode is in the works.

It isn't very often that a new piece of gear for amateur astronomers has literally caused my jaw to drop. That happened multiple times for me while using this tiny scope. I still can't believe I'm out in my backyard night after night (well the S30 is, I'm in my warm den) delivering images of "impossible" objects like the California and Horsehead Nebulae from my light-polluted sky. All I can say is "Viva the smartscope revolution!"

■ Contributing Editor **ROD MOLLISE** enjoys the ease that smartscopes like the S30 bring to his astrophotography.

What Is a Star Party?

SEAN WALKER

LEAFING THROUGH the pages of this magazine, you may have come across our Events Calendar on page 83 (during the odd months — January, March, and so on). Some listings are labeled "Star Party," and you might very well be wondering what that entails. The word "party" (at least to me) conjures up images of revelry, music, festive meals — in other words, a bucketload of fun. And a "star party" is just that — a bucketload of fun, together under the stars. Astronomers from all over haul their telescopes and, more often than not, family members to congregate in a field for several nights, oohing and aahing at the sights in their eyepieces.

Star parties typically take place in out-of-the-way locations — observers seek dark skies, and the more remote a location, the darker it is (usually). Consequently, accommodation often involves some form of camping but frequently cabins are also available. If you prefer creature comforts, many star parties are a short drive away from a hotel.

On the observing field, you'll encounter a dazzling range of equipment, from binoculars to computerized Go To telescopes to gigantic Dobsonians. Nowadays, you'll also spot imagers, usually sitting by their equipment as it whirrs away, all bathed in the soft glow of red light. Some attendees live up to the "party" bit of the event's name and hang out in rambunctious groups discussing the views in each other's eyepieces — a few observers might be perched atop ladders if they have one of the big Dobs. If you wander into those groups, you'll likely be invited to take a peek through a scope. But some amateurs prefer to do their observing in solitude — they're often set a bit apart so they can focus on their observing undisturbed.

Don't have your own equipment? No problem. You can simply gaze up into the night sky with your eyes alone. Most observers, however, are happy to share the view and will likely ask if you want to take a peek at what they're looking at — indeed, many often bring their scopes intending to do just that.

There's one very important rule that all star-party-goers must adhere to: After twilight, there's to be absolutely *no white light* whatsoever. This means no regular flashlights, and especially no car headlights. Even a phone's screen blinking on in the darkness is frowned upon. To avoid the wrath of fellow observers, equip yourself with a dim red-light flashlight, or even a headlamp so as to keep your hands free.

During the daytime (usually the afternoon, so people can catch up on sleep in the mornings), star parties offer a program of talks to keep you entertained when you're not observing. Speakers hail from all walks of astronomy: Professionals discuss the latest scientific discoveries while amateurs share other facets of the hobby.

If you can't plan a trip to a remote location, many local astronomy clubs organize events closer to home, at schools, public libraries, or city parks. Look up a club near you to find out where their next star party might be.

The main thing is that everybody is welcome. Head to our online resource **https://is.gd/StarParties** and start planning your next adventure under the stars! ■

The Pill-Bottle Secondary Mount

This precision tool is surprisingly easy to construct.

WHEN LAUREN WINGERT discovered that her secondary mirror was too small for her Hubble telescope replica (*S&T:* Dec. 2024, p. 74), she bought a larger secondary and I offered to make a mount for it. The existing mount was one of those frustrating things that use hex wrenches with three tiny adjusting screws, one of which always seems to be hiding directly beneath a spider vane. I decided to make something much easier to use when collimating the scope out in the field. I hoped to make it lightweight, too. Lauren's scope was already front-heavy, and I didn't want to add to that.

And lastly, I wanted to make it out of found parts. Lauren's Hubble project is a masterpiece of adapting common materials to fit a design goal, and I felt that my contribution should express the same philosophy.

So I wandered around my house and shop, looking for inspiration. It didn't take long before my gaze fell upon an empty pill bottle. You know the kind: amber plastic with a white cap that can go on two ways, childproof or simple screw-on. When you get to be my age, you have plenty of them lying around.

The label peels right off, leaving a nice, smooth surface. The plastic is brittle, but if you're careful you can cut it at a 45° angle with a table saw, arm saw, chop saw, or even just a hacksaw.

A little experimentation showed that when the cap was in childproof mode it was too loose to hold the mirror rigidly in place. The screw-on mode, however, let me snug it up good and tight. Plus, that let me cut off the wide rim of the cap and remove the tab and plastic ring that encircled the top of the bottle.

There are two basic ways to attach a secondary mount to the spider: have the center bolt pull the mount upward while the adjustment screws push downward, or vice versa. This design lends itself to the former, in that you can simply drill a hole in the center of the cap and run a bolt up through it. That lets you hang the mount from the spider and even remove the mirror for cleaning without unbolting anything. Using an acorn nut (also known as a cap nut) on the end of the center bolt allows the mount to tilt a bit while you're adjusting collimation. A big fender washer between the acorn nut and the plastic cap prevents the cap from flexing. (You'll need to drill out the apex of the acorn nut for the bolt to pass through, and either lock it down with another nut or glue it in place.)

I find having four adjustment screws is far more intuitive and easier to use than three, so I cut a circle out of a piece of aluminum and tapped four holes in it to accommodate four #10-32 plastic screws. They reach down inside the hollow end of the cap, which holds them snugly in place. I had to scrape off the raised plastic lettering inside the cap to let the bolt ends slide easily around

▼▲ To make a pill-bottle secondary mount, you need the bottle, a center bolt, an acorn nut, a fender washer, four adjustment screws, and an armature to hold the adjustment screws. Plus some paint, glue, and of course a secondary mirror.

JERRY OLTION (3×)

▶ When gluing the mount to the mirror, use three globs of silicone glue. Spread the glue out a bit to make sure it bonds well to the plastic and to the mirror. Get it inside the pill bottle, too. Use toothpick spacers to keep the mount's plastic edge from directly contacting the mirror.

▲ The secondary mount's center bolt goes through the center hole of the spider. The collimation-adjustment screws push it downward, while the center bolt pulls it upward.

LAURA WINGERT

in a circle, but that was straightforward with a small wood chisel. It turned out that the center disk that holds the spider vanes together was a little too wide for the collimation screws' spacing, so Lauren filed notches in it for them to fit.

I tried a metal center bolt, but that proved to be the heaviest part of the entire mount. I couldn't find a long enough plastic bolt, so I made one from some quarter-inch PVC rod I had on hand. The threads cut a little unevenly, so the rod isn't perfectly straight, but it works fine just the same.

I painted everything flat black, then Lauren glued the secondary mirror to the bottle. To make sure she got a good bond, we scuffed up the inside of the bottle and she smeared the silicone glue well up inside it, as well as out onto the rear surface of the mirror. After the glue cured, she painted the back of the mirror flat black, too.

To mount it in the scope, the center bolt slides up through the center hole in the spider and a nut holds the secondary at the right depth. The collimation screws snug down against the cap and tighten everything up. For security you can jam a second nut against the first to prevent loosening, but it's not strictly necessary.

That's the pill-bottle secondary mount. Simple, inexpensive, and extremely effective.

■ Contributing Editor **JERRY OLTION** enjoys building things out of found objects.

NARROWBAND RAINBOW

Kasra Karimi

The large emission nebula NGC 1499, the California Nebula, lies roughly 1,000 light-years away in the constellation of Perseus. An association of hot, young stars, including bright Menkib at bottom right, ionizes the surrounding gas while the stars' strong winds carve the nebula's intricate details.

DETAILS: *Askar 103APO triplet refractor and ZWO ASI6200MC Pro camera. Total exposure: 16 hours through narrowband filters.*

▷ COSMIC OWL

Massimo Di Fusco

Planetary nebula M97 in Ursa Major is a popular target for observers and imagers alike. It formed when the aging, Sun-like star at its center ran out of fuel and expelled its outer layers into space, creating an ionized, gaseous envelope measuring some 2 light-years across.

DETAILS: *Konus Konusky 200-mm Newtonian and Player One Poseidon-C camera. Total exposure: 65.8 hours through Optolong L-Ultimate and L-Quad Enhance filters.*

▽ SHATTERED COMET

Matt Ferguson

Several days after its nucleus had crumbled, Comet ATLAS (C/2024 G3) sported a long, broad dust tail as it cut across Piscis Austrinus above the hills of Cowra in New South Wales, Australia.

DETAILS: *Canon EOS R5 camera and 100-mm lens. Total exposure: 27 minutes at f/2.8, ISO 2000 recorded on January 23rd.*

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Under A Shared Sky

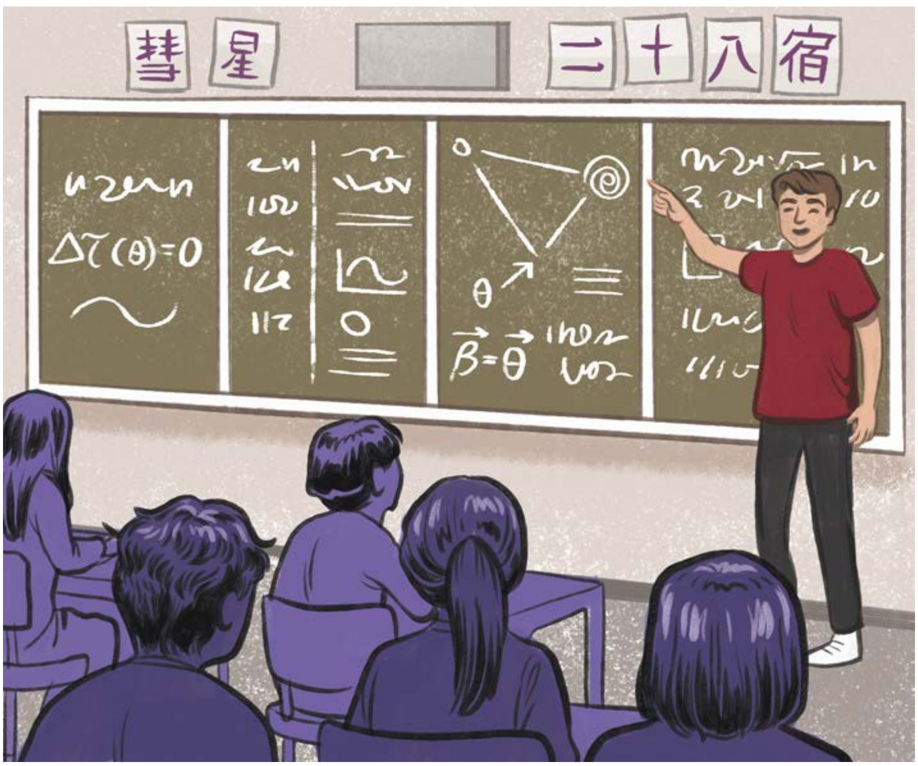
An American university student teaches astronomy in China.

NO MATTER WHAT our vantage point on Earth, on any night the sky will look largely the same. Ignoring the effects of light pollution, someone looking up at the summer stars over Washington, DC, sees approximately the same ones that someone did in Beijing 12 hours earlier. Years ago, as a Carl-Sagan-obsessed child, this observation struck me as profound — that even if we're separated by thousands of miles, by linguistic and political barriers, we share the same night sky. And, crucially, we're driven by the same curiosity. Pondering that, I had to ask: How different are we actually?

Last August, I had the unique opportunity to answer that question, when I taught astronomy in Beijing at the Harvard Summit for Young Leaders in China (HSYLC). Each year, HSYLC runs conferences in four major Chinese cities for advanced students, primarily to enhance dialogue between Americans and Chinese in various fields.

Drawing on my childhood ruminations, I shaped the class by describing the history of astronomy through our cultural relationship with the sky. I covered topics as varied as the Aztecs' measurements of Venus's synodic period; Aryabhata's predictions of Earth's axis of rotation; the Indonesians' observation of Earth's precession; and the Kenyans' precise mapping of bright stars. I sought to demonstrate, as outlined in my syllabus, "humans' relationship with astronomy and . . . the curiosity that brings us all, no matter where we're from or what we believe in, together."

Shortly after lessons began, I quickly discovered that I was as much a pupil in my class as I was its teacher. My students hailed from the country's largest cities as well as its rural provinces. They spoke fluent English or hardly any; some went on luxury vacations while others had never even been to Beijing. And yet all of them, no matter their background, arrived in class with a shared curiosity and a shared excitement about astronomy.



My students' projects were as varied as their backgrounds. One pupil devised his own experiment for determining Earth's radius. After outlining it in class, he hoped to carry it out — but he didn't find a building tall enough to make his measurement! A group taught themselves the physics of comet motion and shared the details on the chalkboard. We learned from each other: Dozens of students would show up in my office, and I'd explain gravitational lensing to them, while they would teach me about the Twenty-Eight Mansions (the Chinese constellations that the Moon travels through each sidereal month). My students expressed the same wonder that second-graders would upon seeing Saturn's rings for the first time in a telescope at school star parties.

I witnessed firsthand the lessons that Carl Sagan taught me as a kid, lived out in my class in Beijing.

After returning to the U.S., the students would occasionally send me photos of their hometown night skies. Although limited by light pollution, their skies, I noted, were little different to mine back home. As our nations and scientific institutions find themselves in uncertain and divisive times, we may be inclined to focus on our differences. But astronomy gives us a unique opportunity to realize that we all share the same sky, the same Earth, and the same curiosity. We mustn't forget to look up into the night sky and see in the stars the interconnectedness of the human story and the generations of humans past who, flirting with challenges here on Earth, used the stars to find their way. Even now, I trust that we won't forget.

■ **WILLIAM J. GOTTEMOLLER** is a second-year undergraduate at Harvard studying astrophysics. William's grandfather, who inspired his love for astronomy, was a 50-year-long *S&T* subscriber.

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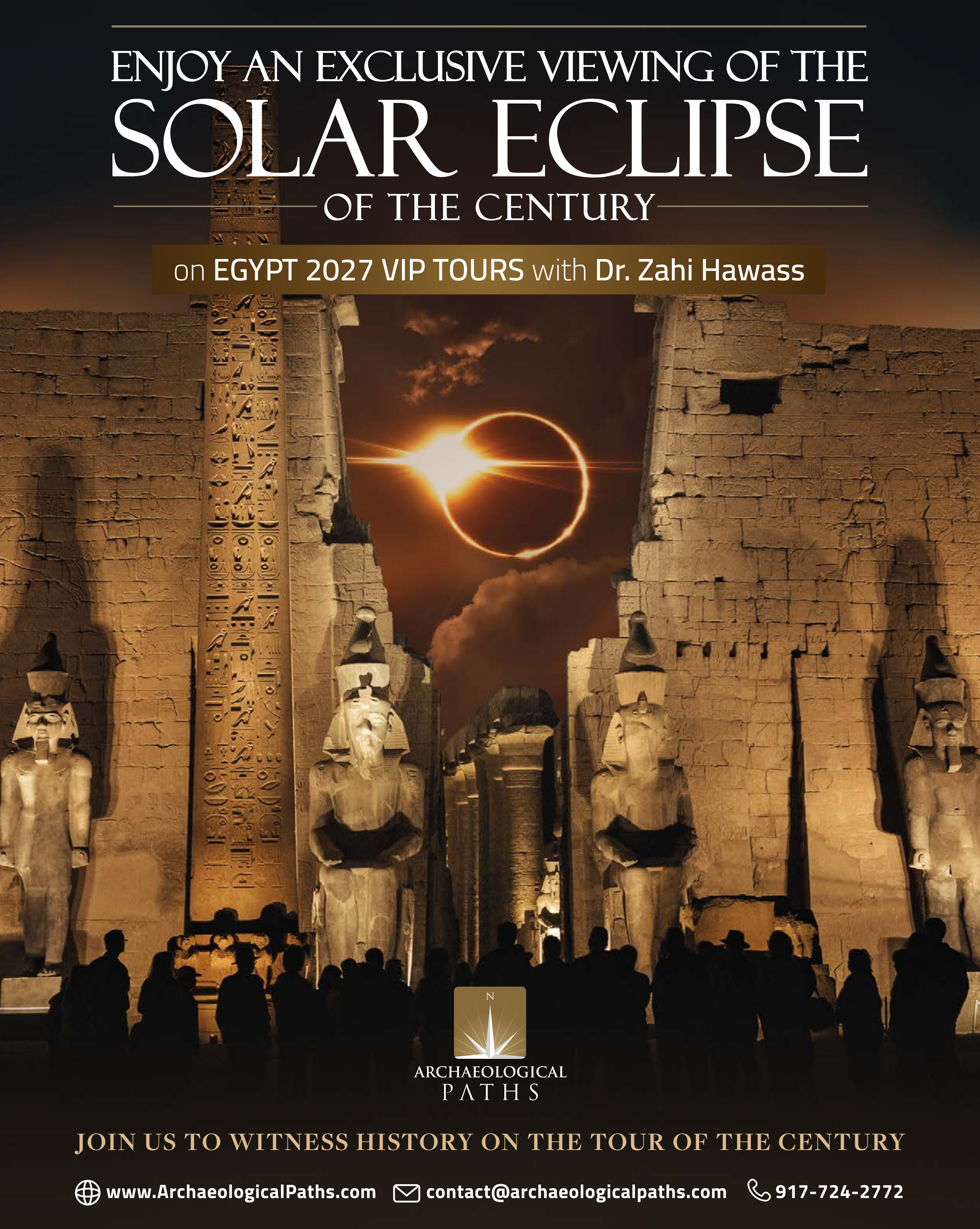
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