**ONE NIGHT ONLY:**
Dash Through the Messiers
PAGE 20

**TEST REPORT:**
Airy Disk's 106-mm Refractor
PAGE 68

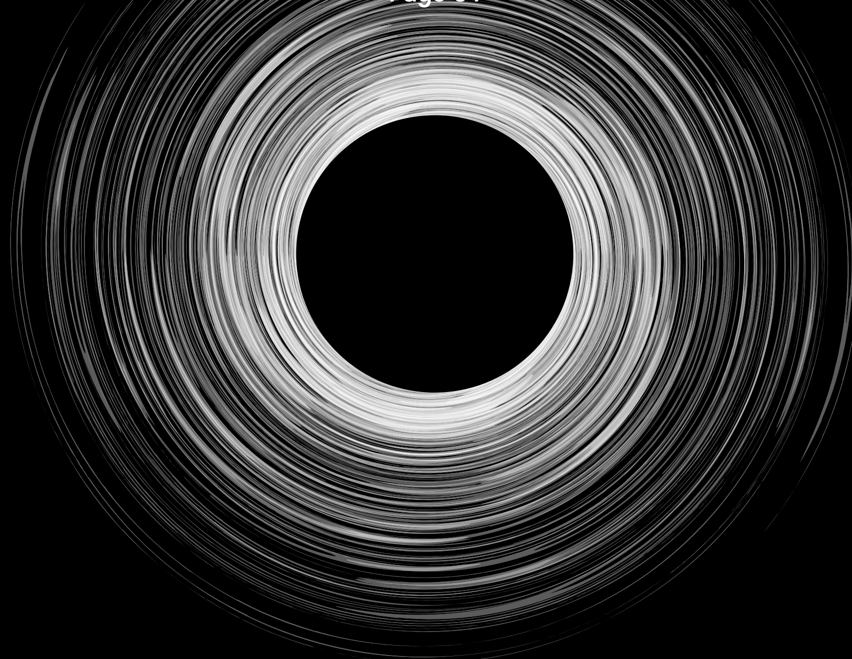
**OBSERVING:**
The Major Lunar Standstill
PAGE 48

# SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY
APRIL 2025

## Primordial Black Holes
# ARE THEY OUT THERE?

Page 34



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CONTENTS

# SKY&TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY


FRANK SACKENHEIM / STEFAN BINNEWIES / JOSEF PÖPSEL / CAPELLA OBSERVATORY

## FEATURES



## OBSERVING



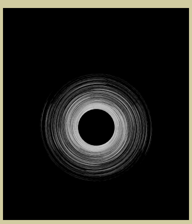
## S&T TEST REPORT



## COLUMNS / DEPARTMENTS



## ON THE COVER



Conceptual illustration of a black hole

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# April's Assortments

**OFTENTIMES,** this column highlights a particular subject or article in the issue. But this month, I can't pick just one. So let me instead give you a whirlwind tour — the magazine equivalent of a Messier Marathon.

This is indeed the time of year to tackle the marathon, in which hardy observers attempt to espy all 110 Messier objects in one night. On page 20, Jan Hattenbach and Ronald Stoyan offer invaluable tips on how to bag the lot — you'll want to follow those closely if you aim to complete the marathon in one go. You'll need to position yourself in the right place and the right time to complete this task — but as the authors mention, it's an inspiring exercise simply to attempt it, if anything as a test of your observing skills. At the same time, you'll be following in the footsteps of a historic observer.

Regular readers will know that Science Editor Camille Carlisle has a special fondness for black holes. So who better to regale us with a tale of whether primordial ones formed in the earliest moments of the universe? Far from esoteric, these little enigmas could solve big mysteries, and the very question of their existence has sparked lively debate in the astronomical community. Camille weaves a mighty good yarn, threading origin stories with implications for dark matter research and galaxy-formation scenarios. Turn to page 34 to immerse yourself in her thought-provoking essay.

*S&T* has been a part of the (current) American Astronomical Society since 2019 — this AAS has been around since 1899. But did you know that there was a different AAS even earlier, formed by a bunch of intrepid astronomers in 1880s Brooklyn? On page 28, Contributing Editor Trudy Bell takes us on a journey back in time and offers us intriguing insights into the formation, development, and subsequent demise of this short-lived astronomical society.

For those imagers among you who have struggled with off-kilter detectors, Chris Schur outlines a methodical approach on page 62 for correcting a tilted sensor. He shares his ingenious method as clear step-by-step instructions, complete with informative photos. (I was inspired to go off in search of my toolbox.) If you follow his carefully outlined plan, you, too, can aspire to record perfect pinpoint stars right across your image, from edge to starry edge.

One last thing: April is Northeast Astronomy Forum month. At *S&T*, we're all excited to once again set up our booth at Rockland Community College in Suffern, New York, on April 5–6. We're especially looking forward to meeting you, our readers and subscribers. So, if you're planning on attending NEAF, please also make time to come by and say hello — we'll be delighted to have a chat. Hope to see you in Suffern!

Editor in Chief

**SKY & TELESCOPE**
**The Essential Guide to Astronomy**

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

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## Breathless Galaxy Cluster

In "Ancient Lights Magnified by Cosmic Lenses" by José Diego and Steven Willner (*S&T:* Oct. 2024, p. 36), the opening image is just utterly outstanding and incredible! This image of an early galaxy cluster that used data from both the James Webb and Hubble Space Telescopes leaves me breathless. My husband and I just said "WOW!!!"

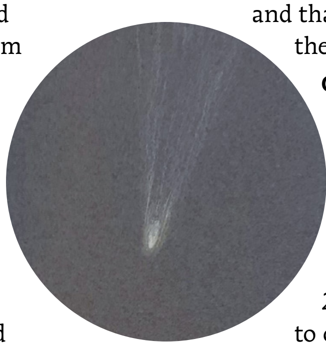
**Barbara Barnes • Junction, Texas**

▲ This image of MACS0416 opened "Ancient Lights Magnified by Cosmic Lenses" in the October issue. The colors indicate wavelength, with the shortest in blue and the longest in red. Redder galaxies tend to be more distant or are suffused with dust.

## Calming Comet

On October 17, 2024, I showed some of my neighbors the beautiful Comet Tsuchinshan-ATLAS (C/2023 A3) through my 8-inch Celestron Schmidt-Cassegrain, after reading about it in Bob King's "Comet Tsuchinshan-ATLAS on the Morning Stage" (*S&T:* Sept. 2024, p. 48) and "Comet Tsuchinshan-ATLAS Soars at Dusk" (*S&T:* Oct. 2024, p. 48).

Here in Florida, we had all been dealing with the stress and hardship of recovering from the effects of Hurricane Milton sweeping across our state a few weeks earlier, and I wanted to share the view with my neighbors. It was a fantastic sight, ethereal and lovely. One of my neighbors said it reminded him of how beautiful nature can be, especially after seeing how destructive and frightening it can be.



I was so moved by those comments that I not only drew a colored pencil sketch of how the comet looked through the eyepiece that evening but also emailed Bob King to thank him for his articles. He responded with a very cordial and friendly email.

Thank you, Bob, for your kindness, and thank you, *S&T*, for being there each month.

**Greg Simpson**
**Pinellas Park, Florida**

## The Big Chomp

I read Günther Juncker's letter "The Pac-Man in the Moon" (*S&T:* Nov. 2024, p. 6) and would like to offer Walther Crater as a possibility: **https://is.gd/WaltherSunset**. If you watch the animation, it illustrates quite a chomp-down!

I've recently been fixated on Walther after having caught it back in June. Then, the rim of the crater was illuminated all around while the interior was inky black, save for that region of uplift, which gave the appearance of a spooky face rising up out of that deep, dark tarn. Edgar Allan Poe would have loved it!

**Dave Ross**
**North Canton, Ohio**

**Jerry Oltion replies:** *Excellent find! Walther Crater certainly looks like a good candidate for Günther Juncker's Pac-Man. It's 134 kilometers across (83 miles), so it's certainly large enough to be conspicuous even in a small telescope, and those closing shadows in the animation certainly do look like a Pac-Man in action. It looks like this would be visible right around third quarter. Cindy Krach, illustrator of my article "Go Loony for Luna!"* (S&T: *July 2024, p. 34), also found that same website, and is including the Pac-Man in her personal list of Clair Obscur and Interesting Light Features. She's also considering making an Astronomical League observing program with these lunar features, which would include this interesting light-ray event as well as others. We tried to catch this during the last lunation's third quarter, but the weather stymied us. We'll keep trying. Thanks for the tip!*

## DIY Refractors

I read Jerry Oltion's "Build Your Own Refractor" (*S&T:* Nov. 2024, p. 60) with interest. As a lidar engineer, I have been building inexpensive refractors for professional and personal use for years from readily available refractive achromats in the 25-to-100-mm class. I've wondered why more folks didn't do so given the availability of quality optics.

The sturdy lens tubes, eyepiece adapters, and brackets from suppliers like Thorlabs make the assembly of high-quality refractors up to 3 inches (76 mm) quite easy and relatively cost effective. Extension adapters can be used to accommodate lens diameters larger than 3 inches along the lines of Jerry Oltion's scope, and adapters for 1.25-inch eye-

MACS0416: NASA / ESA / CSA / STSCI / JOSÉ M. DIEGO (IFCA), JORDAN C. J. D'SILVA (UWA), ANTON M. KOEKEMOER (STSCI), JAKE SUMMERS (ASU), ROGIER WINDHORST (ASU), HAOJING YAN (UNIV. OF MISSOURI); COMET SKETCH: GREG SIMPSON pieces to the 2-inch Thorlabs lens tubes can be found or made. Building quality beginner scopes that will not disappoint beginners is relatively straightforward and quite satisfying. Moreover, they have the added feature of easy assembly and disassembly for portable telescopes that pack into convenient carrying cases.

**Carvel Holton**
**Blacksburg, Virginia**

## Lost But Not Forgotten

Reading Richard Wright's "Travel Tips for the Astro-Adventurer" (*S&T:* Oct. 2024, p. 62), I thought of my trip to see my first solar eclipse in 1991, and I agree: Keep your telescope with you always!

I was on my way from northern California to the Baja California Peninsula in Mexico and stopped in San Francisco on the way to my sister's apartment. Foolishly, I left my Edmund Scientific Voyager 6001 telescope and camera in the back of my pickup-truck shell. My truck was broken into overnight, so instead of viewing the eclipse with my telescope, I viewed it with my naked eye. But, not being distracted by a telescope, I saw shadow bands on a white sheet I brought with me and appreciated all the details of the landscape. I miss it though, that was a great little telescope.

I was also sad to see Govert Schilling's obituary for Wil Tirion (*S&T:* Nov. 2024, p. 10). I bought his charts (*Sky Atlas 2000.0*) in high school back in 1981 and used them with my Voyager 6001 until its loss. Today, I still use them with my 6-inch Orion Dobsonian. Although now I have to wear glasses to see them in the dark!

**Caroline Torkildson**
**Duluth, Minnesota**

## One Last Pleiad

I thoroughly enjoyed reading Ray Norris's "Why Are There Seven Sisters?" (*S&T:* Nov. 2024, p. 36), Stephen O'Meara's "Tales of the Pleiades" (*S&T:* Nov. 2024, p. 45), and Peter Tyson's "A Paean to the Pleiades" (*S&T:* Nov. 2024, p. 4). All of them were interesting and informative.

As a footnote, Maria Mitchell, who was arguably the most famous American astronomer of the 19th century, referred to her students in her poem *The Dome* as,

*"I think of my girls soon women to be*
*Who bring peace and joy to me*
*Who watch the Bear whirl around*
*its lair,*
*Who get up too soon to look at*
*the moon*
*Who go somewhat mad on the*
*last Pleiad"*

**Edward S. Ginsberg**
**University of Massachusetts, Boston**
**Lexington, Massachusetts**

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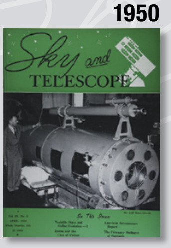
## 75, 50 & 25 YEARS AGO by Roger W. Sinnott

1950




1975


2000


**◖April 1950**

**Variable Universe** "[Alfred H.] Joy's recent investigation shows that the Cepheid variables in globular clusters appear to duplicate closely the spectrum of W Virginis. . . . Similarly, these variables in globular clusters are intrinsically fainter than the corresponding individual Cepheids in the galaxy. Joy concluded that for some obscure reason ordinary Cepheid variables are exceedingly rare, or perhaps completely absent, in the globular clusters . . ."

*Joy's discovery had a profound ramification. Astronomers, in rethinking their use of Cepheids to gauge cosmic distances, would soon push all remote galaxies twice as far away.*

**◖April 1975**

**Solar Power** "Potentially, the sun's radiation is a limitless source of power, far in excess of the world's needs. [The best way to harness this energy] may be to place both the collector and the converter in [synchronous] orbit around the earth. This imaginative concept has been explored by a team of scientists and engineers headed by Peter Glaser of Arthur D. Little, Inc., Cambridge, Massachusetts. . . . The Satellite Solar Power Station as now envisioned is truly enormous, its two collector arrays having a combined area of 45 square kilometers . . .

"The power produced and collected by the SSPS will be converted to microwaves . . . The proposed receiving antenna at the earth's surface is to be over seven kilometers (4.35 miles) in diameter. . . . Fantastic? It is Dr. Glaser's considered opinion that [SSPS] may be operating in the 1990's, supplying electricity at a cost that is competitive with other sources . . ."

*Glaser's vision is still just that, but it got a boost in 2023 when Caltech's Space Solar Power Project successfully sent microwaves from a low-orbit satellite to a small receiver on campus.*

**◖April 2000**

**Healing Hubble** "*December 23rd:* My hands are still sore from the space walk that Steve and I did yesterday. We were outside for more than eight hours, two hours longer than planned. . . .

"For our first task, Steve and I put a support post under the telescope to keep it stable while we worked on it. Then I reached out and touched the telescope for the first time — for me, a magical moment. Next we set out to open the doors on the observatory's aft shroud, where the scientific instruments are housed, but the bolts wouldn't turn with our power wrench, which didn't have enough torque. I set the tool to 'manual' and freed the bolts with a fair amount of force."

*While floating in space aboard Space Shuttle Discovery, astronaut John Grunsfeld penned much of this article about his and Steven Smith's experience repairing the Hubble Space Telescope.*

INNER PLANETS

## Ancient Venus Didn't Have Oceans After All

**ASTRONOMERS HAVE CONDUCTED** a long and fierce debate about whether Venus was always a dry hellscape with oven-like temperatures. Now, as published December 2, 2024, in *Nature Astronomy*, three researchers from the University of Cambridge, UK, offer support for that idea.

Of two rival theories of Venus's past, one argues that Venus was once temperate and hosted oceans of water — enough to cover the surface to a depth of 500 meters (1,600 feet). But then, more recently, volcanoes released vast quantities of carbon dioxide and sulfur dioxide, greenhouse gases that trapped the Sun's heat. The water first evaporated, then escaped into space. Alternatively, Venus may always have been too hot and dry to support liquid water.

Tereza Constantinou and her colleagues utilized the Venusian atmosphere — largely the product of volcanic gases from within the planet — to probe the interior and examine how dry the planet really is.

The team calculated the current rate at which water, carbon dioxide, and carbonyl sulfide (COS) molecules are destroyed in the planet's atmosphere. They also considered chemical reactions occurring between Venus's air and surface, weathering that can cause these molecules to be stored in the planet's crust.

Constantinou and her team conclude that Venus's volcanic gases are at most 6% water. This implies the planet's interior is too dry to ever have brought large quantities of water to the surface.

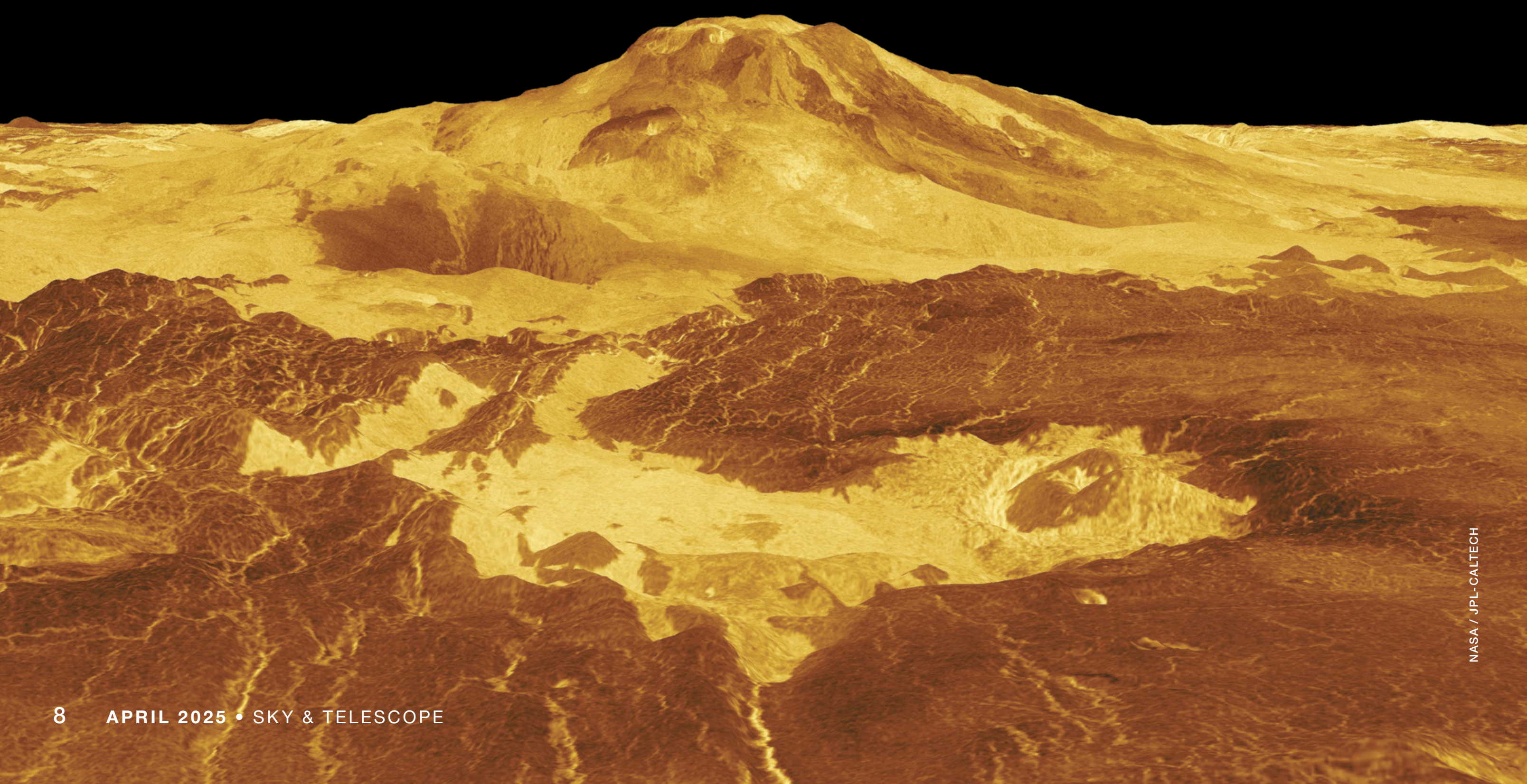
"This is an intriguing study," says James Holmes (Open University, UK), who was not involved in the research. However, he adds, "There still remain uncertainties that are likely to influence the results, such as the precise chemical composition of the deep atmosphere and the current rate of active volcanism."

Not everyone is convinced by these new calculations. "They make two assumptions that I would question," says Richard Ghail (Royal Holloway, University of London), who was also not involved in the research. "Their assumption about Venus surface weathering is, I suspect, wrong." If the team overestimated the amount of carbonyl sulfide and carbon dioxide that chemical reactions deposit into the planet's crust, then there would be fewer of those molecules relative to water. Then, to keep the atmosphere in balance, the amount of water ejected from the planet's interior would need to be higher than the team estimated.

"I think they [also] significantly underestimate the importance of the sulfur cycle," Ghail adds. For example, as sulfur-rich minerals break down on the surface, carbonyl sulfide could be put back in the air, providing another way to shift the ratio of that molecule relative to water. The team admits the story for sulfur is "more nuanced."

Perhaps it will take future missions — including NASA's VERITAS and DAVINCI, and the European Space Agency's Envision — to settle the debate on Venus's past once and for all.
■ COLIN STUART

▼ This computer-generated 3D model of Venus's surface (with a vertical scale exaggerated 10 times) shows the summit of Maat Mons, a site of past and perhaps current volcanic activity.



NASA / JPL-CALTECH

ASTEROID BELT

## New View Shows Surprising Number of Small Asteroids

**A NEW ANALYSIS** of archival James Webb Space Telescope data, published online December 5th in *Nature,* reveals that small asteroids in the main asteroid belt are more numerous than thought. The finding could change calculations of the impact rate on Earth from such bodies, which range from 10 to 500 meters (30 to 1,600 feet) across.

Larger main-belt asteroids, whose orbits are between those of Mars and Jupiter, tend to remain in relatively stable orbits. However, gravitational interactions more frequently perturb smaller objects, which might then enter the inner solar system to become potential impactors. The high number of small objects now found in the main belt — at least five times more than expected — could affect calculations of the frequency of such impacts.

Artem Burdanov (MIT) and colleagues used a shift-and-stack approach, often used to provide images of faint, fast-moving objects in the solar system. Usually, this process involves precisely tracking an object with a known or presumed orbit; dozens or even hundreds of digital images added together can then allow an object to emerge from the random background noise that changes from frame to frame.

But without knowing the orbits of Webb-detected targets (which were found as foreground objects in archival images of the TRAPPIST-1 system), the team used a "brute force" variation on shift-and-stack, looking in every possible direction with reasonable velocity ranges for potential moving targets.

The initial blind search produced more than 1,000 candidates. Burdanov and his colleagues then narrowed these down and confirmed 138 previously unknown asteroids, as well as eight known ones. Because the infrared (thermal) energy emitted per unit surface area doesn't vary much among objects in the asteroid belt, the astronomers could determine the diameters of Webb's discoveries to within 10% to 20%.

▲ As this artist's impression suggests, the region between Mars and Jupiter appears to contain far more small asteroids than previously thought.

These results open the prospect of mining similar JWST datasets, enabling an improved census of various asteroid families. Team member Richard Binzel (MIT) says, "These asteroid findings fill an important knowledge gap for tracing the source of meteorites and larger potentially hazardous asteroids in Earth's vicinity."

■ **DAVID L. CHANDLER**

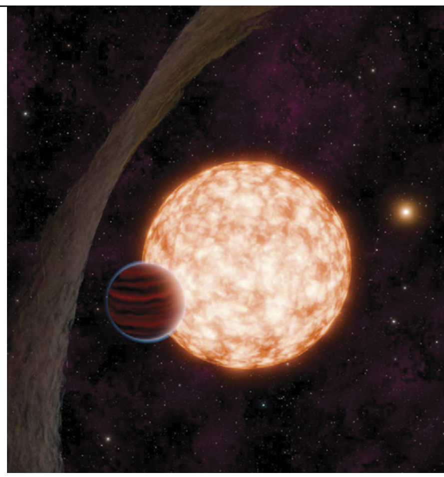
EXOPLANETS

## Transiting Planet Found Around Infant Star

**PLANETS FORM WITHIN** disks of dusty gas encircling newborn stars — disks that tend to shield those planets from view. Now, astronomers have detected a still-forming planet — thanks, perhaps, to a stroke of luck that flipped the obscuring disk out of the way.

The youngest planet previously found by the transit method (in which a planet dims its star's light while passing in front of it) was about 10 million years old — long enough for most of the dusty disk to have cleared. The new planet, found with NASA's Transiting Exoplanet Survey Satellite (TESS) and cataloged as IRAS 04125+2902b, is only about 3 million years old. The discovery is published in the November 21st *Nature.*

Until now, it wasn't clear that planets could form so quickly. While a handful of such young planets have been found via other methods, they tend to be far more massive and moving in wide orbits.



▲ The young exoplanet TIDYE-1b orbits the primary star of a wide binary. This illustration shows the star's planet-forming disk tilted out of the system's orbital plane.

The new planet was only detectable because its star's large outer dust disk is oriented almost perpendicularly to a sparse inner disk in which the newfound planet orbits. The star is part of a widely separated binary about 520 light-years away in Taurus. At first the team thought that the pull of the companion star might have warped the disk, but the secondary star orbits the primary in the same plane as the newfound planet and the inner disk. Instead, it's possible that another star flipped the disk as it passed close by, says study lead Madyson Barber (University of North Carolina at Chapel Hill); however, she adds, "That's not something we can really test." Alternatively, the outer disk may have been warped due to surrounding gas falling in along another plane.

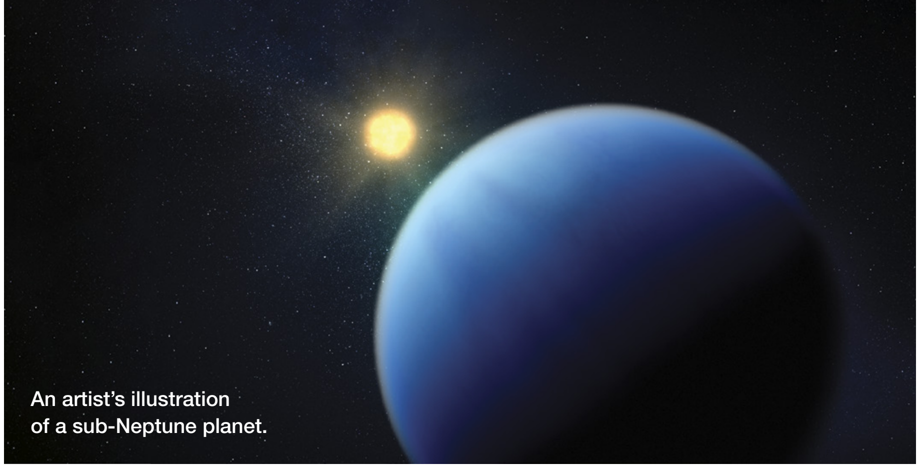
TIDYE-1b, as it's also known, is almost the size of Jupiter and orbits its star every 8.83 days. Yet it has less than 30% of Jupiter's mass, perhaps having lost its outer layers in the face of the young star's winds and radiation. It might end up as a sub-Neptune, a type of planet common in the galaxy but absent in our solar system. Follow-up observations of this young example may shed light on these planets' evolution.

■ **DAVID L. CHANDLER**

ASTEROID BELT ART: NASA / JPL-CALTECH; ARTIST'S ILLUSTRATION OF NEW PLANET IN UNIQUE SYSTEM: NASA / JPL-CALTECH / R. HURT, K. MILLER (CALTECH / IPAC)

EXOPLANETS

## Webb Telescope Reveals "Featherweight Giant" Planet



An artist's illustration of a sub-Neptune planet.

**EVERY NEW YOUNG** transiting planet is a valuable target for planet-formation scenarios — which is why, for several hours in February 2023, the James Webb Space Telescope turned its attention to what was thought to be an infant hot Jupiter called HIP 67522b.

But the new observations, published in December's *Astronomical Journal*, show 17-million-year-old HIP 67522b looks nothing like the giant of our solar system. If the planet had a Jupiter-like mass, its gravity would have hugged its envelope of gases closer. Instead, Webb's observations indicate the atmosphere extends farther out than expected. The puffy atmosphere came as a surprise to the team, led by Pa Chia Thao (University of North Carolina at Chapel Hill), who suggest the planet must have a much smaller mass than anticipated.

Further analysis of the atmosphere's thickness by these researchers implies that HIP 67522b equals roughly 14 Earths. This makes it one of the least-massive giant planets ever discovered — and more similar to sub-Neptunes than Jupiters.

Although sub-Neptunes are absent from our solar system, they're one of the most common types of planets in the galaxy. Astronomers think they might lose their initial gaseous envelopes through processes that include star-induced boil-off. HIP 67522b's low current mass likely dooms it to this fate. It's probably already losing its atmosphere at a prodigious rate, and most of it will be gone in the next billion years. All that will be left is the shrunken core.

"Measuring the atmospheric properties of young planets provides a unique opportunity to understand the formation and evolutionary histories of these planets," says Munazza Alam (Space Telescope Science Institute), who was not involved in the study. "Placing constraints on atmospheric escape early on in a planet's lifetime can help us better understand the processes at play that sculpt their atmospheres."

■ **BENJAMIN CASSESE**

---

KUIPER BELT

## Distant Makemake Might Have a Hot Spot

**DESPITE ITS DISTANCE** from the Sun, the far-flung Kuiper Belt object 136472 Makemake is warmer than expected, leading to some surprising conclusions.

Averaging 45 astronomical units from the Sun and with a brightly reflective methane-ice cover, Makemake should have a mean surface temperature around 40 kelvin. Some 15 years ago, observers indeed found such cold temperatures across most of the body, which spans 1,430 km (900 miles) — but something on (or near) it registered as significantly warmer.

Now observations from the James Webb Space Telescope (JWST) have revealed that some portion of Makemake is even warmer than previously realized, prompting new explanations. The study, led by Csaba Kiss (Konkoly Observatory, Hungary) and published November 20th in *Astrophysical Journal Letters*, combines JWST measurements with those from the Spitzer and Herschel space observatories and the ground-based Atacama Large Millimeter/submillimeter Array to view Makemake's emission over a broad range of wavelengths. According to Kiss's team, the best-fit scenario involves a small patch, as little as 20 km across, of something very warm by Kuiper Belt standards: 150K (–195°F). The source, they suggest, could be a "hot spot," a cryovolcanic flare-up piping heat from the warmer interior.

▲ Distant Makemake and its small, unnamed moon are depicted in an artist's concept.

Another set of JWST observations provides circumstantial evidence for this possibility, revealing that the methane ice on Makemake's surface has less heavy hydrogen, or *deuterium*, than expected, which could result from recent chemical reactions with water.

Alternatively, Kiss and his colleagues suggest that a dark ring could match the observations. Rings aren't unusual, even around small solar system bodies, but the particles circling Makemake would have to be both unusually small and have an unusual carbon-rich composition for the explanation to work — and the ring's orientation would have to be just so to have avoided detection when Makemake occulted a star in 2011.

Kiss and his colleagues point out that the two explanations aren't mutually exclusive. Perhaps the purported cryvolcano erupts tiny carbon-rich particles along with its cryolava, particles that then encircle Makemake as a dark ring.

■ **EMILY LAKDAWALLA**

EXOPLANET ILLO: NASA / ESA / CSA / DANI PLAYER (STSCI); MAKEMAKE AND ITS MOON: NASA / ESA / ALEX PARKER (SWRI)

INNER PLANETS

## Icy Rivers May Have Flowed on Ancient Mars

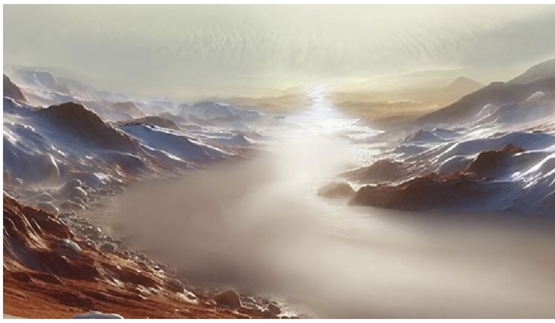
**MARS IS A FROZEN** desert world, enshrouded in an atmosphere too rarefied for liquid water to flow on the planet's surface. Yet the planet's landscape is replete with ancient river networks and other signs of water-based erosion. Peter Buhler (Planetary Science Institute) explores the connection between these valley networks and the polar ice caps in November's *Journal of Geophysical Research: Planets*.

Around 3.6 billion years ago, as its atmosphere thinned, Mars could no longer efficiently transport heat from the warmer equatorial regions up to its poles. Carbon dioxide gas over the poles froze and fell to the ground, building up caps of $CO_2$ ice on top of water ice. Buhler proposes that this carbon-dioxide ice acted like a heavy thermal blanket, trapping the planet's internal heat and melting the base of the water-ice sheet. The meltwater snuck out in ice-encased rivers that oozed like solid-crusted lava flows, Buhler explains.

From the south pole, these rivers could have wound their way equatorward, spilling into Argyre Planitia, an impact basin roughly the size of the Mediterranean Sea. Excess water overflowed that ice-covered lake and then meandered northward again, perhaps draining into equatorial plains thousands of kilometers from the pole. This scenario would explain several geologic features that scientists have observed in these parts of Mars, Buhler says.

Anna Grau Galofre (Laboratory of Planetology and Geosciences, France) says that, at least as far as the larger valleys in the south circumpolar region are concerned, Buhler's scenario is provocative but plausible. But she's skeptical of larger-scale implications for valley networks closer to the equator.

"The strength of this idea is that we know the phenomenon of atmospheric collapse occurs," says planetary geologist James Head (Brown University). "But can it have such a major effect? Fortunately, the hypothesis is testable."



▲ An artist's illustration of an ice-covered river sourced from meltwater beneath Mars's south polar cap.

Both Head and Buhler say these tests include more detailed analyses of geologic features and computer modeling of global climate processes — efforts that could enable scientists to link specific features to model predictions with more confidence.

■ CAMILLE M. CARLISLE

To read more, visit **https://is.gd/MarsIceRivers.**

PETER BUHLER / PSI

## IN BRIEF

### Parker's Closest Approach to the Sun

NASA's Parker Solar Probe flew by the Sun in the first of three close (and closest) approaches that will complete the primary mission. The 22nd perihelion on December 24, 2024, took the spacecraft 6.2 million km (3.9 million miles) from the solar surface — about nine times the Sun's radius, breaking previous record approaches. Since the eighth close pass in April 2021, the mission has truly been "touching the Sun," as it flies through the part of the solar atmosphere dominated by our star's crackling magnetic field. NASA's STEREO A and the European Space Agency's Solar Orbiter, observing from near Earth's vantage point, provided a wider context for the Parker data. The mission's perihelia are now occurring during the peak of activity in Solar Cycle 25, so the observations provide a comparison for data collected during the Sun's quieter years. Project scientist Nour Rawafi (John Hopkins University Applied Physics Laboratory) says the team is planning a proposal to extend the mission for years to come.

■ DAVID DICKINSON

Read more at **https://is.gd/ParkerProbe.**

### Proba 3 Launches to Study Solar Corona

The European Space Agency's Proba 3 rocketed to space on December 5th. Built to provide views of the solar corona, this is the third spacecraft of a series designed to test new technologies while also carrying scientific instruments. The spacecraft will separate into two parts, dubbed the Occulter and the Coronagraph. A 1.4-meter-wide (4.6-foot) disk on the Occulter will cast a shadow onto the Coronagraph's instrument package. For this to work, the two spacecraft must fly 150 meters (500 feet) apart while maintaining their separation to within a few millimeters. In this formation, Proba 3 will image the corona as close as 1.1 solar radii from the Sun, providing the closest view we have right now. (The LASCO C2 camera aboard the Solar and Heliospheric Observatory can only image as close as 1.5 solar radii.) Proba 3's view won't be constant, though. The paired craft have an elongated, 19.7-hour orbit and will only conduct observations during the 6-hour window when they're farthest from Earth. Proba 3's instruments will provide insights into the solar corona, solar wind, and the Sun's total power output.

■ DAVID DICKINSON

Read more at **https://is.gd/Proba3.**

### Lucy's Second Earth Flyby

NASA's Lucy spacecraft passed by Earth on December 12–13 during a gravity-assist maneuver that will help to propel it to the outer solar system. As part of its mission to explore 11 asteroids, Lucy is primarily intended to explore the two camps of objects that circle the Sun in dynamically stable locations on either side of Jupiter: the Greek camp located at Jupiter's $L_4$ Lagrangian point (ahead of the planet on its orbit) and the opposing Trojan camp at the $L_5$ point behind Jupiter. Getting there takes some complicated orbital gymnastics, including three Earth flybys. This one was the second of those; the first occurred in 2022. December's flyby increased the spacecraft's velocity relative to the Sun by 7.3 km/s (16,000 mph). At its closest approach, the spacecraft was only 360 km (220 miles) above our planet's surface, whizzing by at 14.8 km/s relative to Earth. This flyby followed Lucy's visit to 152830 Dinkinesh and its satellite Selam in November 2023 (*S&T:* Mar. 2024, p. 11). Now the spacecraft is headed to the main-belt asteroid 52246 Donaldjohanson, named for the discoverer of the "Lucy" hominid fossil, and will pass 922 km (573 miles) from it on April 20, 2025.

■ DAVID DICKINSON

Read more at **https://is.gd/LucyFlyby2.**

**ASTEROID TRACKS** NASA's WISE space telescope captured dozens of asteroids in this infrared view from March 2010. Some stand out as a series of dots, where each dot in a track shows the asteroid captured at different times as it marched across the sky. The asteroid at center left is called 2415 Ganesa. The open cluster NGC 2158 glitters at center right. The green clouds are gas and dust.

# *Farewell to*
# NEOWISE

From Earth's nearest neighbors to the edge of the observable universe, the WISE/NEOWISE mission gave us an inimitable view of the infrared sky.

Even small spacecraft missions can take nearly a career's worth of time to complete. Such was the case with the Wide-field Infrared Survey Explorer (WISE). First envisioned in 1994 and launched in 2009, WISE mapped the whole infrared sky in six months, seeing everything from nearby cool stars to the most luminous galaxies in the universe. Following its fantastic success at finding and characterizing hard-to-spot Earth-approaching asteroids, this SUV-size spacecraft was given second, third, fourth, and many more chances at life, eventually conducting an extended survey that lasted until July 2024. By the time natural orbital decay forced an end to the mission, the core scientists had been working on it for 30 years. I am a relative newcomer to the project, having started in late 2003 as a freshly minted PhD.

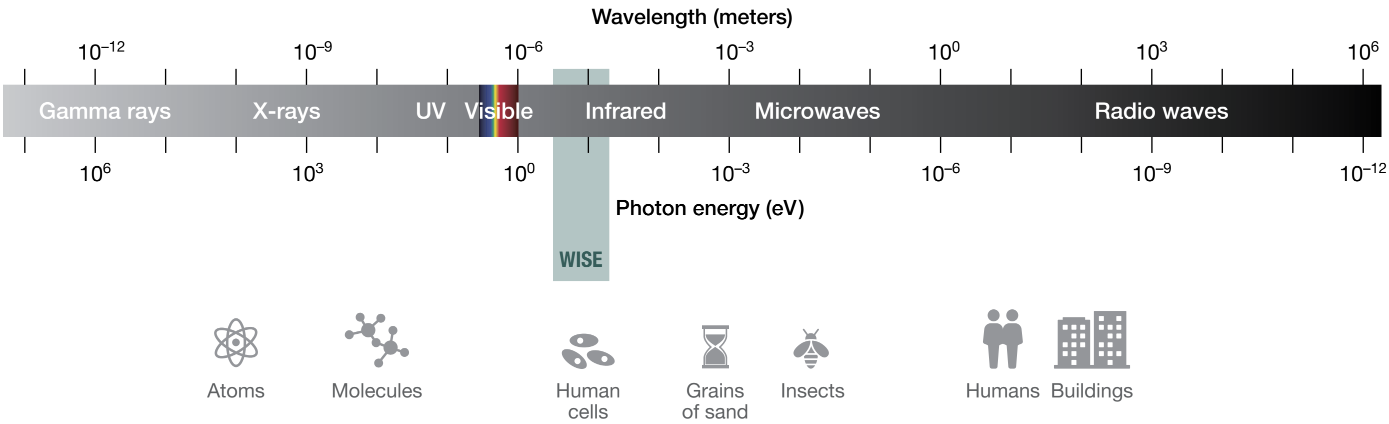
The WISE mission's original objective was to map the entire sky in infrared wavelengths of light, which humans perceive as heat. The four infrared channels that WISE employed ranged from 3.4 to 22 microns, or wavelengths roughly 5 to 30 times longer than the reddest light our eyes can see.

Infrared light offers enormous advantages to astronomers. Infrared cameras can peer through dust clouds that are opaque at visible wavelengths. Distant galaxies whose light has been stretched by their mind-boggling velocities via the redshift effect become detectable at longer infrared wavelengths. Finally, the faint sparks of heat emitted by cool objects too dim to be seen at visible wavelengths can appear as brilliant sources in infrared light.

Earth's atmosphere does a remarkably good job of blocking a great deal of infrared radiation, though — or holding it in like a thermal blanket, giving rise to the heat-trapping greenhouse effect. This warmth makes it difficult to see the faint heat emitted by distant objects in space: Heat from the atmosphere and the telescope itself creates an impenetrable glow that blocks out all but the brightest infrared sources in the sky. One of my col-

▲ **THE SPACECRAFT** Seen here in the lab before launch, the WISE space vehicle's white cryostat encloses the instrument and also contains the solid-hydrogen tanks, imaging optics, and detector arrays. The silver dome-shaped cover was ejected shortly after launch.

ASTEROID TRACKS: NASA / JPL-CALTECH / UCLA; CRAFT: NASA




▲ **ELECTROMAGNETIC SPECTRUM** The human eye can see only a tiny fraction of the electromagnetic spectrum. Observing infrared radiation, which humans perceive as heat, greatly expands what we know about the universe. (Objects with sizes similar to the wavelengths are also shown.)

leagues likens observing infrared sources using ground-based telescopes to trying to observe the sky at visible wavelengths during the daytime while using a telescope made out of fluorescent light bulbs.

It's better to go into space, where there's no atmosphere and no day or night. There, we can cool the telescope and camera down to temperatures approaching absolute zero, achieving an orders-of-magnitude improvement in sensitivity. Even a modest-size infrared telescope becomes vastly more powerful once it's put into space and cooled so that the heat from the optics and sky become negligible.

## The Revolution Will Be Electronic

Before WISE, the whole sky had not been surveyed in mid-infrared light since the 1983 launch of the Infrared Astronomical Satellite (IRAS), which used a then-groundbreaking 62-pixel camera to create the first all-sky infrared image. More modern, powerful infrared detectors were trained on the sky with the launch of the Spitzer Space Telescope in 2003. Spitzer covered similar wavelengths as IRAS, with a larger and more sensitive telescope, but it was designed to make highly detailed observations of small regions of the sky.

The (then upcoming) launch of the James Webb Space Telescope (JWST) made the creation of a modern all-sky infrared map all the more important. JWST's gigantic 6.5-meter mirror would offer spectacular sensitivity and capability beyond Spitzer, but with an even smaller field of view, effectively peering through a tiny straw. Scientists would need a "finder map" to identify the most interesting targets for JWST.

WISE was designed to provide that map. Professor Edward "Ned" Wright (University of California, Los Angeles), the WISE principal investigator, had been refining the mission concept since 1994. NASA finally confirmed WISE for flight through its Medium-class Explorer program in 2006.

Ned and his colleagues developed a survey concept elegant in its simplicity. The 40-cm (16-inch) WISE telescope would orbit roughly 525 km (325 miles) above Earth in a so-called *Sun-synchronous orbit*, always traveling above Earth's day-night line while looking outward at the sky. The spacecraft would continuously scan as it moved along its orbit, using a small mirror about the size of a makeup compact to "freeze-frame" the image onto the detectors. Such a survey pattern would result in an image taken every 11 seconds, efficiently building a complete sky map in just six months.

Making this map in the infrared was the first and most important mission goal, at wavelengths of 3.4, 4.6, 12, and 22 microns. The team selected these wavelengths in order to study two primary science targets: the nearest stars to the Sun and the most luminous galaxies in the universe.

We chose the two shortest wavelengths to exploit a feature of brown dwarfs, objects intermediate in mass and temperature between Jupiter and a star whose internal pressure and temperature are too low to sustain nuclear fusion. Like Jupiter, brown dwarfs are rich in methane, a gas that absorbs powerfully at 3.4 microns but is transparent at 4.6 microns. The cooler the object, the stronger the signal of methane absorption. By comparing an object's brightness in the 3.4- and 4.6-micron channels, astronomers could pick out the unusual infrared colors of methane-rich, ultracool brown dwarfs.

Given that small, cool stars vastly outnumber warmer Sun-like stars inside our galaxy, scientists predicted that a brown dwarf might lie even closer to our Sun than our current nearest stellar neighbor, Proxima Centauri. If such an object existed, WISE would find it.

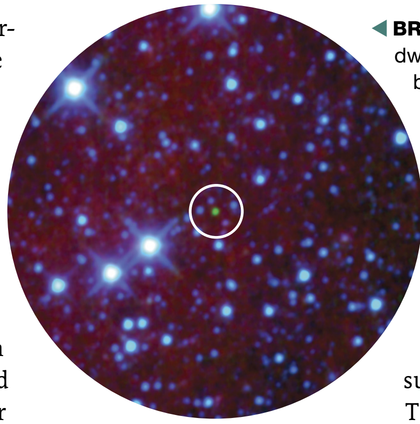
At the other end of WISE's vision, the longer wavelength channels at 12 and 22 microns were designed to pick up dust emission from so-called *ultraluminous infrared galaxies* — galaxies faint in visible light but immensely bright in infrared. Galaxies like our Milky Way exist today in relative calm. However, in an earlier era long ago, massive collisions, mergers, and near-misses were much more common. As galaxies shredded one another or merged, the pileup and mixing of massive clouds of dust and gas set off huge waves of star formation, resulting in a blaze of infrared light that WISE could see.

Other science objectives included examination of the

ELECTROMAGNETIC SPECTRUM: TERRI DUBÉ & BEATRIZ INGLESSIS / *S&T*; ATOMS: CREATIVE STALL / THE NOUN PROJECT; MOLECULES: DELWAR HOSSAIN / THE NOUN PROJECT; HUMAN CELLS: TERRI DUBÉ / S&T; GRAINS OF SAND: DENNIS / THE NOUN PROJECT; INSECTS: VECTORSTALL / THE NOUN PROJECT; HUMANS: ADRIEN COQUET / THE NOUN PROJECT; BUILDINGS: UN·DELIVERED / THE NOUN PROJECT nearest galaxies, planetary debris disks encircling newly formed stars, and asteroids. The WISE science team predicted that large numbers of objects in the main asteroid belt between Mars and Jupiter would be detectable due to their relatively cool temperatures and concentration along the plane of our solar system.

But the telescope was not designed to find large numbers of the asteroids that most closely approach Earth, the near-Earth objects (NEOs). NEOs tend to be distributed over nearly the entire visible sky due to their close proximity, and even with WISE's wide-field view, it wasn't enough to spot large numbers of them. The original version of the science-data processing pipeline also didn't search for new moving objects in the data: We could only detect asteroids and comets that had been found by other observers.

Just a year and a half before WISE went to space, we obtained the resources to augment the data-processing system to enable us to discover new asteroids and comets. We named the software *Near-Earth Object WISE*, or *NEOWISE*.



◀ **BROWN DWARF** The green dot (circled) is the ultracool dwarf WISEPC J045853.90+643451.9, WISE's first brown dwarf. The dwarf looks green here because it stands out at 4.6 microns (colored green in this composite) but not at 3.4 microns (blue) due to methane absorption in its atmosphere.

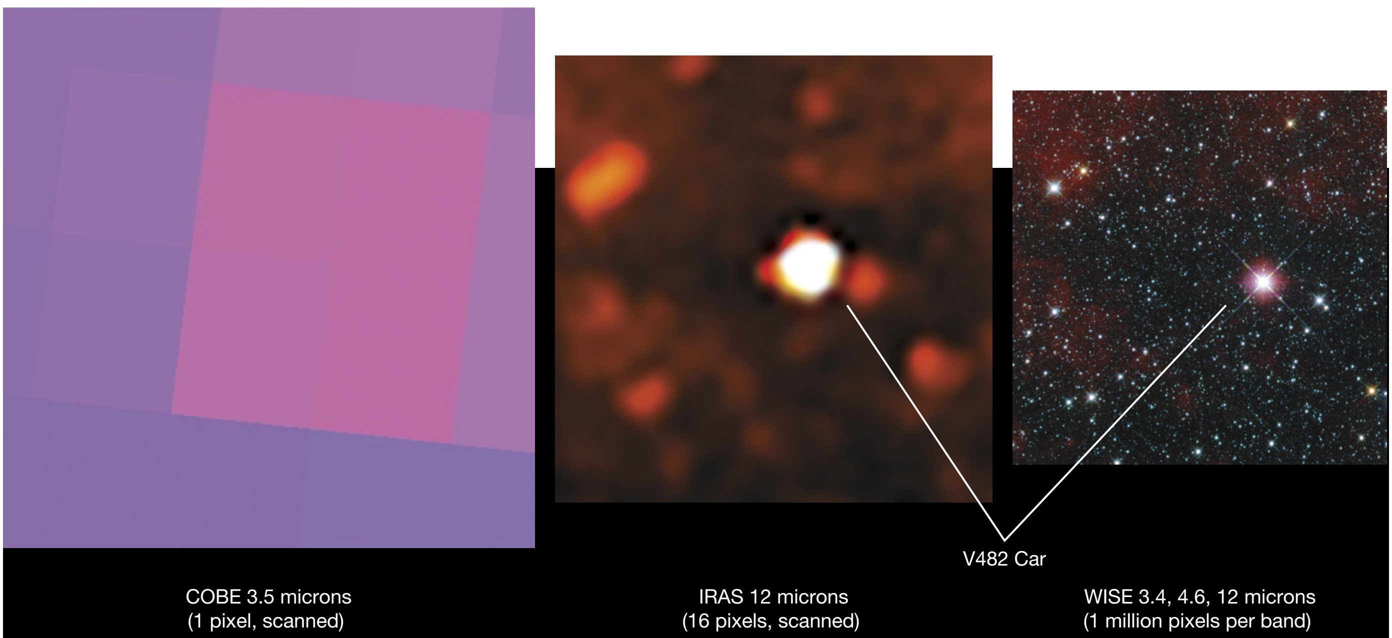
## To the Universe and Beyond

When WISE rocketed into the skies on December 14, 2009, the pressure was on to commission the instrument. The telescope and camera chips relied on two tanks of frozen solid hydrogen to maintain operating temperatures as low as 7.8 kelvin, in order to catch the faintest wisps of heat emanating from distant celestial objects. Despite the spacecraft's orbit far above Earth's warm surface, we expected the hydrogen to last long enough only to finish the commissioning period and collect one complete sky survey before it sublimated away.

The team worked feverishly to calibrate the spacecraft and instrument. We were rewarded with a first-light image glowing with stars and cosmic dust, released on January 6th. Comparing this randomly chosen patch of sky to the corresponding images from the preceding all-sky infrared surveys showed the difference that 26 years of improvement in detector electronics enabled.

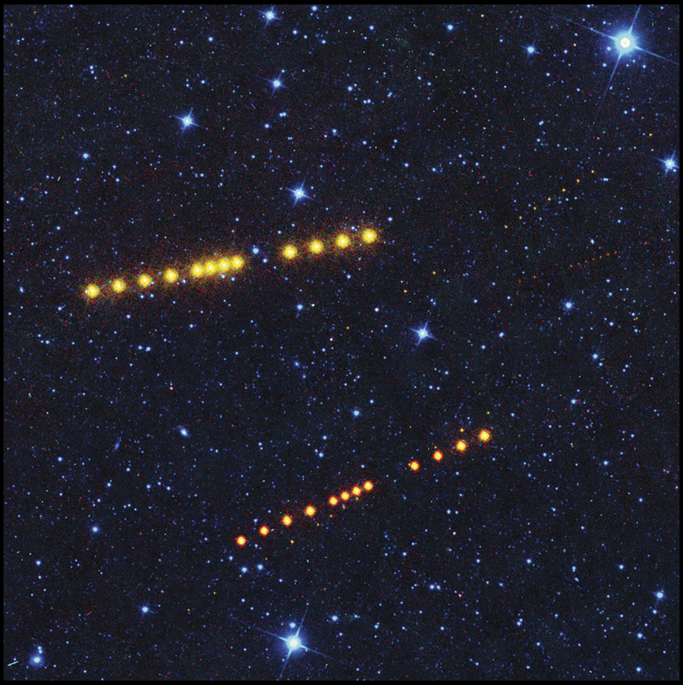
Meanwhile, we were sifting through thousands of images using the upgraded software, searching for new near-Earth asteroids. We were so excited that we worked through the night, finally finding WISE's first NEO discovery on January 12, 2010. That object, now known as 2010 $AB_{78}$, turned out to be as dark as a piece of coal.

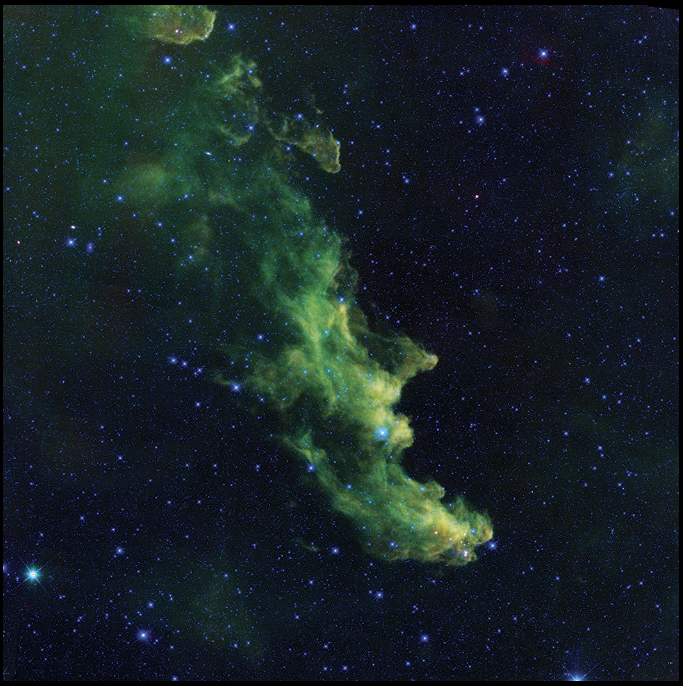
Other results rolled in as the survey progressed, each day bringing thousands of images. We mapped the Andromeda Galaxy, so close to our own that it stretches about 3° across the sky, revealing the warp and twist of its outer regions as well as its satellites. Waves of star formation lit up more

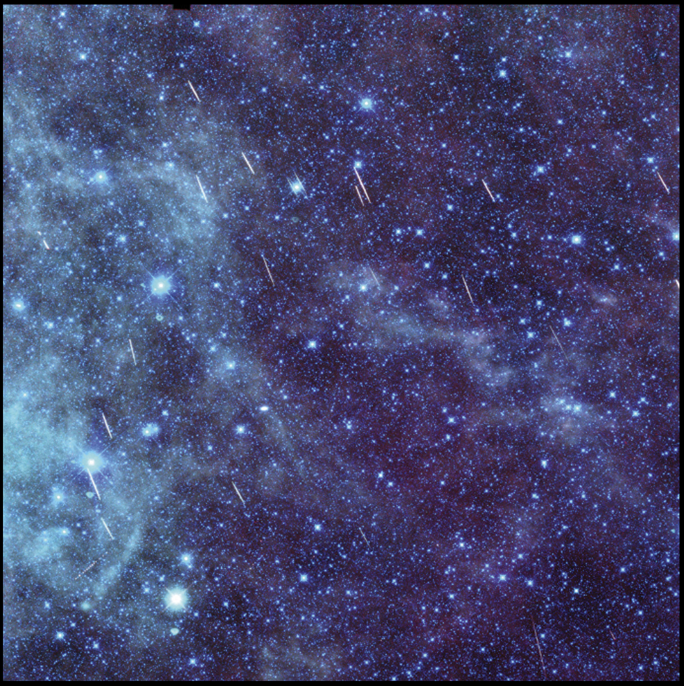



**BETTER VISION** *Left:* A typical view of the sky at 3.5 microns from the COBE mission (1989–1993), using its single available pixel. *Center:* The same patch of sky, taken at 12 microns by the IRAS spacecraft (1983). *Right:* WISE's first-light image of the region in 2010, using 1024×1024 pixels in each channel. The arrows indicate the variable star V482 Carinae.

BROWN DWARF: NASA / JPL-CALTECH / WISE TEAM; THREE PANELS OF THE SKY: PETER EISENHARDT / JPL-CALTECH







**BREADTH OF OBSERVATIONS** *Top left:* Asteroids appear as bright orange-red dots here because they are much cooler than background stars, which appear blue. *Top right:* The Andromeda Galaxy reveals its warped disk and waves of star formation in the dust-rich orange bands. *Lower left:* Infrared image of IC 2118, colloquially known as the Witch Head Nebula, a vast dust cloud in Orion lit up by the newly formed stars inside it. *Lower right:* Other Earth-orbiting satellites pass overhead of the WISE spacecraft, appearing like streaked raindrops.

distant galaxies; gas glowed around young stars still hidden in their natal cocoons. Earth-orbiting satellites streaked overhead like a car driving through raindrops.

WISE delivered on its promised science almost immediately: Before long, the first new brown dwarf was discovered by searching for the telltale signs of methane absorption in the 3.4- and 4.6-micron images. In the classic sequence of stellar spectral types, articulating the progression of stellar temperature from hottest to coolest, stars belong to type *O*, *B*, *A*, *F*, *G*, *K*, or *M*. But astronomers had since added two more categories for brown dwarfs, *L* and *T*, with a third proposed called *Y*. That first new WISE-discovered brown dwarf was a *T* dwarf with a chilly temperature of 600° above absolute zero. Soon after, scientists found *Y* dwarfs with even more contrasting infrared colors, indicating temperatures cooler than Earth's.

Although we have turned up a couple of new brown dwarf systems within 10 light-years of Earth, the hunt is still on for a brown dwarf closer to the Sun than Proxima Centauri. Scientists suspect that it likely does not exist.

## Finding Things That Go Bump in the Night

Asteroid discoveries continued to pour in. Armed with the *NEOWISE* software augmentations, we quickly determined that WISE was particularly good at spotting asteroids with incredibly dark surfaces, like the first one it discovered.

We could also distinguish asteroids' sizes. To visible-light telescopes, objects that are large but dark have the same brightness as objects that are small but lighter colored. But using the asteroids' heat signatures, we could tell the two apart. WISE's infrared eyes allowed us to make robust size measurements for the asteroids zipping through Earth's neighborhood.

Still, although WISE could pick out the candidate moving objects, we needed follow-up by ground-based observers using visible-light telescopes to obtain solid orbital predictions. This proved challenging because the candidates were so dim, often requiring large 4- to 8-meter telescopes. We made friends all around the world as we sought help from the international community to chase our NEO candidates: Planetary defense truly is a global sport.

By mid-July 2010, we had successfully made the first complete survey of the entire sky, fulfilling the baseline mission requirement. The solid hydrogen in one tank was exhausted in August 2010, immediately resulting in the loss of the 22-micron channel as it became blinded by its own heat. The hydrogen in the next tank held out longer; the 12-micron channel continued to operate, along with the 3.4- and 4.6-micron channels. NASA's Astrophysics Division, with additional support from its Planetary Science Division, granted us permission to continue to survey until February 1, 2011, long enough to complete a survey of the main asteroid belt's inner edge. Our last smidgen of hydrogen-ice coolant disappeared by October 2010, blinding the 12-micron channel. The remaining 3.4- and 4.6-micron detectors warmed to 75K but continued to operate normally.

### Hollywood Cameo

Comet NEOWISE served as the prototype for the comet in the 2021 movie *Don't Look Up*, in which astronomers find a comet on course to hit Earth within six months, but most people don't believe them. Such short notice is standard for comets. We discovered the real Comet NEOWISE on March 27, 2020, and by July 3, 2020, it made its closest approach to the Sun. (Although unlike its fictional counterpart, Comet NEOWISE had no chance of Earth impact.)

With only these two shorter-wavelength channels, we were less sensitive to asteroids in the main belt between Mars and Jupiter. But NEOs tend to spend much of their time closer to the Sun. Their warmer temperatures make them bright even at shorter infrared wavelengths. So we continued to discover and detect NEOs.

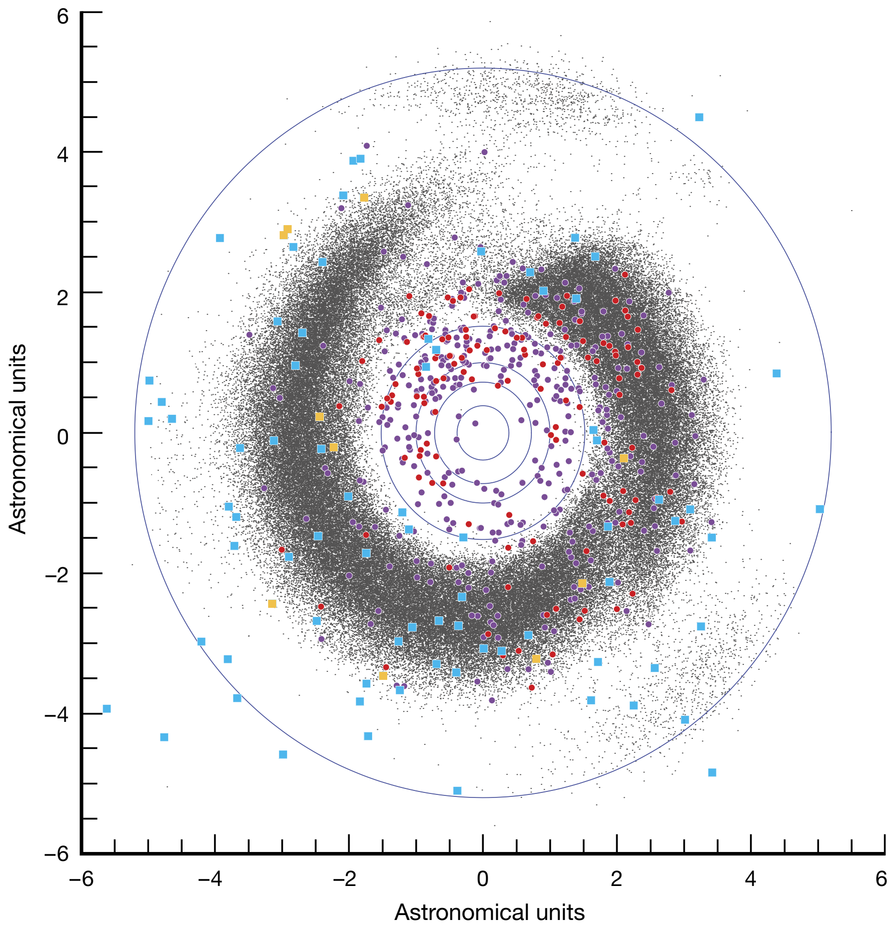
On the first day after losing the 12-micron channel, we discovered an asteroid that proved to be in a most unusual orbit. Dragged by Earth's gravity into our planet's path around the Sun, it is locked into a resonant orbit that keeps it perpetually ahead of us. This so-called *Earth Trojan* was the first such companion discovered for our planet. While Jupiter is known to have thousands and possibly millions of Trojan asteroids trapped by its powerful gravity, no one had ever found an Earth Trojan until the discovery of 2010 $TK_7$.

Because of its orbit, 2010 $TK_7$ perpetually lurks in the near-Sun sky, a difficult region for Earth-based observers to search. But that's precisely where our telescope pointed.

February 1, 2011, came quickly. While funding for NASA's program devoted to discovering and studying potentially hazardous asteroids had risen somewhat from $4 million per year, the agency still did not have enough to extend our mission again. We had to shut down the spacecraft.

Running out of funding was sad, but we felt satisfied that we had exceeded our mission's requirements. We placed the spacecraft in hibernation, turning off the instrument and leaving the telescope pointed continuously at the north ecliptic pole. Because its aperture cover was ejected after launch, WISE now viewed the warm Earth for half of each orbit, and the instrument's temperature quickly shot up to roughly 200K, blinding even the 3.4- and 4.6-micron channels.

We set about analyzing the archival data. We saw hundreds of NEOs, enabling study of their statistical properties. By searching for asteroids using their heat signatures rather than the sunlight they reflect, we could obtain a fair census of how many NEOs have coal-dark surfaces versus lighter stony or metallic ones. We found that there was a sizeable population of dark NEOs that visible telescopes often missed. Roughly 40% of the NEO population turns out to be made of dark, carbon-rich material, likely scattered in from the outer solar system.




◀ **WISE ROUNDUP** This "top-down" view of the solar system shows asteroids and comets discovered by WISE through February 1, 2011. Main-belt asteroids are shown in black. Near-Earth objects discovered by other surveys are purple, while those discovered by WISE are red. The squares are comets: Previously known comets are blue, and comets discovered by WISE are yellow. When the spacecraft's two solid hydrogen tanks were exhausted, the craft's own heat blinded the 12- and 22-micron bands, but the survey continued at 3.4 and 4.6 microns. The drop-off in detections at the figure's top is due to that reduced sensitivity.

ADAPTED FROM A. MAINZER ET AL. / *ASTROPHYSICAL JOURNAL* 2011 (731:53)

We also learned that the NEO surveys had done a good job of finding the largest near-Earth asteroids, objects big enough to cause global extinctions. But the community had not found the majority of smaller asteroids still large enough to cause severe regional disasters.

Our small-body discoveries extended beyond near-Earth space. The previous all-sky infrared survey, IRAS, had detected roughly 2,000 asteroids. Now, we had measurements of diameters and reflectivities for more than 140,000, mostly in the main belt. We found that main-belt asteroids tend to break up into families that produce distinctive clumpings of bright and dark objects. We studied Jupiter's Trojan asteroids, ancient objects likely captured early in our solar system's history, and showed that the cloud leading Jupiter has more members than the cloud trailing in the giant planet's wake. Comets found by the mission were revealed to have dark nuclei consistent with a carbon-rich composition.

The rest of the astronomical community quickly dove into the data, and a steady stream of new results turned into a flood of papers.

## Episode IV: A New Hope

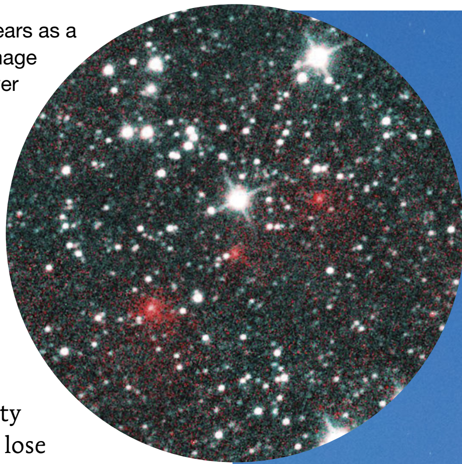
In 2012, NASA issued a request for proposals to build a new camera mounted on a geostationary satellite to search for NEOs. I put together a study team, but we noted that new construction would be expensive, more than $100 million, while delivering only similar capability as a simpler and much cheaper option: reactivating the WISE spacecraft. For an annual budget of roughly $5.5 million, we could efficiently characterize NEO sizes and reflectivities.

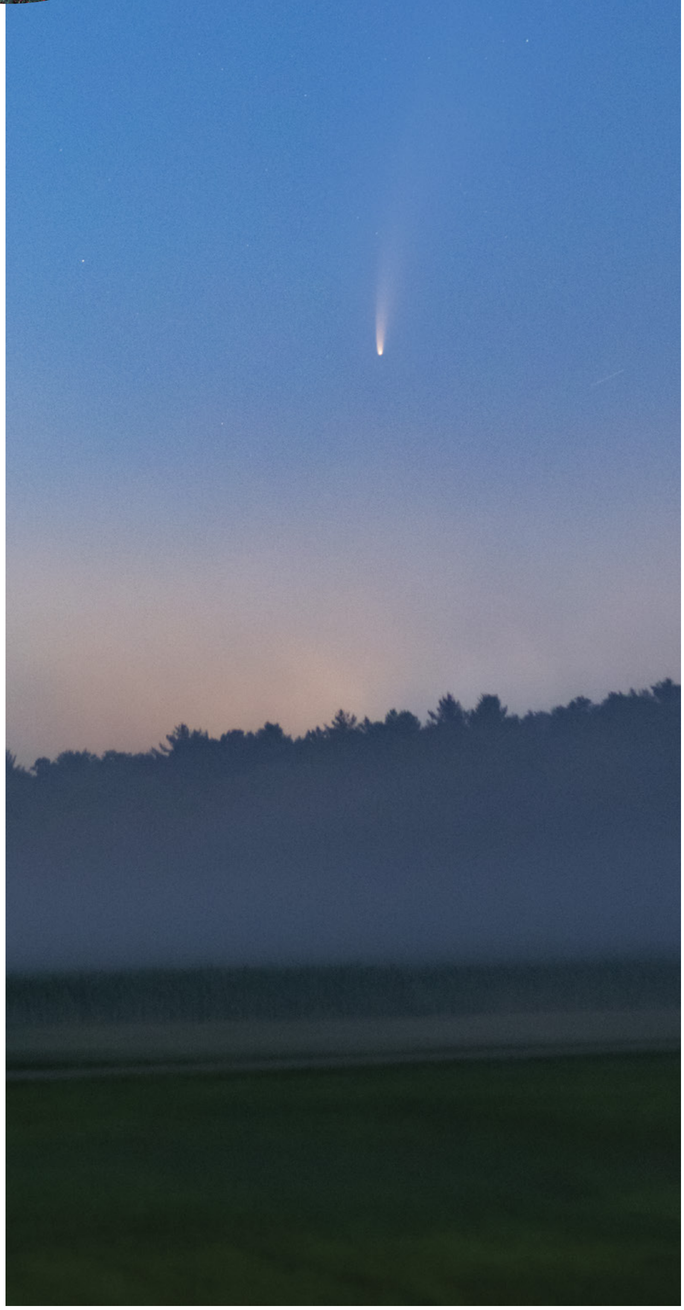
This cost fit the limited budget of NASA's Near-Earth Object Observations program, and they accepted our proposal. By December 2013, we once again pointed the spacecraft away from Earth, beginning survey operations shortly after the telescope cooled back down to 75K. In honor of its new mission, we renamed the spacecraft NEOWISE.

We continued to find new NEOs, most of which were dark. We also supported a planetary defense campaign to simulate the discovery of the asteroid 99942 Apophis, a 340-meter-wide space rock that will not impact Earth but will come hair-raisingly close — underneath our geostationary satellites — in the year 2029. Although Apophis was discovered long ago, the international community engaged in an exercise to treat its 2020–21 close approach as if it was an unknown new object, helping to hone astronomers' responses to future discoveries. The NEOWISE infrared observations of Apophis provided a diameter estimate that quickly ruled out sizes consistent with global devastation, limiting its destructive potential to "merely" regional catastrophe.

In 2020, at the height of the pandemic, we found a fuzzy-looking object in the images: the naked-eye comet C/2020 F3 NEOWISE (*S&T:* Nov. 2020, p. 14). I remember driving along a remote mountain road seeking a glimpse of it, only to find hundreds of other people lining the roadside, skygazing together while social distancing. Seeing the comet that had been a dot on my computer screen now in the sky with my own two eyes embodied the power and beauty of science.

We kept expecting to eke one to two more years out of NEOWISE. Extensions were meted out accordingly by NASA. The unexpected boon was that the Sun remained unusually quiet. The increased influx of radiation during the peak of the





▶ **COMET NEOWISE** *Inset:* Comet C/2020 F3 appears as a string of fuzzy red dots in this composite infrared image taken by NASA's NEOWISE mission, used to discover the comet on March 27, 2020. *Far right:* The comet graces New Hampshire skies on July 9th.

11-year solar cycle causes Earth's atmosphere to puff up, increasing drag forces on spacecraft in low Earth orbits. A long stretch of solar calm reduced atmospheric drag and kept our orbit in good shape, allowing us to observe and characterize thousands more asteroids.

But by 2022, it was clear that solar activity was picking up again, causing NEOWISE to lose altitude faster. It was difficult to predict the endgame, but we decided to propose one final mission extension. We chose the end of July 2024 as the survey's last day, hoping to squeeze the last science out before drag forces caused spacecraft malfunctions.

We collected the last image on July 31, 2024. Reentry occurred on November 1, 2024, sweeping away any lingering doubts I had about the survey's end date. We chose the perfect time: The last image was just as lovely and star-spangled as the first.

The extended NEOWISE mission gave us a multi-year view of the entire sky at 3.4 and 4.6 microns, complementing other time-domain surveys at different wavelengths from other ground- and space-based observatories. Today, there are roughly 10,000 refereed citations using the WISE and NEOWISE data, with more studies being published every day.

The results from NEOWISE also suggested we could do more. In 2006, I proposed a mission to NASA to make a much more comprehensive survey of the NEOs, now known as the NEO Surveyor telescope. It was later accepted by NASA's Planetary Defense Program and is now finally under construction and slated to launch in late 2027. By adding many more pixels and placing the spacecraft farther from Earth to keep the instrument cool without expendable cryogens like hydrogen or helium, we will be able to search the dusk and dawn skies where potentially hazardous asteroids spend much of their time. We learned a lot about discovering NEOs with a space telescope from NEOWISE, and its bigger, badder cousin NEO Surveyor will find and characterize many more.

All space missions are symbols of hope: in the power of people to dream up creative ways to solve difficult problems, in their ability to work seamlessly together and build something that survives the hostile environment of space, and in their steadfast dedication to see a project through to the end. I was lucky to be a part of WISE/NEOWISE. Though it took more than 20 years, the big science that is still coming from this small mission was worth the wait.

■ **AMY MAINZER** is a professor of planetary science at the University of California, Los Angeles, where she leads the NEOWISE and NEO Surveyor missions.

SPACE IMAGE: NASA / JPL-CALTECH; COMET OVER LANDSCAPE: SEAN WALKER / S&T

 by Jan Hattenbach and Ronald Stoyan

# Mastering the Me

**THE STARTING LINE** As dusk ends at the author's Messier marathon viewing location on La Palma, the constellations Cetus, Pisces, and Andromeda are already setting. The bright zodiacal light rises under darker skies, making the galaxies M77, M74, and M33 particularly difficult. Brilliant Venus hovers above the horizon in this image from March 18, 2023.

RONALD STOYAN

# ssier Marathon

**Few have seen all 110 Messiers in a single night, but with careful planning you could be one of them.**

As the sky turns from blue to black, we're getting nervous. At 1,400 meters (4,600 feet) above the Atlantic, on the western slope of La Palma in the Canary Islands, our view is breathtaking. The zodiacal light's triangular glow stands tall on the western horizon with Venus glaring at its center. And yet, all we care about are two faint blobs of extragalactic light. We know that if we don't catch M74 and M77 before they drop into the sea, our mission will have failed right at the start. That mission? To observe all 110 Messier objects in a single night.

## At the Starting Line

In the 18th century, French comet hunter Charles Messier compiled his famous catalog containing some of the night sky's most beautiful clusters, nebulae, and galaxies. Today, most stargazers are content to simply enjoy the sights, but for others the Messier list presents a challenge. In the 1970s, avid deep-sky observers noted that no Messier objects lie between the ecliptic longitudes of roughly 320° to 30° — a 70°-wide gap. From that realization, the idea of seeing all 110 objects in a single night was born. For this to be possible, the Sun must be located near the middle of that gap — something that happens each year around the time of the spring equinox. (There's second gap in October, but it's less favorable as the Sun is positioned nearer to Virgo and its hoard of Messier galaxies.)

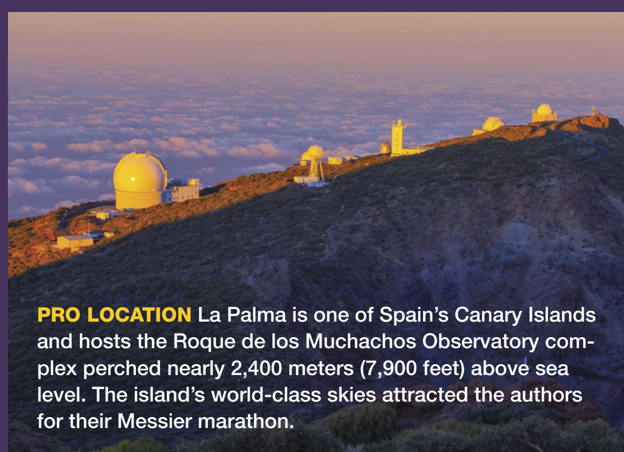
It's 2023, and we've chosen the night of March 18–19 for our attempt, or rather, the *Moon* has chosen the date for us. We'll need the darkest skies we can get to see the faintest Messiers. The marathon window stays open from roughly mid-March until mid-April, so ours is a bit on the early side. Thankfully, at this time of year the night is still reasonably long, and the most difficult evening objects are higher than they'll be in April. However, the notorious Phantom Galaxy, M74, is still tricky. It sets early and its low surface brightness makes it difficult to discern against the zodiacal light.

Thanks to the transparency of La Palma's sky, a big finderscope, and a little guidance from nearby Venus, we finally spot M74 and quickly claim M77 as well. With those two galaxies out of the way, we breathe a sigh of relief. The first difficult hurdle has been cleared, and the marathon has begun!

MAXI PEREZ / SHUTTERSTOCK.COM

## 10 Tips for a Successful Messier Marathon

1. Choose a site (or sites) with unobstructed horizons.
2. Wait for a night when the sky is moonless and free of haze down to the horizon. (A slender lunar crescent is acceptable, however.)
3. Be set up and ready by sunset at the latest.
4. Use a telescope fitted with 50-mm optical finder, which can show most Messiers directly and speeds up the search.
5. Use charts and maps you're already familiar with to quickly orient yourself.
6. Have a detailed observing schedule ready. This is particularly important for objects visible only briefly during evening and morning hours.
7. Don't despair if you fail to find an object. Try again with a different star-hopping route. (You may have started at the incorrect star!)
8. If you're not seeing the Messier you're looking for, don't waste valuable time aimlessly scanning the area. Start fresh — you may have taken a wrong turn and ended up at the wrong spot!
9. Check off the summer Milky Way objects in one go as soon as they're high enough. You'll need all the time you can get later for the morning Messiers.
10. Make sure you're well rested and have snacks and hot or energizing beverages at hand.



**PRO LOCATION** La Palma is one of Spain's Canary Islands and hosts the Roque de los Muchachos Observatory complex perched nearly 2,400 meters (7,900 feet) above sea level. The island's world-class skies attracted the authors for their Messier marathon.


▲ **A CELESTIAL RACE TRACK** This map shows the distribution of Messier objects across the spring night sky. Those near the dusk and dawn horizons are the most challenging to observe. Note the dense concentration of galaxies in the Leo and Virgo regions (near the map's center) and the clusters and nebulae that dot the summer Milky Way on the left side.

## Join the Club

Many deep-sky observers have run Messier marathons, but the "Club of 110" remains rather small. While it's not hard to see 80 to 90 Messiers in one night from many locations, there are a handful of objects that are particularly tricky. History has it that the first to try a Messier marathon were a trio of Pittsburgh, Pennsylvania, amateurs. Ed Flynn logged 98 objects with a 6-inch reflector on the night of March 24–25, 1977, only to be superseded by Tom Hoffelder who tallied 101 the following night. Hoffelder's record held until April 11–12 that same year, when Tom Reiland made it to 103. Renowned comet hunter Don Machholz (who sadly passed away in 2022) was another early participant. To this day he likely remains the most prolific marathoner of all, with more than 50 attempts to his credit. His 2002 book, *The Observing Guide to the Messier Marathon*, is highly recommended to anyone interested in Messier, his catalog, and the marathon.

It wasn't until 1985, however, that Gerry Rattley and Rick Hull managed to complete the first full marathon on March 23–24 that year. Both used 10-inch telescopes and reached 110 within an hour of each other. Rattley and Hull observed from Arizona and California, respectively. They were significantly farther south than their predecessors, demonstrating that latitude is also key to completing a marathon. You can't do 110 at any time *or* from any place!

Messier compiled his catalog from France, at a latitude of 49° north, so his objects are concentrated on the northern celestial hemisphere. Many can be viewed from much farther south, but to catch them all during a single night, you have to be north of +10° latitude. Too far north, however, and you'll miss the most southern ones. For example, M7, the beautiful open cluster near the tail of Scorpius, is practically unobservable poleward of 53° north.

Between latitudes 40° to 50° north (comprising the northern U.S., southern Canada, and most of central Europe), a full Messier marathon is possible only theoretically, as three objects (globular clusters M30 and M55, and the aforementioned galaxy M77) are extremely difficult to catch.

For some, the idea of running a marathon is to simply record as many objects as possible from a given location, even if catching all 110 isn't possible. One of us (Ronald) pioneered European marathons from 49° north in Bavaria, Germany, where he logged 103 objects in 1993. In 2001 Arto Oksanen and Harri Hyvönen completed the first digital Messier marathon when they imaged 82 objects on CCD from Finland, more than 60° north.

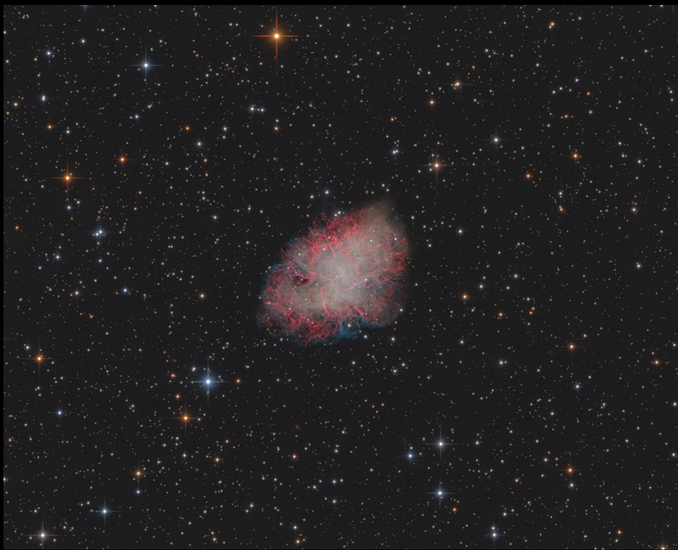
But despite these accomplishments, the sweet spot for a full Messier marathon is about latitude 25° north; however, anywhere between 10° and 35° north will work. This means the southern continental U.S. is marathon territory, as well as Hawai‘i, the Caribbean, and even the southern tip of Japan. For European observers, the Canary Islands are the best place to go. On La Palma we were at 28° north — close to the ideal latitude!

## Our Marathon Night

Even if you're at an ideal location and have set up your telescope on the optimum date, a successful marathon requires planning. You have to observe the objects in the right order to have the best chance at seeing all 110 of them. For our attempt, we created a list (see page 23) that sorted the objects into one-hour slots corresponding to the optimal observing time. Such a script is especially useful during the stressful evening and morning hours, when time is tight and the right sequence is crucial.

On our marathon night, we set up our main instrument — a 10-inch Dobsonian reflector — but since many Messiers are fairly bright, we also use 15×56 binoculars, 2×54 opera glasses, and of course our naked eyes. In effect, we are doing four parallel marathons at the same time.

S&T ILLUSTRATION



▲ **MESSIER NUMBER ONE** Although the Crab Nebula in Taurus holds the distinction of being the first object in French comet-seeker Charles Messier's famous catalog, on marathon night it's distinctly middle of the pack. This supernova remnant is best sighted in late evening, after more challenging objects have already been logged.

▲ **NUMBER ONE ON THE HIT PARADE** Known as the Phantom Galaxy, M74 in Pisces is among the first targets sought by those participating in a Messier marathon. This face-on spiral lives up to its ghostly reputation especially in twilight when its low surface-brightness compounds its elusive nature.

M1: BERNHARD HUBL M74: RON BRECHER

## Marathon Observing Sequence #1
### (for latitude 28° north on March 21st)

**$19^h$ to $20^h$: M45, M31, M32, M110, M33, M74, M77**
M45 can be seen in twilight; the other targets need a low horizon to the northwest. Both M110 and M33 have very low surface brightnesses and can be difficult in poor skies. M74 is the toughest of the evening targets. It also has a very low surface brightness and can only be observed after astronomical twilight ends.

**$20^h$ to $21^h$: M52, M76, M103, M34, M36, M37, M38, M1, M35, M78, M42, M43, M79**
M52 needs a low horizon to the northwest, but can be observed in the morning if missed now.

**$21^h$ to $22^h$: M50, M41, M47, M46, M93, M48, M67, M44**
Most of these objects remain very high and can be observed later if necessary.

**$22^h$ to $23^h$: M95, M96, M105, M65, M66, M81, M82, M108, M97, M109, M40**

**$23^h$ to $0^h$: M106, M94, M63, M51, M101, M102, M3, M53, M64**

**$0^h$ to $1^h$: M98, M99, M100, M85, M84, M86, M88, M87, M91, M90, M89**
The Virgo Cluster. Observers unfamiliar with the region should be very careful as non-Messier objects are present in many fields.

**$1^h$ to $2^h$: M58, M59, M60, M49, M61, M104, M68, M83**
The eastern and southern part of the Virgo cluster. After finishing this section you're more than halfway through and can take a short break.

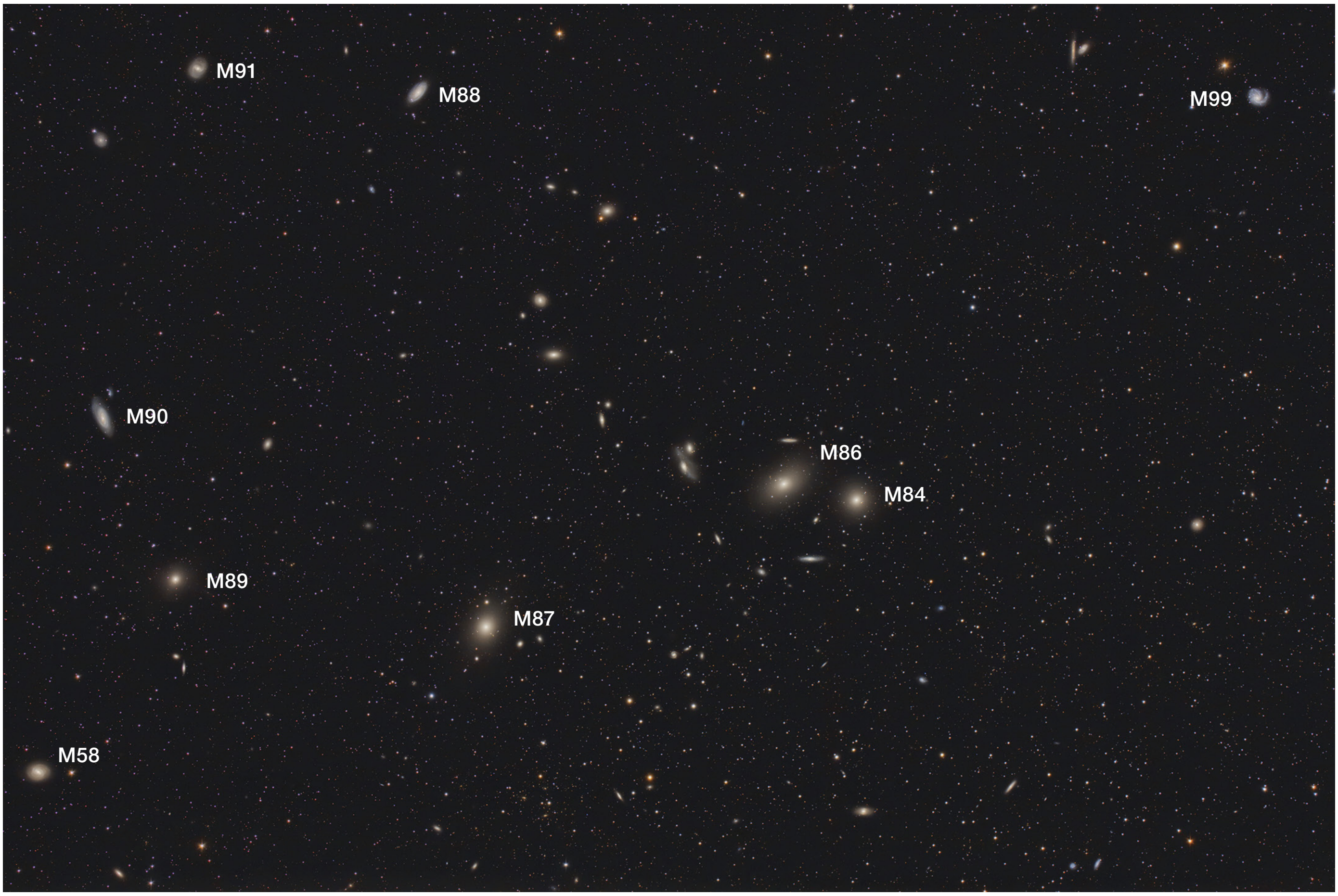
**$2^h$ to $3^h$: M13, M92, M5, M10, M12, M107, M14**
Catch these objects as soon as they rise above the eastern horizon.

**$3^h$ to $4^h$: M57, M56, M29, M39, M27, M71, M80, M4, M9, M19, M62, M11, M26**
Again, log each object as it clears the eastern horizon.

**$4^h$ to $5^h$: M16, M17, M18, M24, M23, M20, M21, M8, M25, M22, M28, M6, M7**
Work your way through the summer Milky Way from north to south.

**$5^h$ to $6^h$: M72, M73, M15, M2, M55, M75, M54, M70, M69**
All these targets need an unobstructed horizon to the east.

**$6^h$ to $7^h$: M30**
The remaining object is the only tough one in the morning sky. It must be observed under cloudless and haze-free conditions at dawn from a location with an unobstructed east-southeastern horizon.




▲ **HAPPY HUNTING GROUND** The region of sky between Epsilon (ε) Virginis and Beta (β) Leonis contains a veritable swarm of Messier galaxies, nine of which are identified in the 5°-wide field of this image, including M84 and M86 that anchor a string of galaxies known as Markarian's Chain. Marathoners need to exercise caution when exploring this densely packed region. As this photo makes clear, numerous non-Messier galaxies abound!

BERNHARD HUBL

As soon as twilight begins to fade, we start our marathon. After checking off galaxies M74, M77, and the equally difficult globular cluster M79, we turn our attention toward the northwestern horizon. There, M45 (the Pleiades), along with M31 (the Andromeda Galaxy), M32, and M110 (Andromeda's companion galaxies) are dropping fast, but we manage to catch them. M33, the Triangulum Galaxy, requires some effort as it's just above the west-northwestern horizon. It, too, eventually shows itself in the 10-inch. After about an hour, the pace is less frantic, and we turn our attention toward the winter Milky Way. These Messiers are high in the sky and remain so for much of the night. Only Cassiopeia's open cluster M52 needs an unobstructed horizon to the north-northwest, but it's circumpolar at our site and can be tallied in the morning if missed now.

Since our night is about 10 hours long, that works out to an average of a bit less than 6 minutes to locate and log each object. Of course, this benchmark can easily be beaten with some practice and by combining neighboring objects. There's even time to marvel at some of the brighter gems or to study objects we don't set our eyes on very often. We do, however, make sure to follow the Messier Marathon Code of Honor, which requires that every object is found "by hand," using a star chart and a finderscope — Go To scopes aren't permitted! Just like at a real marathon, shortcuts aren't allowed.

We're more than two hours into the marathon when we turn our attention eastward to where Leo, Virgo, and Coma Berenices are rising. It's galaxy time, and the Messiers come thick and fast! The Virgo Cluster with its many faint fuzzies poses a particular challenge — we need to carefully identify every single smudge of light in the eyepiece to make sure we don't confuse our targets with similar, non-Messier objects. This requires patience and a detailed chart. If we're not 100% sure that we have the right galaxy, we begin our star-hop again from the start.

After completing the eastern and southern parts of the Virgo Cluster, we're halfway through the marathon and it's just past midnight. Now is a good time for a break since it's still a bit early for the second half of the list to have risen. Because the marathon goes from dusk to dawn, fatigue is an issue. A snack is important, and energy drinks certainly help. But nothing works as well as a siesta — adapted to marathon needs by moving it from the afternoon to the early morning hours. If you're going to nap, this is your chance to do so.

## Marathon Observing Sequence #2
### (for latitude 40° north on March 21st)

**$19^h$ to $20^h$: M45, M74, M77**
M45 can be seen in twilight; the others require a low horizon to the west. M77 and M74 are the most challenging objects and are visible only at dusk as they set. M77 is very compact, so try it first. M74 is the toughest of the evening targets.

**$20^h$ to $21^h$: M31, M32, M110, M33, M34, M52, M103, M76, M79, M42, M43**
Both M110 and M33 have very low surface brightnesses, making them difficult in poor skies. Be careful to catch M79 before it sinks into the horizon.

**$21^h$ to $22^h$: M78, M1, M35, M37, M36, M38, M50, M41, M47, M46, M93, M48, M67, M44**
M93 needs a low horizon to the southwest.

**$22^h$ to $23^h$: M95, M96, M105, M65, M66, M81, M82, M108, M97, M109, M40**
Most of these objects are very high in the sky and can be observed later if necessary.

**$23^h$ to $0^h$: M106, M94, M63, M51, M101, M102, M3, M53, M64**
These objects are also very high and can be logged later as well.

**$0^h$ to $1^h$: M98, M99, M100, M85, M84, M86, M88, M87, M91, M90, M89**
The Virgo Cluster. Observers not familiar with the region should proceed with care as many non-Messier objects are also present.

**$1^h$ to $2^h$: M58, M59, M60, M49, M61, M104**
The eastern and southern part of the Virgo Cluster. After finishing here you're more than halfway through the marathon.

**$2^h$ to $3^h$: M68, M83, M13, M92, M5, M10, M12, M107, M14**
M83 needs a good horizon to the south.

**$3^h$ to $4^h$: M57, M56, M29, M39, M27, M71, M80, M4, M9, M19, M62, M11, M26**
Observe each of these as soon as they rise above the eastern horizon.

**$4^h$ to $5^h$: M16, M17, M18, M24, M23, M20, M21, M8, M25, M22, M28, M6, M7**
Work your way through the summer Milky Way from north to south. M6 and M7 need an unobstructed horizon to the southeast.

**$5^h$ to $6^h$: M69, M70, M54, M75, M72, M73, M2, M15, M55**
These are all low in the east or south! M55 is the lowest — attempt it after you have logged the others.

**$6^h$ to $7^h$: M30**
Dawn has set in and you're only waiting for M30. It rises about 45 minutes before the Sun. Hint: Center the star Zeta (ζ) Capricorni in the eyepiece, shift about 1° south, then wait 14 minutes for Earth's rotation to carry M30 into the field of view.

▲ **EASY FIND** More than a dozen Messier objects can be observed without optical aid, including the Pleiades (M45) in Taurus, which is visible at dusk and may be the first object sighted in a marathon. Venus sat to the left of the cluster when this twilight scene was photographed in 2018.

ALAN DYER

▲ **BREAKING THE TAPE** Capricornus globular cluster M30 may not be as famous as M13 in Hercules, but for marathoners it's a welcome sight at dawn, marking the finish line for those seeking to tally all 110 Messiers. The nearby 5th-magnitude star (41 Capricorni) is a helpful guide to locating M30 in brightening morning twilight. The cluster won't look its best, but you can always seek it out again in autumn when it's well placed in the evening sky.

BERNHARD HUBL

## The Home Stretch

Our site has a great view to the west, but not to the east, so we have to relocate. By skipping a siesta, there's time for the 90-minute drive to the opposite side of the island. Here, just a few kilometers away from La Palma's famed observatories and with a view toward the neighboring island of Tenerife, we set up for the second half of our marathon and its grand dawn finale. It was on Tenerife that Petra Saliger and Gernot Stenz completed the first European full marathon in March 2004. (Although the Canary Islands belong to Spain, technically they're considered part of Africa.)

But will we succeed and ascend to the Club of 110s? There's only one way to find out. We start by logging spring's beautiful set of globular clusters: M13 and M92 in Hercules, M5 in Serpens, and the quartet of M10, M12, M14, and M107 in Ophiuchus. To conserve time, we pick each one off as soon as it rises above the horizon. It's now 3 a.m., and things are about get a lot more hectic.

At this hour, the bright and broad summer Milky Way lies along the eastern horizon, where its luminous star clouds are easily confused with terrestrial clouds. Thankfully, our sky remains clear. We continue with M57, Lyra's famous Ring Nebula, and then on to the constellation's globular, M56. Moving into Cygnus we sight open clusters M29 and M39, and then catch Vulpecula's sole Messier, the Dumbbell Nebula, M27. Next, we head southward to claim globular clusters M71, M80, M4, M19, and M62. We're enjoying views of objects that most of the time get sidelined in favor of the brighter, more famous Messiers. And talking of famous objects, next on our list is M11, Scutum's Wild Duck Cluster — an easy target that we regularly visit.

As we work our way through the Milky Way's hazy band from north to south, we collect M16, the Eagle Nebula in Serpens, then slip into Sagittarius for M17, the Omega Nebula, and of course M8 and M21, the Lagoon and Trifid nebulae, respectively. Before leaving the area, we pause at M24, the Small Sagittarius Star Cloud. Moving on to autumn targets we at last reach triple-digit territory as we check in on M73 — a four-star asterism in Aquarius. The time is almost 6 a.m., and we have a little more than one hour of darkness remaining to locate the final batch of Messiers. The marathon really feels like a race now!

The effects of sleep deprivation are kept in check by excitement as we inch closer to our goal with each object we find. Were we located farther north, this final hour would be very stressful or even frustrating since all the remaining targets (M72, M73, M75, M69, M70, and M54) must be found practically simultaneously in bright twilight. But they're not easy even from our favorable latitude. This is the most critical moment. Our final total depends on how we tackle this final stretch.

One way around this dawn crunch is to choose a later date and simply concede the evening objects M74 and M77. In mid-April the difficult morning targets will be higher up than in March, giving you a bit more time to find them before dawn breaks. It's not much though — M75, one of the most critical twilight objects, only gains 12′ (less than half the Moon's diameter) per day.

In 2011, Ronald attempted two marathons within just four weeks from latitude 49° north. On both attempts, globular clusters M55 and M30 eluded him at dawn. However, in March he made it to 102 objects, catching M74 and M77, but missing M72, M73, M75, M69, M70, and M54 in the morning. In April, he tallied 106 by logging those morning objects but missed the two evening galaxies. Still, both runs were remarkable considering the latitude.

Our La Palma location, however, not only is much farther south, but it's also at an elevation of 2,000 meters (6,600 feet), which allows us to see about 1½° lower than at sea level. Even M55, though challenging, quickly falls victim to our dark-adapted eyes. Now, as dawn approaches, only M30 in Capricornus remains. We nervously wait as twilight grows brighter by the minute. It all comes down to this.

Suddenly, the 8%-lit waning crescent Moon pops up on the east-southeastern horizon. Quickly realizing that it's just 6° left of M30, we sweep our telescope parallel to the horizon. And there it is — our 110th and final target! It's not a pretty sight, perched less than 5° above the ocean, but it's clearly the 6.9-magnitude globular positioned just west of the 5th-magnitude star 41 Capricorni.

We did it. We made it to 110 Messier objects! Amazingly, we were able to tally 108 objects in our 15×56 binoculars, missing only M74 and M30. With the 2× opera glasses we spotted 47, and 23 were visible without any optics — all thanks to La Palma's dark skies.

As we watch the Sun rise over Tenerife, we're as euphoric as real marathon runners crossing the finish line. We still can't quite believe what we've accomplished — our long night of Messier hunting raced by unbelievably fast.

"Why should I go through so much stress and fatigue to search for objects that I can see much better in other nights?" We don't blame anyone for asking that. It *is* a stressful exercise — and stress isn't something we typically turn to stargazing for. But our answer is simple: Because it's fun!

JAN HATTENBACH

◀ **BASKING IN THE GLOW** After a long night logging all 110 Messiers, the authors' marathon concluded with a spectacular sunrise over nearby Tenerife Island.

Even if your observing site doesn't allow you to attempt the full 110, a Messier marathon is still a great way to test your observing skills. Every year, hundreds of amateurs around the world give it a try. If you're tempted, we have one final piece of advice: Do it with a friend or your local astronomy club. Together, you'll be able to keep each other awake and have someone there to witness to your success. Most of all, sharing a Messier marathon doubles the enjoyment.

■ **JAN HATTENBACH** is a German amateur astronomer with a background in particle physics. He resides on the island of La Palma, where he enjoys some of the Northern Hemisphere's finest night skies.
**RONALD STOYAN** is a veteran deep-sky observer from Bavaria, Germany, and one of the pioneers of Messier marathons in Europe. He's also author of *Atlas of the Messier Objects*.

## Messier Marathon Resources

### Books

*Atlas of the Messier Objects: Highlights of the Deep Sky*, Second Edition, by Ronald Stoyan (Cambridge University Press, 2024)

*Deep-Sky Companions: The Messier Objects* by Stephen James O'Meara (Cambridge University Press, 1998)

*The Observing Guide to the Messier Marathon: A Handbook and Atlas* by Don Machholz (Cambridge University Press, 2002)

*The Next Step: Finding and Viewing Messier's Objects* by Ken Graun (Kenpress, 2004)

### Websites

Larry McNish's Messier Marathon Planner: **https://calgary.rasc.ca/darksky/messierplanner.htm**

The Messier Marathon: **www.messier.seds.org/xtra/marathon/marathon.html**

Guide to the Messier Marathon: **www.richardbell.net/marathon.html**

# The First "American Astronomical Society"

Well before today's American Astronomical Society was founded, astronomy practitioners in Brooklyn, New York, organized a different group with that same name.

On Monday evening, January 22, 1883, thirteen men gathered in the Brooklyn Heights mansion of Wall Street stockbroker Stephen Van Culen White and formed what they called the American Astronomical Society. The Brooklyn group was the first astronomical body in the nation created purely to share knowledge rather than to establish an observatory. As such, reported the *Brooklyn Argus,* "The hope is cherished that a centre [sic] of information and a medium of communication may be established."

However, around 1888, the group seemed to disappear without a trace. What became of it? Its apparently short-lived existence was known to 20th-century historians but largely dismissed. Richard Berendzen wrote in *Physics Today* (December 1974), "Almost predictably, the effort failed, undoubtedly in large part because it was not led by the only persons who could make it succeed, the professionals . . ." In *Social Studies of Science* (1981), Marc Rothenberg added, "The grandiose name obscured the reality that this was simply a local amateur's [sic] organization with considerable pretensions."

As a New York University grad student in history of science in 1976, I happened across a thick uncataloged scrapbook in the library of the old Hayden Planetarium in New York City. It was stuffed with newspaper clippings, typed meeting transcripts, draft manuscripts of talks, and letters dated from 1883 to 1890, which revealed that in fact the Brooklyn AAS did not die. Instead, in 1888 the society was induced to become the Astronomi-

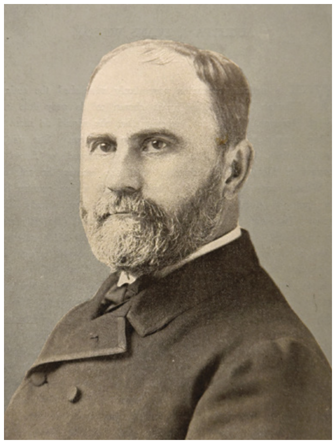

◀▲ **SENTRY ON THE EAST RIVER** Stephen Van Culen White's observatory — a tall white building and dome was clearly visible to people in ferries or on the Brooklyn Bridge crossing the East River. It held a 12-inch refractor begun by Henry Fitz and completed by Alvan Clark before June 1867. This detail, from an 1879 bird's-eye view of Brooklyn, is the only known image of the observatory.

C.R. PARSONS / LIBRARY OF CONGRESS / PUBLIC DOMAIN cal Department of the Brooklyn Institute of Arts and Sciences, which eventually morphed into today's Brooklyn Museum.

After finding the overstuffed scrapbook, I wondered whether a *second* scrapbook documenting the Brooklyn group's later history might exist somewhere, because the first volume seemed to end simply because it ran out of pages.

In early 1979, Massachusetts-based astronomy antiquarian bookseller Paul W. Luther called me privately, saying: "I think I've found the second scrapbook" from an estate sale. It covered the first six decades of the Brooklyn Institute's Astronomical Department from June 1888 through 1948, overlapping two years in the first scrapbook. It also included eight loose inserts, the most significant of which was the unpublished, 10-page, single-spaced typed personal recollection of the Brooklyn group from its earliest days in 1883 to 1940 by founding member Breading G. Way. After several years of private discussion and a personal visit, in July 1982 I purchased the second scrapbook from Luther for $200.

The two unpublished scrapbooks — plus a wealth of additional primary documents more recently made available online — reveal that as the Brooklyn Institute's Astronomical Department, the fledgling society grew rapidly and became highly successful, lasting well into the 20th century. It also left at least some early fingerprints on today's AAS.



◀ **MAN OF INFLUENCE** Although born in North Carolina, White migrated with his family to the Midwest and eventually practiced law in Iowa. He moved to New York in 1865 and gained success on Wall Street before serving a term in Congress representing Brooklyn.

### Crucial Pre-1883 Context

From the 1840s through the 1890s, public interest in astronomy across the U.S. had reached an all-time high. Much of the nation then was forest, farmland, or dotted with small villages, and the rural night sky was dark — the heavens were thick with stars so numerous that the constellations themselves were lost. Outside of major cities, streetlights didn't flood the sky nor did smog dim the glory of celestial wonders, and observers regularly saw down to 6th magnitude.

The 19th century also was astronomically spectacular, with several dramatic meteor showers, two total solar eclipses whose paths of totality crossed the U.S. (1869 and 1878), two transits of Venus (1874 and 1882), and more than a dozen comets so brilliant they could easily be seen just by eye — including two in 1882. Stories of astronomical expeditions and discoveries were popular topics in newspapers, magazines, books, and public lectures. And reporting on it all was *The Sidereal Messenger,* begun March 1882 and published 10 times per year at Carleton College Observatory. Although directed toward teachers and amateurs, at that time it was the only U.S. periodical dedicated exclusively to astronomy.

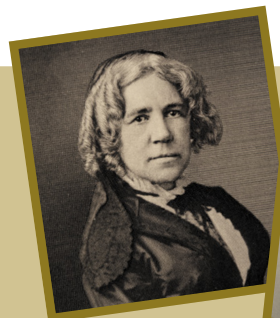
By 1882, the public imagination thrilled to accounts of the ongoing construction of what would be the largest refracting telescope in the world: the 36-inch at Lick Observatory atop Mount Hamilton, California. This great refractor was the handiwork of the internationally renowned American telescope opticians Alvan Clark & Sons and mechanical

## No Men's Club

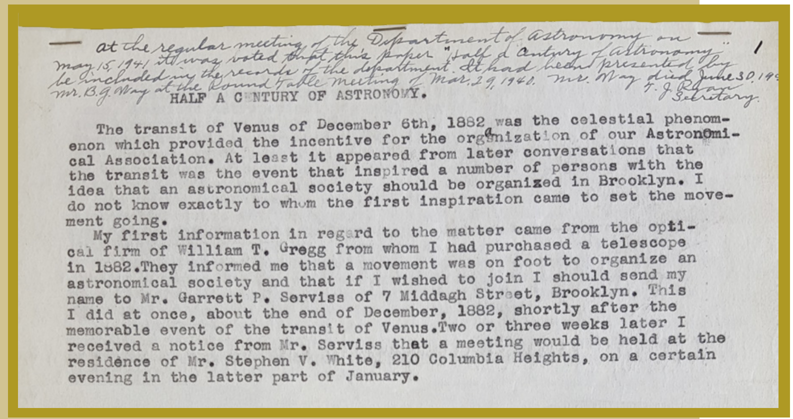
From its beginning in 1883, the Brooklyn AAS encouraged the participation of women. Several of the group's early male members were principals or professors of mathematics and physics at female academies and colleges, or at co-ed institutions. Others staunchly advocated university education and professional careers for women.

By 1885, two of the AAS's early corresponding members were renowned Vassar College professor and observatory director Maria Mitchell and astronomy professor Sarah F. Whiting at Wellesley College. In 1896–1900, Whiting helped secure White's 12-inch Fitz/Clark refractor for Wellesley's Whitin Observatory, where it continues operation today.

At the Brooklyn Institute, by 1892 women accounted for nearly a third of the Astronomical Department membership and began appearing as occasional speakers two years later. By the early 20th century, these had included Antonia C. Maury (who worked with Pickering at Harvard on a catalog of stellar spectra), Mary Proctor (popular speaker and writer on astronomy; daughter of British astronomy popularizer Richard Proctor), and Mary W. Whitney (student and successor to Maria Mitchell as Vassar College professor of astronomy). In the early 20th century, women also began to serve on the Astronomical Department's executive committee and to be elected as officers.



▲ Two of the Brooklyn AAS's early corresponding members were Maria Mitchell of Vassar College *(left)* and Sarah Whiting of Wellesley College.

at the regular meeting of the Department of Astronomy on May 15, 1941 it was voted that this paper "Half a Century of Astronomy" be included in the records of the department. It had been presented by Mr. B.G. Way at the Round Table meeting of Mar. 29, 1940. Mr. Way died June 30, 194

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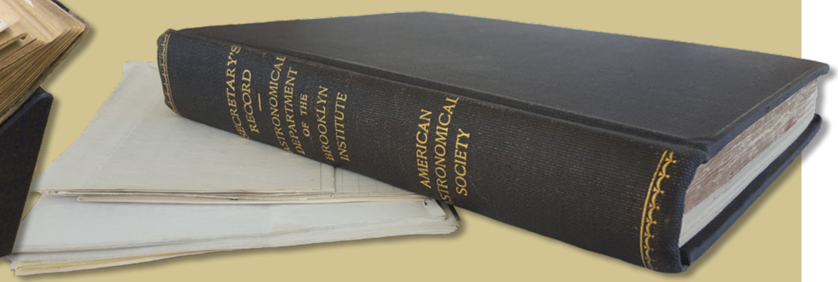
HALF A CENTURY OF ASTRONOMY.

The transit of Venus of December 6th, 1882 was the celestial phenomenon which provided the incentive for the organization of our Astronomical Association. At least it appeared from later conversations that the transit was the event that inspired a number of persons with the idea that an astronomical society should be organized in Brooklyn. I do not know exactly to whom the first inspiration came to set the movement going.

My first information in regard to the matter came from the optical firm of William T. Gregg from whom I had purchased a telescope in 1882.They informed me that a movement was on foot to organize an astronomical society and that if I wished to join I should send my name to Mr. Garrett P. Serviss of 7 Middagh Street, Brooklyn. This I did at once, about the end of December, 1882, shortly after the memorable event of the transit of Venus.Two or three weeks later I received a notice from Mr. Serviss that a meeting would be held at the residence of Mr. Stephen V. White, 210 Columbia Heights, on a certain evening in the latter part of January.




▲ **TREASURE TROVE #1** *Bottom left:* The first of two unpublished scrapbooks documents the initial five years (1883-87) of the American Astronomical Society in Brooklyn and the first two years of the group under the name of the Astronomical Department of the Brooklyn Institute (1888–90). The scrapbook is now in the special collections of the American Museum of Natural History in New York City.

▲ **PAPER TRAIL** *Top left:* The constitution and bylaws of the Brooklyn AAS, preserved in the first scrapbook, included a three-page list of corresponding and regular members for 1885. Also included are three issues of "Papers Read Before the American Astronomical Society," published in 1885, 1887, and 1888. Some entries recount original observational or optical work by members.

▲ **TREASURE TROVE #2** *Bottom right:* The second unpublished scrapbook documents the proceedings of the Astronomical Department of the Brooklyn Institute from 1888 to 1948. It's actually two compendiums that were bound together in 1935. Both the spine and the title page acknowledge the earlier name of the "American Astronomical Society."

▲ **KEY RECOLLECTIONS** *Top right:* Among the loose inserts in the second scrapbook is a 10-page single-spaced typed manuscript of a talk delivered in March 1940 by Brooklyn AAS founding member Breading G. Way, describing his personal recollections of the group's origin and history. It also recounts how the first scrapbook and other early records were scattered or lost.

engineers Warner & Swasey (see "The Great Telescope Race," *S&T:* June 2011, p. 28). Meantime, to satisfy growing demand for telescopes, the Clarks plus a host of lesser-known optical firms equipped scores of schools and private owners.

Although using refractors and a few reflectors with relatively small apertures (3 to 6 inches), serious amateur observers were discovering and monitoring a wealth of double stars, variable stars, asteroids, comets, and sunspots. Indeed, at least some professional astronomers recognized that the growing number of skilled amateurs, if organized into a systematic program, could collect volumes of data essential to fundamental astronomical research. To that end, in 1882, Harvard College Observatory director Edward C. Pickering issued a 15-page pamphlet, *A Plan for Securing Observations of the Variable Stars,* inviting amateurs to contact him for further instructions and appealing even to "ladies . . . especially among the graduates of women's colleges" because "the work may be done at home, even from an open window."

## Who Founded the Brooklyn AAS?

Into this milieu of celestial excitement, the Brooklyn AAS was born. As recounted by Breading Way, at that first meeting the organizers settled on the name "American Astronomical Society" as befitting their sense of creating something potentially of national importance. They elected officers and appointed committees to draft a constitution and bylaws. Afterward they adjourned to White's magnificent backyard observatory, which housed one of the world's largest telescopes then in private hands: a 12-inch refractor (also reported to be 11⅞ inches in aperture) with a focal length of 17 or 18 feet.

TRUDY E. BELL (4)

Indeed, by that time, many of the new society's other officers and members had private observatories and telescopes. Among the largest was the 9-inch f/12 refractor owned by dedicated variable-star observer Henry M. Parkhurst, who quickly responded to Pickering's 1882 request for observations. Another serious amateur was Brooklyn AAS treasurer Arthur C. Perry, who designed and distributed star maps for other variable-star observers for decades (including ultimately for the American Association of Variable Star Observers after it was founded in 1911).

Many of the Brooklyn AAS's core members had some long-standing professional connection to astronomy, either as commercial makers of astronomical and surveying instruments or as academics in the area's private schools and colleges. Still others wrote regularly on astronomy for well-known publications (notably George M. Hopkins for *Scientific American* and Garrett P. Serviss for *The Sun* in New York City).

Last, most AAS core members were prominent Brooklyn residents who had political and cultural ambitions for their city. Until 1898, the term "New York City" referred only to the island of Manhattan. Nearby Brooklyn was one of four neighboring jurisdictions (later becoming "boroughs" of the consolidated city), each with its own identity. Indeed, Brooklyn was a wealthy, fast-growing manufacturing center that aspired to become a major cultural center and was rapidly establishing elite schools, colleges, and museums.

## Amateurs Versus Professionals

During its inaugural five years, the Brooklyn AAS met the first Monday evening of each month from October through June. Because the group had no dedicated meeting space, it was a movable feast. Each month AAS secretary Serviss sent members a postcard informing them of the current month's venue, which rotated among several Brooklyn educational institutions or members' homes. Newspaper reporters were always invited.

From the outset, the Brooklyn AAS's constitution specified three classes of membership: active, associate, and corresponding. Active members were "those who are engaged in the actual study of astronomy, theoretic or practical." Associate members were those simply "interested in advancing the science of astronomy." Dues for both were $5 per year (equivalent to more than $150 today), but only active members were eligible for office. By 1885, there were 50 active and associate members, including seven women (see the sidebar on page 29).

Corresponding members, exempt from dues, were invited professional astronomical practitioners who consented to have some connection with the group. One eminent early supporter was Princeton solar astronomer Charles A. Young, who attended several meetings. Others included such luminaries as Harvard's Pickering, Lick Observatory founding director Edward S. Holden, and U.S. Naval Observatory astronomer Asaph Hall (famous for discovering the two small moons of Mars).

## Careers and Telescopes of Brooklyn AAS Members (as of 1885)

| Name | Profession | Telescope |
|---|---|---|
| Stephen Van Culen White* | stockbroker; NY Congressman | 12-inch Fitz/ Clark refractor** |
| Henry M. Parkhurst* | court reporter for NY Supreme Court | 9-inch Fitz/Gregg refractor** |
| William T. Gregg* | telescope maker (father) | 6¼-inch refractor "of my own make"** |
| William T. Gregg, Jr.* | telescope maker (son) | — |
| Charles E. West* | principal of private girls' school | 6¼-inch Byrne/ Gregg refractor** |
| Darwin G. Eaton* | professor at Packer Collegiate Institute | 6⅛-inch Fitz refractor (at Packer)** |
| Asahel K. Eaton* | telescope/ microscope maker | was building a 6-inch refractor in 1882 |
| Gardner D. Hiscox* | professional mechanical engineer | 6-inch self-made reflector |
| Rev. Dr. John M. Ferris* | pastor and missionary | 5-inch Clark refractor** |
| George D. Mackay* | New York banker | 4½-inch refractor |
| Arthur C. Perry* | (not known) | 4-inch refractor |
| Garrett P. Serviss* | popular astronomy writer/lecturer | 3¾-inch Byrne refractor |
| Wallace Goold Levison* | professor at Cooper Union | — |
| George M. Hopkins* | editor for *Scientific American* | 3-inch refractor |
| William C. Peckham* | professor of math and sciences at Adelphi Academy | planning a telescope for the Academy |
| D. W. Edgecomb | lawyer | 9.4-inch Clark/ Young refractor** |
| William Meikleham | VP of New York Life and Trust Co. | 4.3-inch Byrne refractor** |
| John A. Eadie | (not known) | 3¼-inch Byrne refractor |

* Founding member of Brooklyn AAS
** Instrument housed in an observatory

▲ **CELESTIAL STATUS** Of the AAS's members as of 1885, 14 owned telescopes, many predating the group's 1883 formation. Four were dedicated to specific observing programs or optical testing; the others were used for education, public outreach, or personal enjoyment.

However, in February 1884, Simon Newcomb, director of the Nautical Almanac Office in Washington, DC, created a stir when he declined the group's invitation to become a corresponding member. According to the meeting transcript, Newcomb asserted that the very name "American Astronomical Society" implied the local group was a society of leading U.S. astronomers and thus that it "was attempting to be what it was not."

The letter was read aloud at the next AAS meeting, but its exact text was withheld from reporters (nor was it preserved in either scrapbook). But the gist made headlines ("IMPERTINENCE" read one in the *Brooklyn Daily Eagle*) and dominated discussion in the meeting room. The attendees derived little comfort from the fact that, at that same meeting, the same invitation had been warmly accepted by six other prominent professional astronomers.

Not dissuaded, by 1885 the AAS's constitution pamphlet listed 29 corresponding members. To be sure, some were merely big names passively adorning the rolls. Others, however, took lively interest and served as genuine advisors. Indeed, Newcomb seems to have been the only professional astronomer ever to decline the group's invitation.

At monthly meetings, talks were usually given by AAS active members, with mixed success. Surviving manuscripts indicate that, at worst, some talks were highly specialized, mathematical, or just tediously long — one topped 2½ hours! At best, popular lectures by AAS founding member and secretary Garrett P. Serviss (already well known for his popular astronomy column in *The Sun*) attracted audiences of more than 900. Rarely, a corresponding member appeared as a guest speaker; for example, Princeton's Young spoke on the Sun in 1883 and on astrophotography in 1888.

By the late 1880s, however, Serviss had grown uneasy. As most talks became more technical and insular, public attendance dwindled and press coverage became brief and desultory. In February 1888, Serviss wrote to AAS librarian Wallace Goold Levison, "All of the newspapers had invitations as usual, but I have observed that they let us pretty severely alone, of late . . ."

## Enter the Brooklyn Institute

Meantime, the city of Brooklyn was booming. With a population already larger than Chicago's in 1880, it had grown to 806,000 by 1890. Many locals felt that one of the nation's largest cities needed a world-class cultural center, akin to Boston's Lowell Institute or Philadelphia's Franklin Institute, so that "Brooklyn should have an Institute . . . worthy of her wealth, her position, her culture and her people."

So, in 1887, a new Board of Trustees resuscitated an old, nearly moribund Brooklyn Institute (originally founded in 1824) and slightly renamed it the Brooklyn Institute of Arts and Sciences. The rejuvenated Institute had only a few collections and an aging building — but it did have ambitions, backers, and, most importantly, a tireless new president: Franklin W. Hooper, a 36-year-old biologist and geologist who was also a brilliant, dynamic leader.

Hooper's vision was to make the Institute *the* cultural center for the city of Brooklyn. It would be made up of departments, "each department forming a society by itself and yet enjoying all the privileges of the general association." To that end, he systematically approached all the intellectual clubs and organizations in Brooklyn to become departments of the reconstituted Institute.

In late March 1888, Hooper and two other representatives approached the officers of the Brooklyn AAS with a proposal to join the Institute as its Astronomical Department. The first scrapbook reveals that the terms were a sweetheart deal. The Institute had property worth a quarter million dollars, and the AAS was "invited to come in and share with them the use of that property for scientific purposes, upon equal terms with them" under a "mutually agreeable" new name, asking "no surrender of anything we possess."

In truth, Hooper was bootstrapping the entire Brooklyn Institute enterprise from a very modest beginning (in early 1888 its total membership, across all departments, was only 82). Thus, the AAS with its 32 regular and 29 corresponding members was a significant asset, and the Institute would be the beneficiary.

Hooper wanted an answer by the time of the Institute's annual meeting in May, so the AAS officers sent a letter to all corresponding members soliciting their opinions. It explained that the AAS was "originally designed to be a National Society" laying a "foundation in the hope that towers, reaching to the skies would finaly [sic] rest thereon" and "its corresponding members ultimately take it in hand."

About 20 professional astronomers replied. Most were in favor of *an* American Astronomical Society but opposed the Brooklyn group retaining that name. However, two well-known astronomers — Pickering and Holden — remained in favor of the group's original vision. Holden even suggested that Benjamin Apthorp Gould (also a corresponding mem-

◀ **UNFINISHED BUSINESS** Although Franklin Hooper and his administration had grand plans for the Brooklyn Institute of Arts and Sciences, only a portion of the sprawling complex they envisioned was actually built. Today this building houses the Brooklyn Museum.

ber) be induced to publish his *Astronomical Journal* (revived in 1885) as a society organ.

The question of whether the Brooklyn-based AAS should merge with the Brooklyn Institute was put to the active members for a vote. The ayes won by a margin of eight to three. Thus was born the Astronomical Department of the Brooklyn Institute of Arts and Sciences, which held its first meeting under its new name in June 1888.

### After the Name Change

The second scrapbook reveals that as the Brooklyn Institute's Astronomical Department, the renamed AAS did not die; instead, it retained the same organizational structure, the same officers, and the same meeting procedures. But its membership and average attendance grew rapidly. So, what *had* changed?

First, it received an infusion of funds, plus access to the Brooklyn Institute's infrastructure for handling dues, printing meeting notices, and publicizing activities. Yet the biggest benefit was Hooper's gentle but innovative management, teamed with Serviss's involvement as the group's long-serving president (White was gone, having been elected to Congress in 1886).

By the 1890s, the Astronomical Department was hosting talks on current research by such well-known professional astronomers as George Ellery Hale, James E. Keeler, Percival Lowell, David Peck Todd, and professional telescope maker John A. Brashear. In fact, Hale (then in his twenties) took such an interest in the group's activities that he attended several board meetings and contributed lantern slides and other items. Meanwhile, the Astronomical Department's membership rose rapidly to about 250; monthly meeting attendance averaged about 150 but occasionally swelled to more than 1,000 for famous speakers. This pattern lasted well into the mid-20th century.

In his recollections of 1940, Way recounted, "The secretary had kept a very careful record of all our meetings," and "The librarian of our department kept scrap-books containing the articles from the newspapers, and the entire manuscripts of the papers that had been presented." But at some point the early documents were haphazardly packed away, and many were later ruined by rainwater. Some materials were rescued, but most disappeared entirely — until the 1970s, when the scrapbooks described in this article reappeared.

### Legacy of the Brooklyn AAS

Timing suggests that the founding of the first AAS in January 1883 may have inspired the foundation of other astronomical societies around the nation. *The Sidereal Messenger* reported the subsequent creation of astronomical societies in Baltimore, Indianapolis, Philadelphia, Washington, and elsewhere in the 1880s and 1890s. The Baltimore group even followed the pattern of the AAS's evolution, eventually merging with the newly re-founded (1897) Maryland Academy of Sciences.

Such inspiration clearly extended to the professionals. On New Year's Day 1889, Lick director Holden, one of the Brooklyn AAS's old friends, used the occasion of a total solar eclipse across California to establish the Astronomical Society of the Pacific (still active today), in part to form a nationwide group joining amateur and professional astronomers.

Ten years later, professional astronomers co-led by Hale, then director of Yerkes Observatory, founded the Astronomical and Astrophysical Society of America (AASA). At least 18 of its 113 charter members were current or former corresponding members of the Brooklyn-based AAS.

For the nine charter AASA officers, the contact was even closer: six had past or ongoing contact with the Brooklyn group under either name, including its early supporters Hale, Pickering, and Young. The exact significance of those contacts is unknown, but the AASA's founders were clearly aware of the Brooklyn group.

In 1914, the AASA was renamed the American Astronomical Society (AAS), which now boasts 8,200 active members — including a special category for amateur astronomers!

## An Enduring Astronomical Society

"Astronomy was well established as a discipline by the late 19th century, but not as a profession," write historians Brant L. Sponberg and David H. DeVorkin. "Most astronomers spent the bulk of their efforts teaching." So, in 1899, George Ellery Hale and Simon Newcomb — arguably the two best-known astronomers in the U.S. — spearheaded an effort to organize American astronomy around a new national organization. Initially called the Astronomical and Astrophysical Society of America, it became the American Astronomical Society in 1914.

Today the AAS pursues a vision to "create a world where all people value and benefit from a scientific understanding of our universe." Headquartered in Washington, DC, the society convenes two national meetings each year, along with annual meetings of its six discipline-specific divisions. The AAS also publishes four professional journals and (since acquiring it in 2019) *Sky & Telescope*.

**— J. KELLY BEATTY**

■ Contributing Editor **TRUDY E. BELL** has been a staff editor for *Scientific American* and *IEEE Spectrum*. Her journalism and research awards include the David N. Schramm Award from the American Astronomical Society (2006). She thanks the archivists at the American Museum of Natural History and the Brooklyn Museum for generously providing access to the first scrapbook of the AAS and to early issues of the Brooklyn Institute's *Year Book*, along with the late historian Craig B. Waff for Brooklyn newspaper articles from the 1880s and 1890s.

 by Camille M. Carlisle

# Black from the Da

# Holes
# wn of Time

**Black holes created in the earliest moments of cosmic history might explain multiple mysteries.**

Sown throughout the universe could be an invisible landscape of cosmic gopher holes.

These *primordial black holes* would, physically speaking, be just like the black holes we find elsewhere: spots so dense that spacetime has effectively swallowed itself and created bottomless pits. But unlike the objects made from dead stars and other normal matter, primordial black holes would have formed in the earliest moments of the universe, back when everything was a hot, dense soup.

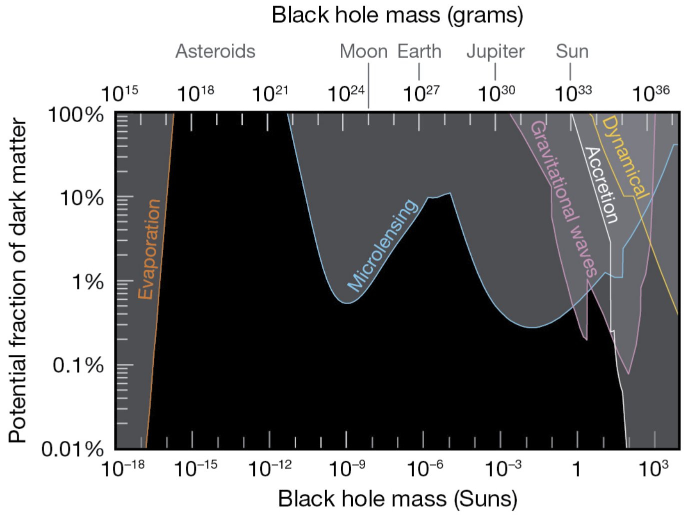
Scientists first proposed the existence of primordial black holes in the 1960s and 1970s. Speculation soon arose that the objects could be the gravitational glue holding things together — the long-sought dark matter, the invisible stuff that serves as the backbone of galaxies and cosmic structure. But primordial black holes remained a fringe topic, eclipsed by dark matter candidates from particle physics. Over the years, their popularity waxed and waned; research papers trickled in at a rate of several dozen to a few hundred per decade.

Since 2016, however, these objects have enjoyed a surge in popularity. The sudden fandom stems from the detection of gravitational waves, ripples in the fabric of spacetime created by accelerating masses. Most of the gravitational-wave events we've detected come from merging black holes (*S&T:* June 2022, p. 12). The suggestion that the first event found might have been the collision of two primordial black holes brought what had been a field in perpetual twilight into the bright light of day.

In the most optimistic scenarios, primordial black holes could explain part or all of the universe's dark matter and some gravitational-wave events. Recent work even suggests they might serve as seeds not only for the supermassive black holes planted in the centers of galaxies but also for the galaxies themselves, explaining unexpected sightings in the early universe. Within a decade, enthusiasts say, we might finally have firm evidence for primordial black holes.

If they exist.

BEATRIZ INGLESSIS / *S&T*



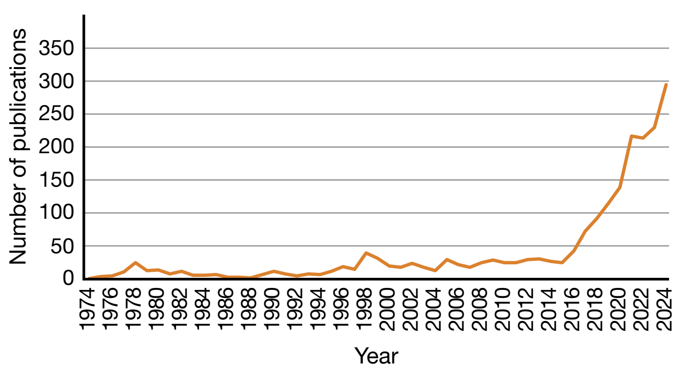

▲ **WHERE THEY COULD HIDE** Thanks to various observations, scientists have placed limits on the fraction of dark matter that primordial black holes of a given mass could account for. Here, gray regions are the excluded possibilities, labeled by measurement type. Additional, contended limits exist but aren't shown.

## From the Cosmic Stew

Back when the universe was a fraction of a second old, it was filled with matter and radiation. This plasma was not perfectly smooth; it had knots of higher density in random places.

As the nascent universe expanded, the plasma soup diluted and cooled. Dense knots naturally expanded more slowly than the surrounding, diffuser stuff. Under the right conditions, some knots could have packed enough mass into the right amount of space to stop expanding, overcome their internal pressure, and collapse, creating black holes.

To overcome the plasma's pressure takes special circumstances, explains Bernard Carr (Queen Mary University of London, UK), who has worked on primordial black holes for some 50 years. Collapse could happen if the smallest density fluctuations were more severe than the ones on larger size scales that later gave rise to galaxies and cosmic structure — fluctuations we see in the *cosmic microwave background*, the afterglow from this early era.




▲ **RISING INTEREST** For the first several decades, there were few research papers with "primordial black hole" in the title. But after scientists announced in 2016 the first detection of gravitational waves from merging black holes, interest surged.

Or collapse could have happened during a *phase transition*. At certain moments in the primordial universe, conditions changed dramatically, akin to when liquid water freezes. During these transitions, the pressure dropped. A region that otherwise wouldn't be dense enough to collapse suddenly might.

The primordial universe experienced several phase transitions. At each epoch, knots of a certain mass and size were most likely to collapse. The smallest primordial black holes, those squeaking in at $10^{-5}$ gram (about one-tenth the mass of a hungry flea), would have formed at the Planck time, $10^{-43}$ second after cosmic history began. Larger black holes would have formed later. A spurt should have occurred at $10^{-5}$ second during what's called the *quantum chromodynamics (QCD) transition*, Carr says, when subatomic particles called quarks combined to create things like protons. Black holes formed at this time would have most commonly had a mass roughly equivalent to that of the Sun.

Only a tiny fraction of the universe would have collapsed to make these objects. Anne Green (University of Nottingham, UK), who has spent her career exploring solutions to the dark matter problem, is skeptical that conditions could have been so precisely tuned to make exactly the right number of primordial black holes at the right time such that they could explain dark matter. Too many too early, and they would upset the balance between radiation and matter.

"You've got to get the perturbations just right to make all of the dark matter primordial black holes, and not to have created a universe that just made the primordial black holes and nothing else," she says.

The smallest primordial black holes would have evaporated away long ago — in fact, it was studying their hypothetical quantum properties that helped lead Stephen Hawking to discover that black holes evaporate. The temperature of an evaporating black hole's radiation is inversely proportional to its mass, so as a black hole shrinks, it heats up. Those still evaporating today would have a mass of 1 quadrillion grams ($10^{15}$ g, or the mass of a small comet), packed into a space a little larger than a proton. Such black holes would radiate gamma rays, albeit slowly — they'd sit "sizzling away" over billions of years, Carr says, before losing their remaining mass in an explosion of gamma rays.

Gamma rays do suffuse the universe in a high-energy haze, from a variety of sources. To stay within the limits set by this haze, at most one-billionth of the universe's total contents could be made up of primordial black holes of comet-like masses.

## An Endless Sea of . . . Nothing?

Primordial black hole (PBH) enthusiasts split on which mass should be the target of ongoing searches. Some, including Carr, favor a solar mass, while others focus on objects as lightweight as planets and asteroids.

The first potential evidence seemed to support stellar-mass objects. In 1997, astronomers reported their results looking for dark matter in the form of *massive compact halo objects*

PRIMORDIAL BLACK HOLE BOUNDS: BEATRIZ INGLESSIS / *S&T*, SOURCE: BRADLEY KAVANAGH / GITHUB.COM/BRADKAV/PBHBOUNDS; NUMBER OF PUBLICATIONS BY YEAR: BEATRIZ INGLESSIS / *S&T*, SOURCE: SAO ASTROPHYSICS DATA SYSTEM

(MACHOs) in the Milky Way. They stared at 8.5 million stars in the Large Magellanic Cloud (LMC) and watched for blips created by unseen objects in the Milky Way's halo passing between us and the stars. These transits temporarily magnify the background star's light, a phenomenon called *gravitational microlensing*.

The MACHO team detected more microlensing events than they expected to see if the only things passing between Earth and the LMC were stars and their ilk. The researchers estimated that perhaps half of the Milky Way's dark matter halo could be in the form of objects with roughly half a solar mass.

"We were really excited," Carr says of himself and his fellow enthusiasts when they heard the result. Half a Sun was a good match for the mass expected from the QCD phase transition. "We thought, 'Wonderful! PBHs really exist.' . . . Not only did they have the dark matter density, they had the right mass."

Subsequent analyses with more data, and studies by other microlensing projects, drastically reduced the fraction of dark matter that could comprise such objects. But the analyses had shortcomings, which gave enthusiasts hope that the window wasn't closed quite as tightly as it seemed to be.

Then, in 2016, scientists with the Laser Interferometer Gravitational-Wave Observatory (LIGO) announced they'd detected two black holes merging. The black holes each weighed in at about 30 solar masses, bigger than any star-made black holes known at the time. They also fell into a potential mass range for PBHs.

Simeon Bird (then at John Hopkins University) and others suggested that the black holes might have been primordial and could have merged after catching hold of each other in a flyby encounter. A universe filled with 30-solar-mass PBHs at a density high enough to match dark matter's effects could lead to a merger rate consistent with that inferred from the single LIGO discovery, the researchers calculated.

Physicists were primed to take interest. The most favored candidate for dark matter, *weakly interacting massive particles* (WIMPs), had failed to materialize. "LIGO coincided with the time when people were considering a broader range of dark matter candidates," Green says. The convergence led to a swell of interest.

Carr now gives talks about PBHs at particle physics conferences. He admits to feeling a bit odd about it.

"When I'm talking to these people, I think, 'My goodness, if the dark matter is primordial black holes, I'm going to be the most hated person in the room.' Because it's saying these people have spent all their lives looking for something that isn't there," he explains. "On the other hand, that's the nature of science, isn't it? Most models are wrong in the end anyway."

Many enthusiasts hold tight to the PBH explanation for gravitational-wave events, Carr says. "If you go to a PBH meeting — and now they have PBH meetings — it's all more or less assumed that [some of the gravitational-wave events] are going to be primordial black holes."

Nevertheless, the idea has never become mainstream. "You can definitely make all the black holes that we have observed so far from astrophysical formation channels," says LIGO astrophysicist Sylvia Biscoveanu (Northwestern University).

Subsequent work showed that if dark matter comprised primordial black holes in the 30-ish-solar-mass range, we'd be detecting mergers far more often than we do, Carr adds.

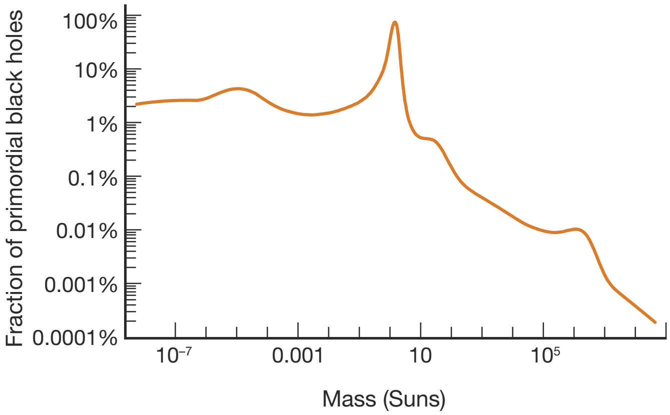
Attention has turned to lower masses, of a few Suns or less. When massive stars die, their cores can become neutron stars or — if they're big enough — black holes. The cutoff should be around 2½ solar masses. Stars struggle to make black holes with masses slightly above that cutoff (we know of only a handful of examples), and they shouldn't make any black holes below it. If gravitational-wave detectors find a merger involving at least one black hole lighter than a solar mass, then the object should be primordial.

So far, scientists with the LIGO, Virgo, and KAGRA projects (united as the LVK collaboration) have not found a

## DARK MATTER

**Technically, a primordial black hole is by definition dark matter: It formed before atomic nuclei did in the early universe, so it's *nonbaryonic* — that is, it didn't form from normal matter the way black holes made from stars and gas clouds have. So if we find a primordial black hole, then we'll have found *some* dark matter. However, that wouldn't necessarily mean that PBHs are *the* dark matter holding cosmic structure together.**

BLACK HOLE BACKGROUND: SUDAKARN VIVATVANICHKUL / SHUTTERSTOCK.COM




▲ **WIDE RANGE** Calculations based on conditions in the early universe suggest that primordial black holes could have formed with a variety of masses. But some theorists have suggested that four mass ranges would be most common (bumps). Each of these preferred masses is set by conditions during a particular transition in the primordial universe, with larger black holes forming later than smaller ones.

single sure merger with an object this small. Even if they did, it would be challenging to definitively show that the object was a black hole and not a neutron star, Biscoveanu says. Neutron stars are somewhat squishy, a trait that will leave a weak imprint on the gravitational-wave signal if the star merges with something of comparable mass. But to have any hope of seeing this effect, we'd need to find a merger of two lightweight objects within a few hundred million light-years of Earth. (That's "local" by cosmic standards.) So far, nearly every event has lain much farther away.

LVK is currently in its fourth observing run, set to end in June 2025, and analysis of the many dozens of mergers detected during this run is under way. But in considering events from previous runs, Zu-Cheng Chen (Hunan Normal University, China) and Alex Hall (University of Edinburgh, UK) concluded that stellar-mass PBHs cannot make up most of the universe's dark matter and can at best explain roughly one-quarter of detected gravitational-wave events.

It is a recent microlensing result, though, that has many ruling this mass range out completely. In 2024, astronomers with the Optical Gravitational Lensing Experiment (OGLE) reported the result of 20 years of monitoring some 79 million stars in the Large Magellanic Cloud. Based on the number of microlensing events they detected and the events' duration — which is related to the lensing object's mass — the researchers concluded that compact objects in the mass range of about 0.0002 to 6 Suns cannot make up more than 1% of dark matter, and objects ranging from $1 \times 10^{-5}$ Sun (equivalent to Neptune) to 860 Suns cannot compose more than 10% of dark matter. "Thus, primordial black holes in this mass range cannot simultaneously explain a substantial fraction of dark matter and gravitational-wave events," Przemek Mróz (University of Warsaw, Poland) and colleagues concluded.

"The beauty of microlensing is that it's a fairly clean thing," says Green, who wasn't involved in the study. "You should be seeing it. You don't see it."

Carr and his colleagues wonder whether some of the OGLE team's assumptions could be skewing the result. For example, primordial black holes' natural propensity to cluster might mean that the OGLE results aren't quite as definitive as they appear, because our sightlines could be missing clusters.

But even if the OGLE results do mean the solar-mass window has slammed shut, Carr remains unfazed. "[It] doesn't bother me too much, because if this argument is correct, that just means, 'Okay, we're forced to another scenario where the PBHs are at a lower mass.'"

## Piddling Black Holes

Given these results, many enthusiasts are investigating primordial black holes of planetary or asteroidal masses instead.

Here, scientists have few observational constraints. Some even suggest we might have already detected signs that PBHs exist in this range.

The conditions in the early universe that made primordial black holes would also naturally have created gravitational waves, explains Guillem Domènech (Leibniz University Hannover, Germany). These waves would exist as a background "noise" in the universe today. This noise could be the same as the gravitational-wave background recently detected by comparing the arrival times of signals from pulsars scattered across the sky (*S&T:* Nov. 2023, p. 12). The background's properties correspond to conditions that would have made primordial black holes similar in mass to Jupiter, he says.

However, so far there's no sign of black holes with these masses among gravitational-wave events. Using LVK data up through late 2019, Andrew Miller (National Institute for Subatomic Physics, The Netherlands) and others found no evidence of planetary-ish-mass PBHs within the Milky Way's stellar halo. It is unlikely that such objects could make up all of the dark matter, Miller says.

Smaller masses, similar to those of asteroids or the Moon, remain a possibility. Some have suggested this gap is also closing: If these small black holes were out there, the argument goes, they'd inevitably encounter stars and merge with them. The primordial black hole would burrow inside the star and eat it from the inside out, transforming it into a black hole with a mass equal to that of the now-gone star. If gazillions of little PBHs were out there, then we should see a multitude of free-floating stellar-mass black holes — which we don't.

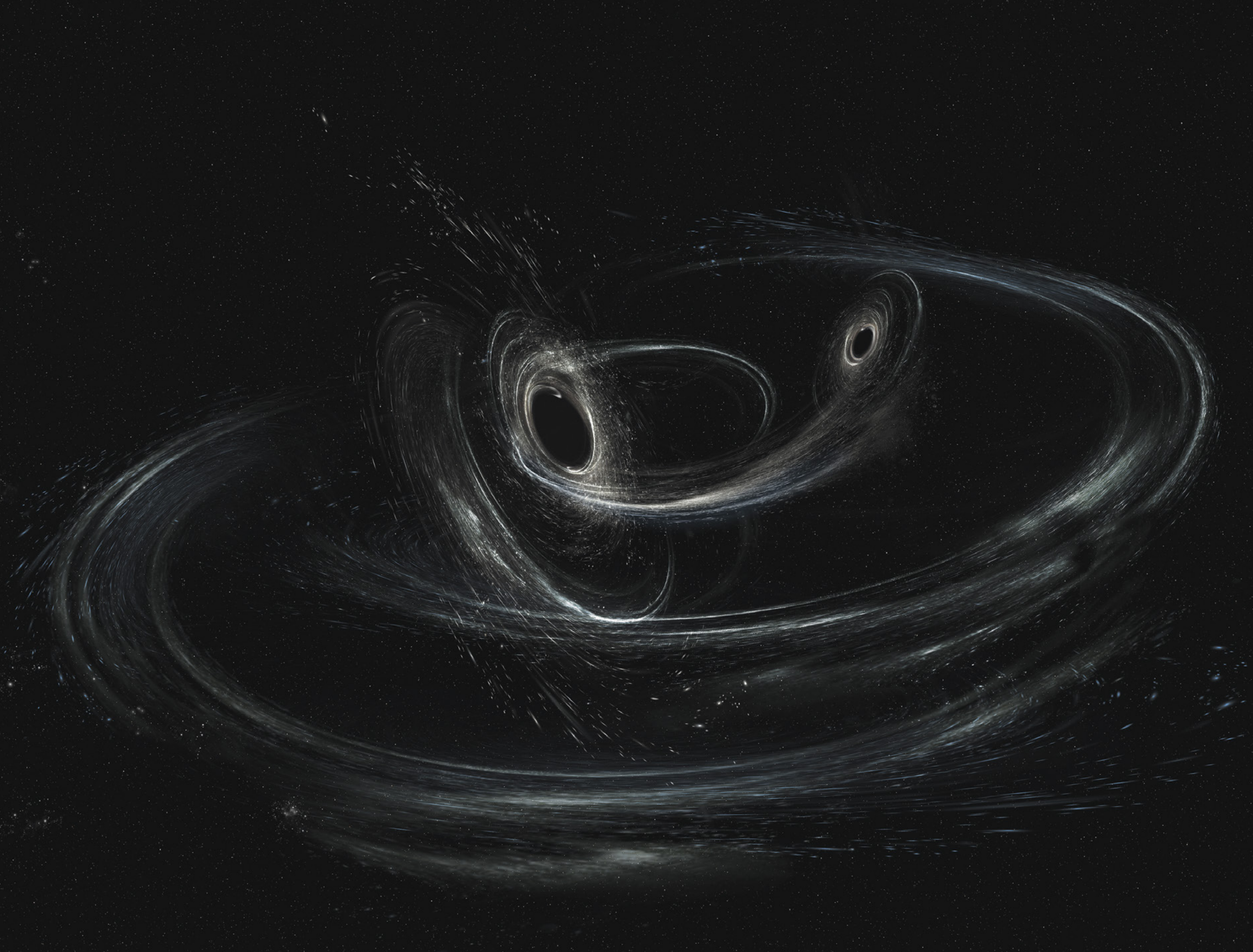
Recent work has refuted this line of reasoning, however. For now, the asteroid mass gap remains open.

## Catalysts of Galaxy Growth

Light of all wavelengths fills the universe with a diffuse glow (*S&T:* Oct. 2023, p. 24). This light comes from different sources. Some we can pinpoint — that X-ray beacon comes from that black hole in that galaxy — but there's also an ambient, unresolved glow. Its sources might be hidden in dusty clouds or too far away for us to see.

This glow is not uniform. Astronomers have found brighter regions in the cosmic X-ray background about an arcminute

SÉBASTIEN CLESSE



**INSPIRALING BLACK HOLES** This artist's concept shows two black holes about to merge. In some cases, like this one, the black holes' spin axes are tilted with respect to their orbital plane. (Gravitational waves would be more complex than the swirls imply, mind you.)

LIGO / CALTECH / MIT / SONOMA STATE (AURORE SIMONNET)

across, explains Priyamvada Natarajan (Yale). Fluctuations appear in the cosmic infrared background at the same spots. The arcminute scale is intriguing: Long ago, when the universe was making its first stars, galaxy formation was proceeding on this same scale in the sky.

The natural source of these bright regions would be big black holes scarfing down gas in the early universe. But standard thinking has been that the supermassive black holes we see today in galaxies' cores formed a bit later, after the galaxies did.

Natarajan and her colleagues decided to explore the idea that gas-guzzling primordial black holes could produce the X-ray and infrared emission instead. For that to be the case, though, the PBHs would need to be deep in the galaxy, right from the start.

"So we said, 'You know what, we just have to make the dark matter primordial black holes,'" she says. The black holes would serve as the seeds for galaxy formation, drawing dark and normal matter together to make galaxies. The biggest PBH would naturally sink to the center and grow into a supermassive black hole.

The trio explored what this scenario would mean for the early universe. They found that, thanks to this early seeding, galaxies would build up earlier than predicted in standard cosmology. The team forecasted that we should see a sharp upturn in the number of galaxies in the universe's earliest years.

There are hints that the James Webb Space Telescope is seeing this upturn: Astronomers have found more galaxies at early cosmic times than they expected. Some appear to be surprisingly large and evolved, implying they formed their stars rapidly within the first billion years. "The remarkable abundance of luminous galaxies at such early times holds the promise of upending theories of primordial galaxy formation," wrote participants of a 2024 workshop on the early universe.

Finding "too many" galaxies at early times won't close the case on primordial black holes, Natarajan warns. Early galaxies might simply have been better at making stars than we expected. Nor does every supermassive black hole have to begin as a PBH. Some seeds might start as the cores of over-massive stars, or as big gas clouds that collapse directly into black holes. Natarajan and her colleagues have found at least one object that shows all the signs of being a direct-collapse black hole (*S&T:* Jan. 2024, p. 8).

But when there's more than one way for something to happen, then chances improve that it does, she says — and there's more than one way to make a primordial black hole. "I'm completely open to the idea that the PBH is formed in the very early universe," she says, "and that some fraction of the supermassive black holes we see were seeded by them."

## Game Changer

Proving or disproving that primordial black holes exist will be difficult. Astronomers might spot the gamma-ray flash from an evaporating black hole, for example. Or we might find signs in the universe's chemical makeup. The existence and evaporation of tiny PBHs in the early cosmic soup could have impacted the distribution of protons and neutrons, and even the production of atomic nuclei such as helium.

Some scientists are convinced that gravitational-wave detectors are going to solve the conundrum. As astronomers push out to greater distances, they're learning how the rate of black hole mergers changes with time. If the black holes come from stars, the rate should track the cosmic star-formation rate, which peaked 10 to 11 billion years ago (at a redshift of 2 to 3) and has dwindled since. Mergers of primordial black holes, on the other hand, should become steadily more common as we look further back in time — and they should happen long before stars formed in the first few hundred million years.

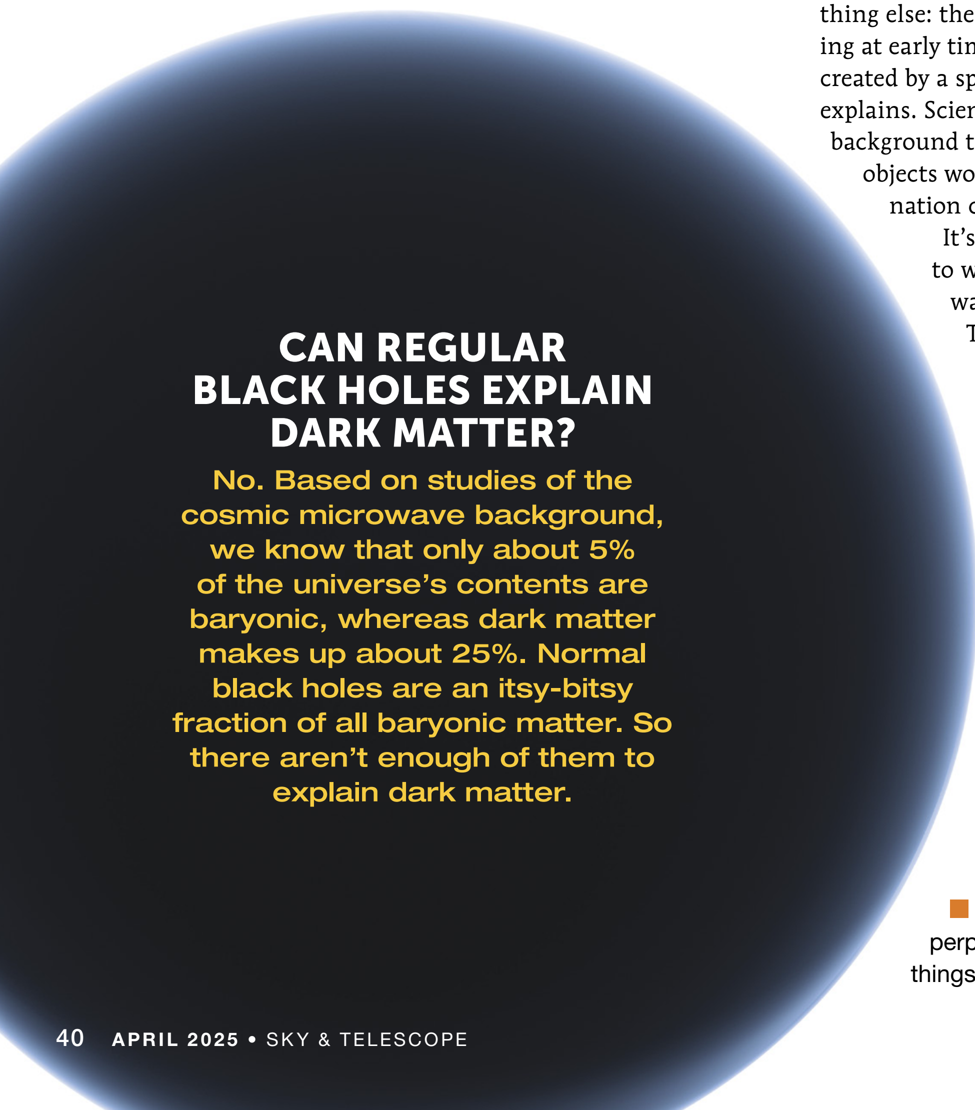
Data from the third LVK observing run show that the rate of black hole mergers increases with look-back time, but that run only reached to about a redshift of 1, or some 8 billion years into the past. The detectors *might* reach far enough in the ongoing fourth observing run to see the turnover. If a subset of black holes of certain masses merge more or less often than those of other masses, scientists might be able to tease the two populations apart. One of those populations could be primordial.

LVK won't be able to detect individual sources much earlier than the peak of star formation, but the fifth observing run, tentatively expected to start in 2027, should turn up something else: the collective hum of countless black holes merging at early times. This hum is like the music of an orchestra, created by a specific combination of instruments, Biscoveanu explains. Scientists could analyze this gravitational-wave background to determine which combination of merging objects would best match the hum they hear. One combination could include primordial black holes.

It's more likely, however, that answers will have to wait until the next generation of gravitational-wave detectors, coming in the mid- to late 2030s. These projects may be able to detect mergers as early as a few tens of millions of years after the Big Bang. If scientists find merging black holes that early, the objects won't be from stars.

Ten years ago, says Carr, very few people believed in primordial black holes. Even he didn't really believe in them when he started working on them in the 1970s. (He's 60% to 70% convinced now.) He stresses that it ultimately doesn't matter whether primordial black holes pan out as dark matter or as a large fraction of today's gravitational-wave events — those aren't the only reasons PBHs are interesting. "As long as they're somewhere, I don't care where it is, or even how much it is," he says. "Because if they exist, that's going to be really exciting."

■ Science Editor **CAMILLE CARLISLE** remains perpetually caught by the gravitational pull of all things related to black holes.



## CAN REGULAR BLACK HOLES EXPLAIN DARK MATTER?

No. Based on studies of the cosmic microwave background, we know that only about 5% of the universe's contents are baryonic, whereas dark matter makes up about 25%. Normal black holes are an itsy-bitsy fraction of all baryonic matter. So there aren't enough of them to explain dark matter.

BLACK HOLE BACKGROUND: SUDAKARN VIVATVANICHKUL / SHUTTERSTOCK.COM

# SKY AT A GLANCE
## April 2025

**1 DUSK:** Face west to see the waxing crescent Moon hanging 1½° above the Pleiades, while Jupiter is a bit farther to the upper left gleaming between the horns of Taurus, the Bull.

**2 DUSK:** This evening, the lunar crescent is still in Taurus and is a bit more than 4½° upper right of Jupiter while Aldebaran shines below.

**5 DUSK:** High in the southwest, the waxing gibbous Moon, Mars, and Pollux form a pleasing right triangle. See page 46 for more on this and other events listed here.

**7 DUSK:** The Moon is in Leo, about 6° above Regulus, the Lion's brightest star. Look to the south-southeast to take in this view.

**12 DUSK:** The full Moon and Spica rise in tandem in the east-southeast. The Moon eclipses the star for viewers in Central America and much of South America.

**17 MORNING:** Face southeast to see the waning gibbous Moon trailing Antares by about 4° as they arc across the sky.

**19 MORNING:** Low in the south-southeast the waning gibbous Moon is in the Sagittarius Teapot (see page 49 for more on the Moon's altitude).

**21–22 NIGHT:** The Lyrid meteor shower is expected to peak. The Moon, just past last quarter, rises in the morning hours interfering with viewing somewhat. Turn to page 48 for details.

**24 DAWN:** The Morning Star, Venus, blazes low above the eastern horizon with Saturn a bit more than 4° lower right. The waning crescent Moon hangs right of the planetary duo.

**25 DAWN:** The thin lunar crescent, Venus, and Saturn are arranged in a triangle low in the east. Catch this sight before the rising Sun brightens the sky.

**28 DUSK:** The delicate sliver of the waxing lunar crescent leads the Pleiades by about 4½° as they sink toward the west-northwestern horizon after sunset.

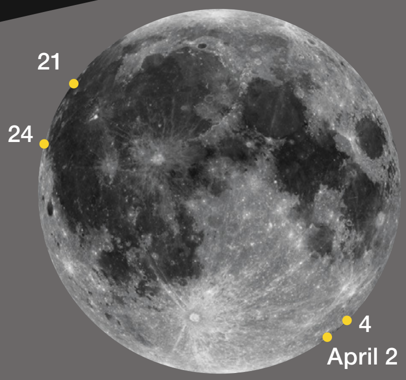
**30 DUSK:** The waxing crescent Moon, back in Taurus as it was at the start of the month, is nearly 6½° above Jupiter.
**—DIANA HANNIKAINEN**

▲ M81 is a prominent spiral galaxy in Ursa Major and a target in the Messier Marathon. Turn to page 20 for details on this challenging, but inspiring, endeavor. FRANK SACKENHEIM / STEFAN BINNEWIES / JOSEF PÖPSEL / CAPELLA OBSERVATORY

**APRIL 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**

April 5

02:15 UT

**FULL MOON**

April 13

00:22 UT

**LAST QUARTER**

April 21

01:36 UT

**NEW MOON**

April 27

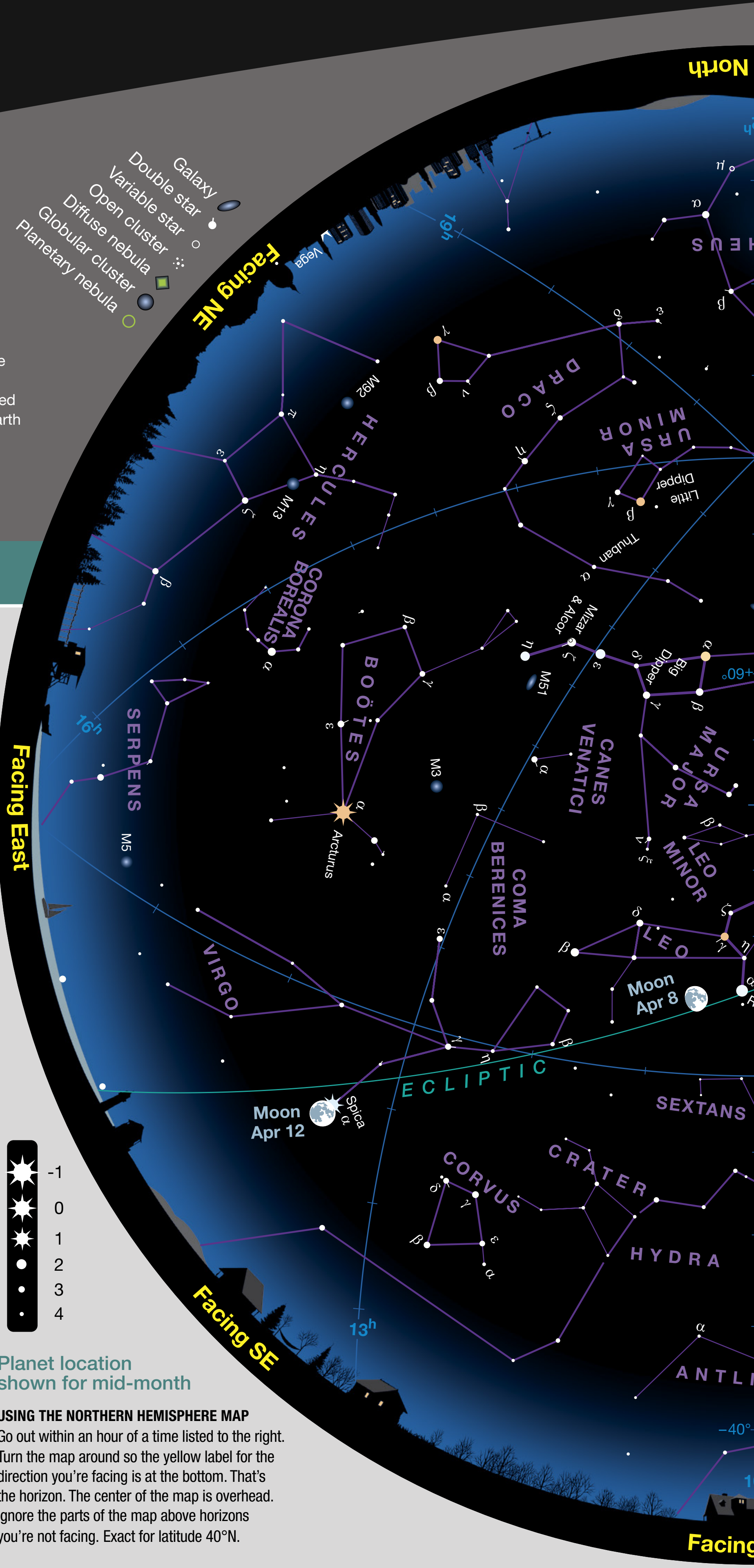
19:31 UT

**DISTANCES**

| | |
|---|---|
| Apogee | April 13, 23$^h$ UT |
| 406,295 km | Diameter 29′ 25″ |
| Perigee | April 27, 16$^h$ UT |
| 357,121 km | Diameter 33′ 28″ |

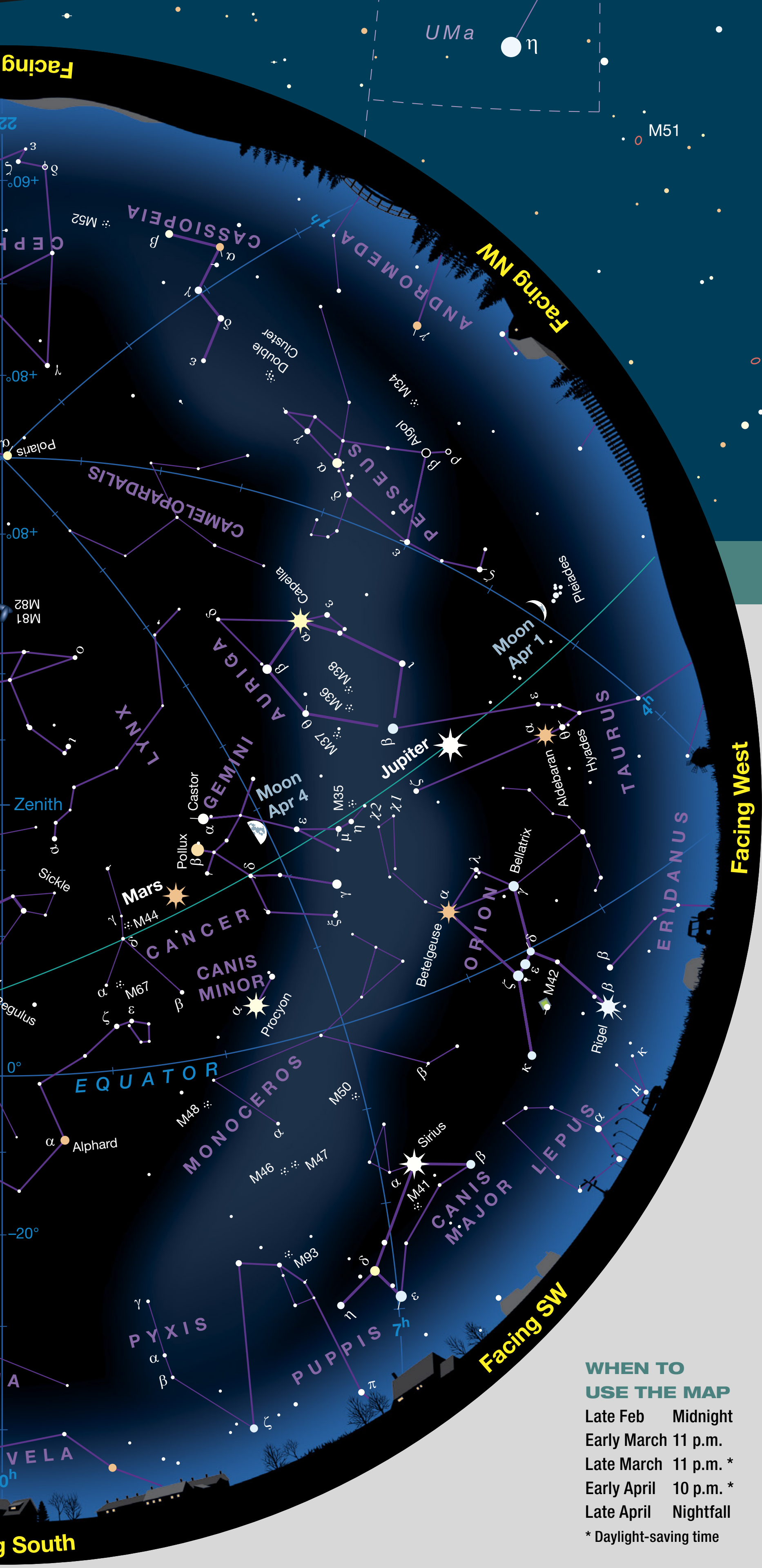
**FAVORABLE LIBRATIONS**

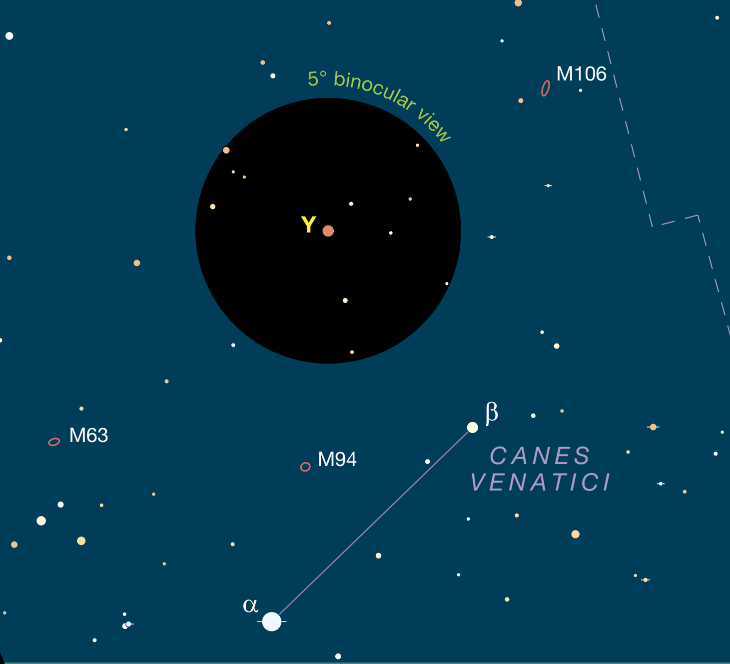
| | |
|---|---|
| • Hanno Crater | April 2 |
| • Oken Crater | April 4 |
| • Ulugh Beigh A Crater | April 21 |
| • Dalton Crater | April 24 |




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

# Secchi's La Superba

For a relatively small constellation that doesn't straddle the Milky Way, Canes Venatici packs in a lot of interesting celestial objects. One of them is our target this month: the carbon star **Y Canum Venaticorum**.

Carbon stars are red giants with powerful convective currents that convey fresh fusion products to the star's outer layers. This — as their name implies — includes carbon, which builds up as "soot" and deeply reddens the giant's light. Most stars this late in their evolution vary in brightness as their fusion fires alternatively rage and sputter, and Y CVn is no exception; its brightness changes from magnitude 4.9 to 5.9 over a period of about 268 days. Under reasonably dark skies, it's visible to the naked eye most of the time and is arguably the finest carbon star for binocular users. Its stark, red color is unmistakable and led the 19th-century Italian astronomer Angelo Secchi (*S&T:* Feb. 2025, p. 26) to christen it La Superba.

Y CVn illustrates some of the bizarre stages that stars go through late in their lives. It has already blown off quite a bit of material into space, making its original mass difficult to determine, but it may have once been about three times as massive as the Sun. At present its radius is more than 300 times that of our home star. Indeed, if placed in the center of the solar system, La Superba would engulf Mercury, Venus, and Earth.

No star can exist in such a rarefied state for long, and in time Y CVn will expel most of its material and become a planetary nebula, with a white dwarf shining at its center. This process will take a few more millennia, but still, go see La Superba while you can!
■ As an anatomist by day, **MATT WEDEL** dreams of freezing a carbon star, wrestling it onto a very large dissecting table, and seeing the weird stuff inside.

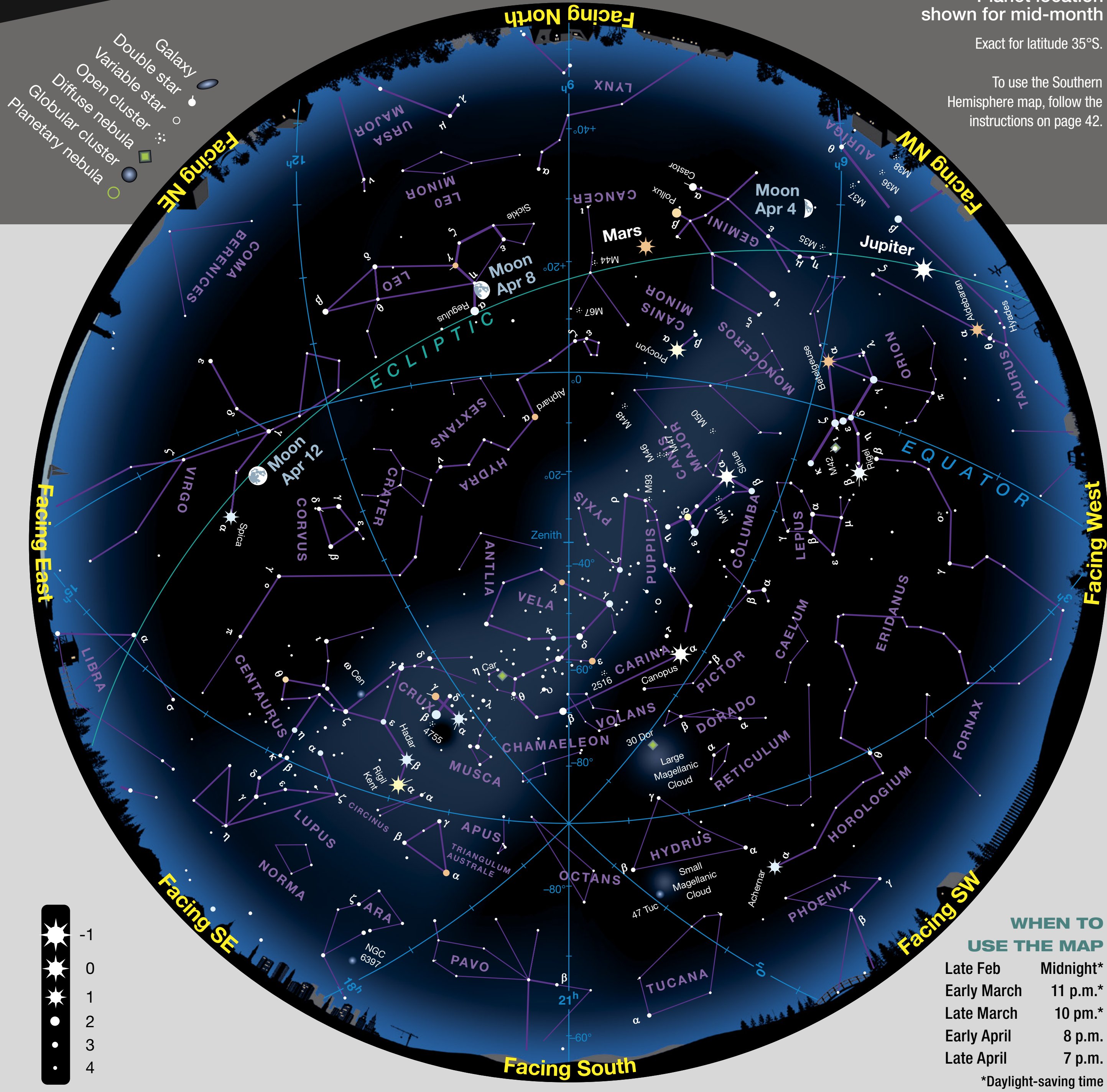
**WHEN TO USE THE MAP**

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

* Daylight-saving time

## Southern Hemisphere Sky Chart

by Jonathan Nally




### WHEN TO USE THE MAP

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

*Daylight-saving time

**DEEP IN THE SOUTHERN SKY,** close to the celestial pole, we find the small and mostly overlooked constellation **Chamaeleon**. Named after the family of lizards that, famously, can vary their color to blend into the background, this aptly named stellar grouping also hides in plain sight. Its brightest stars are only of 4th magnitude, so perhaps that's why it often goes unnoticed — it blends in nicely with its surroundings and does little to call attention to itself. Look for the little lizard due south of 1.7-magnitude Beta (β) Carinae.

A real chameleon has a long tongue (up to twice its body length) that it flicks out at high speeds to capture its prey — insects, such as flies. So, it's definitely no coincidence that celestial cartographers made sure that Musca, the Fly, is one of its neighboring constellations. ■

# Alphard and the Golden Branch

Slip into the night sky's "infernal region" with Hydra, the Water Snake.

▲ In this etching depicting a scene from Virgil's *Aeneid*, the Cumaean sibyl holds the golden bough that will allow her and Aeneas to pass unharmed into the underworld. The entrance is guarded by the multi-headed Hydra; Cerberus, the three-headed hound; and other horrors.



It's spring in the Northern Hemisphere, time for life to push up from the ground after a long winter's sleep. A look at the center star chart on pages 42–43 will show Orion, the Hunter, long a symbol of winter, near setting in the west; Virgo, the Virgin (an ancient fertility goddess), rising in the east; and the Big Dipper upside down in the north, pouring its life-giving waters onto the thirsty earth. Much of the southern sky, however, breaks this celebratory air, as it offers us prime viewing of a mythological realm of the dead.

This region of cosmic gloom has only one stellar beacon: 2nd-magnitude Alphard, the Alpha (α) star of Hydra, the Water Snake (usually female in ancient times). A line from Gamma (γ) Leonis through Regulus, both in the Sickle of Leo, the Lion, points directly to Alphard. Danish astronomer Tycho Brahe (1546–1601) called it Cor Hydrae, meaning Hydra's Heart. The name refers to the star's location in the creature's body; but we can also watch the golden-hued star pulse with the vagaries of our churning atmosphere.

This month, as seen from mid-northern latitudes around nightfall, Alphard lies at its highest, burning in a well of darkness — a vast visual realm of largely inconspicuous stars. The well is capped by three prominent Alpha stars: 0.4-magnitude Procyon in Canis Minor to the west, 1st-magnitude Regulus in Leo to the northeast, and 1st-magnitude Spica in Virgo to the east. The placement of these stars all but covers the length of the Water Snake, which resides in the dark well.

We can visualize the triad of bright stars as the points where Poseidon, Greek god of the sea, struck his trident in the rocks of Lerna to create a spring in honor of Amymone, a water nymph he loved after saving her from a satyr. The spring ended a drought in southern Greece but became the lair of the multi-headed Hydra, whom Hercules was sent to overcome in his 12 labors.

Let's now imagine our celestial well of darkness as the Lernaean spring where Hydra resides. It would fit right in with the legend of Hydra, as popularly linked to the labors of Hercules. But the spring of Amymone was also envisioned as the gateway to the underworld, where Hades, its king, ruled over the souls of the dead.

In Book 6 of Virgil's *Aeneid,* the Trojan hero Aeneas consults the sibyl — the oracle of Apollo at Cumae, a Greek colony near Naples, Italy — and begs the prophetess to guide him into the underworld so he can meet his dead father's ghost. "At this moment," Thomas Bullfinch recaps in the *Golden Age of Myth & Legend,* "with horrid clang, the brazen gates unfolded, and Aeneas saw within a Hydra with fifty heads guarding the entrance."

Usually, the Hydra would attack any unwary traveler with poisonous venom, but the sibyl told Aeneas that, here, the Hydra was only a ghost and could not harm him. In order to pass safely into the underworld, however, Aeneas had to first break off a golden bough from a tree in a neighboring grove and bring it as an offering for Proserpine, queen of the underworld. After handing the bough to Charon, the underworld's ferryman, the sibyl, and Aeneas were allowed to cross the Styx, one of the rivers of the underworld.

We can now look upon golden Alphard as the golden bough, and the sinuous form of Hydra as the River Styx. On the center star chart, note too how Hydra lies close to the gateway to the celestial underworld: the point on the chart where the celestial equator the ecliptic intersect. This is where the Sun "dies" each year as it slips from north to south in its annual journey and the long periods of darkness begin for those of us living in the Northern Hemisphere.

■ 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.

# Gatherings at Dusk and Dawn

The April twilight sky has something for everyone.

## SATURDAY, APRIL 5

There's a lovely clump of luminosity high in the south as twilight fades this evening. In a span of sky less than 10° wide you can see Gemini stars **Castor** and **Pollux** sharing the scene with **Mars** and the **Moon**. Together, the quartet form a cartoon arrow with 1.6-magnitude Castor at its tip. Neighboring Pollux shines at magnitude 1.1, while the Red Planet glows warmly at magnitude +0.5. The Moon, less than a day past first quarter, vastly outshines the rest of the group. Technically its magnitude is –10.6, but that figure is essentially meaningless in this context. The Moon is *bright* — by far the brightest thing in the night sky. We can just leave it at that. The Moon and Mars are separated by only 3°, which makes this the closest conjunction our satellite has with a planet all month.

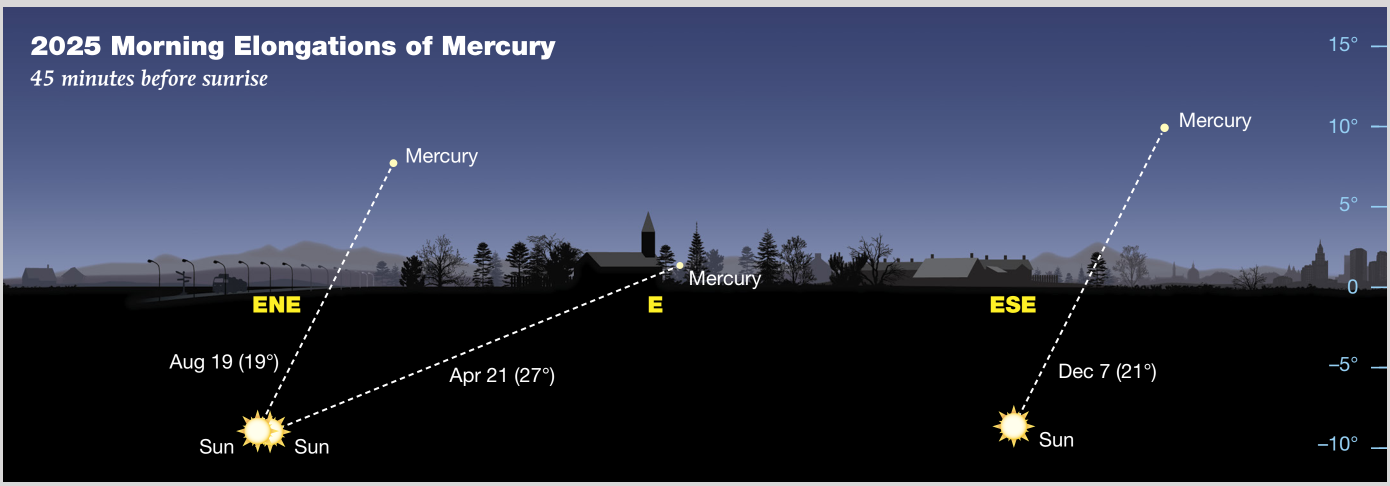
As for Mars, it reached opposition back in January but continues to linger in the evening sky thanks to its steady eastward drift, which keeps the planet ahead of encroaching twilight until it finally succumbs at the end of its apparition in late September. Over the next few nights, however, that drift carries it past Castor and Pollux. On the evening of the 10th, Mars and the two stars form a neat, three-in-a-row line. The gap between Mars and Pollux will be 5½°, which is only 1° greater than the space between Pollux and Castor.

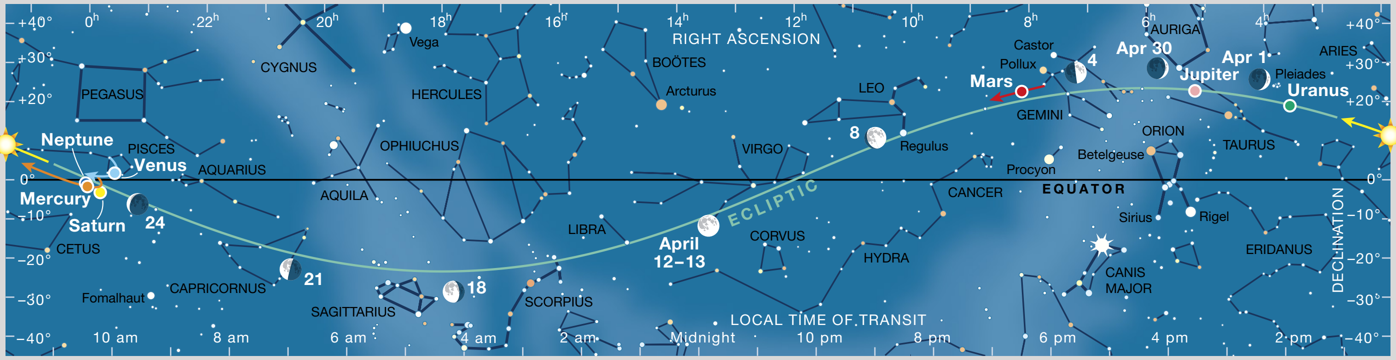
## FRIDAY, APRIL 11

A pair of planets that have been missing in action reappear at dawn today near each other. However, to have any chance of seeing them you'll need two things: a very clear and unobstructed eastern horizon, and binoculars. The planets in question are **Mercury** and **Saturn**. Saturn was lost to evening twilight's glare towards the end of February and was in conjunction with the Sun on March 12th. Mercury, on the other hand, popped up briefly last month for its least favorable dusk elongation of 2025. And now it has its least favorable dawn showing for the year, as the horizon diagram below illustrates. Indeed, this month's appearance is so poor that sighting the little world without optics is tricky. Even on the 21st, when it has its greatest elongation, Mercury rises less than one hour before the Sun.

On the morning of April 11th, Saturn and Mercury are side-by-side and just a touch more than 2° apart. Mercury shines at magnitude +0.9, while Saturn is a little fainter at magnitude 1.2. And they're both very low — achieving an altitude of only 3° half an hour before sunrise. Your best bet is to key off brilliant Venus, hanging about 6½° above the twosome. But realistically, unless you're looking out over water on a haze-free, cloudless morning, your chances aren't great.

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






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

## SATURDAY, APRIL 12

At dusk today, face east-southeast to catch the full **Moon** rising along with **Spica**, Virgo's 1st-magnitude gem. The star is perched less than ½° upper left of the gleaming lunar disk. This is the closest pairing the Moon has with a star all month, but just how close they get depends a great deal on where you are and when you look.

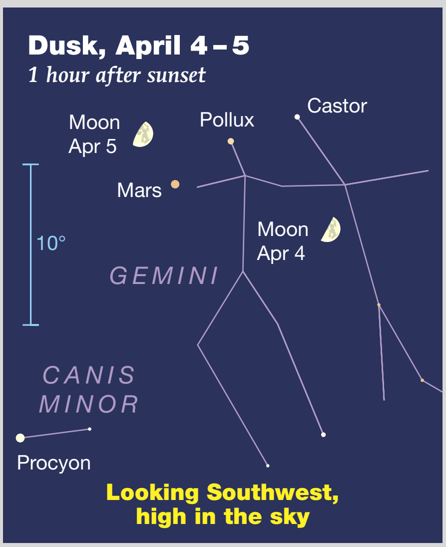
The later you check in on the conjunction and/or the farther west you are, the greater the space between them. There's also a north–south component to the spacing. The farther south you are (up to a point), the closer the pairing. Indeed, if you're far enough south, the Moon actually eclipses Spica! Most of South America, a bit of Central America, and the southernmost tip of South Africa lie in the occultation zone. But for most readers of this magazine, it's a case of "close, but no cigar."

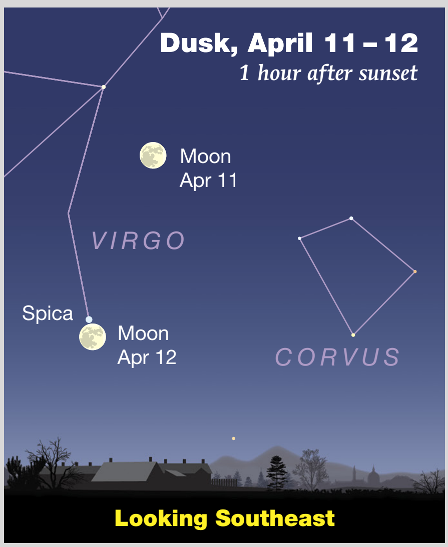
## FRIDAY, APRIL 25

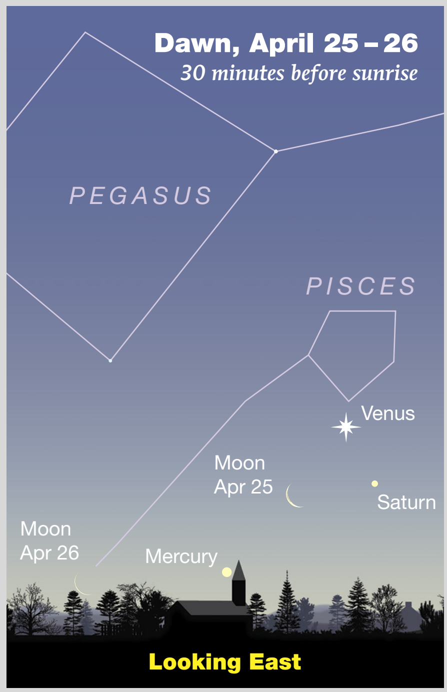
Dawn is a busy time for planet watchers this month with **Mercury**, **Saturn**, and **Venus** all putting in appearances before sunup. The three worlds are configured into a right triangle low in the east, and on this particular morning they're joined by a thin, waning crescent **Moon**. However, I have to confess that I'm probably overselling this gathering a bit. As noted in the April 11th entry, Saturn and Mercury are difficult to spot in bright twilight, though the latter has brightened to magnitude +0.2 since that date. Depending on your sky conditions, this morning might simply amount to a nice conjunction between the earthlit crescent Moon and Venus, the reigning Morning Star. It gleams at an astonishingly bright magnitude –4.8 and sits about 5½° upper right of the Moon. Saturn is 5° right of the Moon, while Mercury is a bit more than 6° lower left of the lunar crescent.

Keep your eyes on the Venus-and-Saturn pairing over the coming mornings to watch the two planets get closer and closer together. The gap between them is at its minimum on the 29th, when the Ringed Planet is less than 4° lower right of its gleaming neighbor.

■ Consulting Editor **GARY SERONIK** watches the sky from his home in southern British Columbia, Canada.



# Lyrids Pulse in April

A sprinkle of late-night meteors arrives mid-month.

One of my favorite signs of spring where I live is the sound of water dripping from the roof while I'm out with the telescope. When night temperatures stay above freezing, the snow remaining on the roof continues to melt into the evening, making a pleasant drip-drip-drip as the stars come out.

Along with water droplets, birdsong, and the year's first leaves, spring also brings the ever-reliable Lyrid meteor shower. Although associated with Vega, the brightest star in the constellation Lyra, the celestial Lyre, the display's meteors actually hail from across the border in Hercules — a reminder of a time when constellation boundaries were more fluid than they are today.

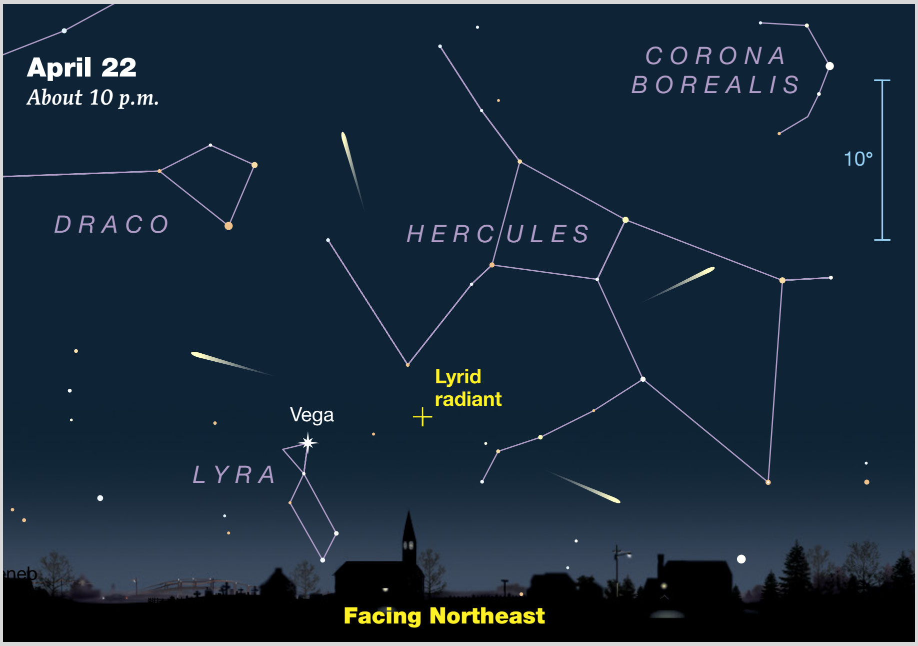
Earth enters the Lyrid stream — the dusty spawn of Comet Thatcher (C/1861 G1) — around April 14th and exits at month's end. The shower is at its best during the early morning hours of the 22nd, when the radiant approaches the zenith. That's also close to the time of maximum, which is predicted to occur around 9:30 a.m. EDT.

Lyrid rates vary from an all-time maximum of 90 meteors per hour, to the more typical 15 to 20 per hour. Although the Northern Hemisphere is favored, southern observers can also enjoy the display though at reduced rates due to the radiant's lower altitude. Fortunately, the Moon won't be a serious problem this year. It rises as a 36%-illuminated waning crescent at around 3:30 a.m. local daylight time, roughly an hour before the start of morning astronomical twilight for observers at mid-northern latitudes.

▲ Yuri Beletsky captured this composite image of the 2017 Lyrid meteor shower from Chile's Atacama Desert. Multiple Lyrids point back to the radiant southwest of the bright star Vega (below center), while the foreground is dominated by the dome of the 1.3-meter Optical Gravitational Lensing Experiment Telescope, located at Las Campanas Observatory.

Lyrid viewing is easy. Simply dress warmly and set up a reclining chair where you're least troubled by neighborhood lights — the direction you face doesn't matter since the meteors can flash anywhere in the sky. You can start as early as 9:30 p.m. on the evening of the 21st, but you'll have more success when the radiant stands higher later that night and into the predawn hours of the 22nd. You'll undoubtedly see an occasional sporadic (random) meteor, but Lyrids stand apart because their paths can be traced back to Vega.

Need more incentive? Let's add a couple of planets to the deal. Stay up to dawn and welcome Venus and Saturn, low in the southeastern sky and less than 5° apart. (Turn to page 47 for more on their conjunction.) If you have a telescope, you can be among the first to glimpse the south face of Saturn's razor-thin rings tipped just 1.6°. The last time anyone got a gander at this side of the rings from Earth was back in 2009, after that year's ring-plane crossing.




# High and Low Moons

**LIKE ALL OF US,** the Moon has its highs and lows. Every month it reaches a northern extreme in easternmost Taurus and dips farthest south in Sagittarius. Over the past year you may have noticed that those extremes have been, well, more *extreme* than usual.

The Moon doesn't strictly follow the path defined by the plane of Earth's orbit, the *ecliptic*. Because it circles our planet at an angle tipped by 5.1°, the Moon can appear significantly above and below the ecliptic. During an event known as a *major lunar standstill*, that 5.1° tilt adds to the ecliptic's 23.4° inclination. When that occurs, the Moon reaches declinations significantly north of the summer solstice point in easternmost Taurus and south of the winter solstice location in Sagittarius. Major standstills happen every 18.6 years. The current one began in 2024 and continues through most of 2025; the next major standstill takes place in 2042.

When the tilt of the Moon's orbit is opposite to that of the ecliptic, 5.1° is instead subtracted from the high-low solstice points, and the Moon's declination range reaches a monthly limit of 18.3° north and south. Such a "minor lunar standstill" happens in 2034.

The Moon's orbit intersects the ecliptic at two points called *nodes*. The Sun's gravity perturbs the Earth-Moon system, causing the nodes to migrate westward (clockwise when viewed from above Earth's North Pole) every 18.6 years. During a major lunar standstill, the ascending node — where the Moon crosses the ecliptic from south to north — is near the celestial equator in Pisces. Two weeks later, the Moon reaches its highest point above the ecliptic. Then it loops south, crosses the descending node and dips to its lowest point below the ecliptic.

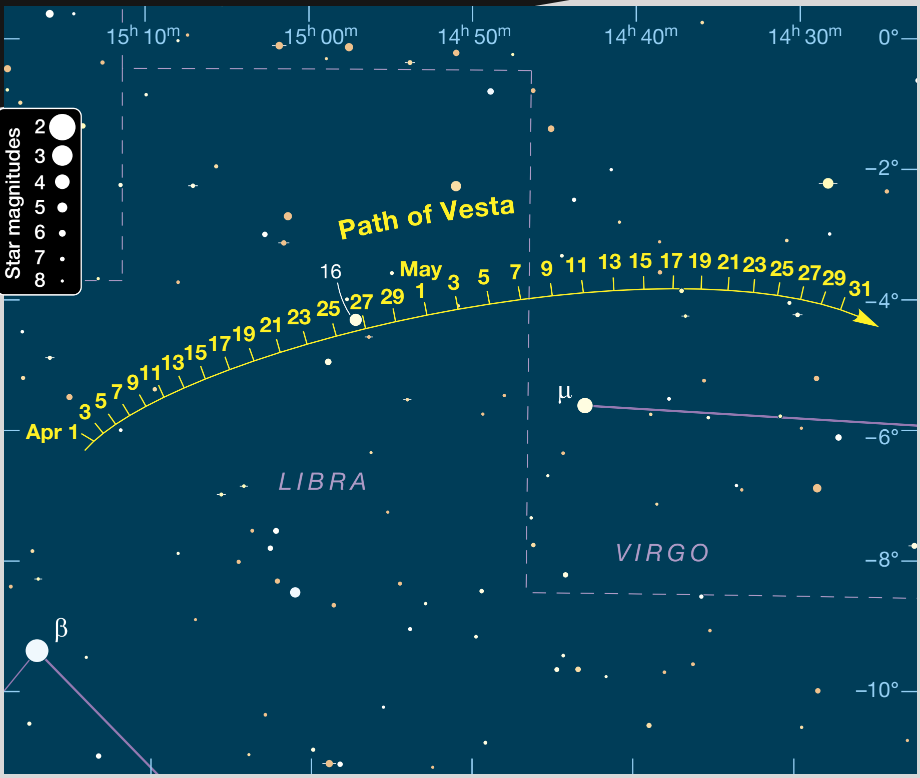
Not only does a major standstill dramatically affect the Moon's altitude, it also impacts its rising and setting points. The Sun's declination — its distance north or south of the celestial equator — has an annual range of about 47°, from 23.4° north to 23.4° south. By comparison, the Moon's monthly range is currently closer to 58°, causing its location along the horizon to shift noticeably north or south at successive moonrises and moonsets.

On the night of April 3rd, the thick lunar crescent tops out at the Taurus–Auriga border with a declination of some +28.5°. Then, on the morning of April 18th, it scrapes bottom at about −29.5° in Sagittarius.

Enjoy the roller coaster ride!

▲ The full Moon aligned with the Sistine Axis in Rome at dawn on December 15, 2024. With a declination of +27.3° at the time, it was the northernmost full Moon until December 2042. The Sistine Axis sits at the center of a late 16th-century urban planning project. Italian astronomers Gianluca Masi and Giangiacomo Gandolfi are researching whether the alignment may have been intentional, with the purpose of creating an urban canyon to frame the Moon at its northernmost setting point.

GIANLUCA MASI AND GIANGIACOMO GANDOLFI

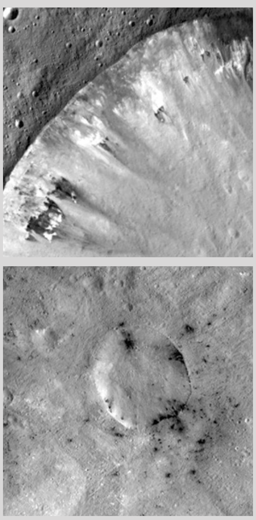



# Vesta Makes a Bright Return

**VESTA REACHES OPPOSITION** approximately every 16 to 18 months, and it hits that mark this year on May 2nd. Five days later it has its closest approach to Earth, when it slips by at a distance of 177 million kilometers (110 million miles). Vesta brightens to magnitude 5.6 this opposition, which means it should be possible to spot without optical aid under a dark sky. The Moon-free period from late April through early May provides your best chance.

As the chart above shows, Vesta begins April just 3¼° north-northwest of 2.5-magnitude Beta (β) Librae and crosses from northern Libra into Virgo on May 7th. From April 21–29, it's within 1° of the star 16 Librae (magnitude 4.5), which serves as a good marker for a naked-eye sighting of the minor planet. Wait until later in the evening when Vesta is highest and use averted vision to claim your prize. Of course, binoculars make sighting the object a piece of cake.

Given its status as the brightest of all asteroids, it's ironic that Vesta is home to some of the darkest materials in the solar system. Inky-black blotches dot craters and their associated impact ejecta. Data from NASA's Dawn probe in 2011–2012 indicate that these dark features are a good match to carbonaceous chondrite meteorites found on Earth, the most famous of which is the Murchison meteorite that fell in Victoria, Australia, in 1969. Similar water-rich impactors struck Vesta and likely all the planets in the past. On one planet at least (ours), the materials may have played a crucial role in the origins of life.



▶ Dark, carbon-rich material is exposed in landslides along the rim of the crater Numisia (top) and as speckles and blotches in a smaller, unnamed crater (bottom) on Vesta. Both images are from NASA's Dawn mission.

NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA

# Action at Jupiter

**ALTHOUGH JUPITER** is still months away from its June 24th conjunction with the Sun, the current apparition is beginning to wind down. As April opens, the planet's altitude remains greater than 30° from sunset to around 10 p.m. local daylight time. However, by the 30th that altitude window only lasts from sunset to 8:30 p.m., when civil twilight is ending. Fortunately, Jupiter is bright enough to observe in a telescope half an hour after sunset, when the dusk sky is still bright. The planet opens the month in Taurus where it shines at magnitude –2.1 and presents a disk spanning 36.1″. Enjoy the views while you can!

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

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

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

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

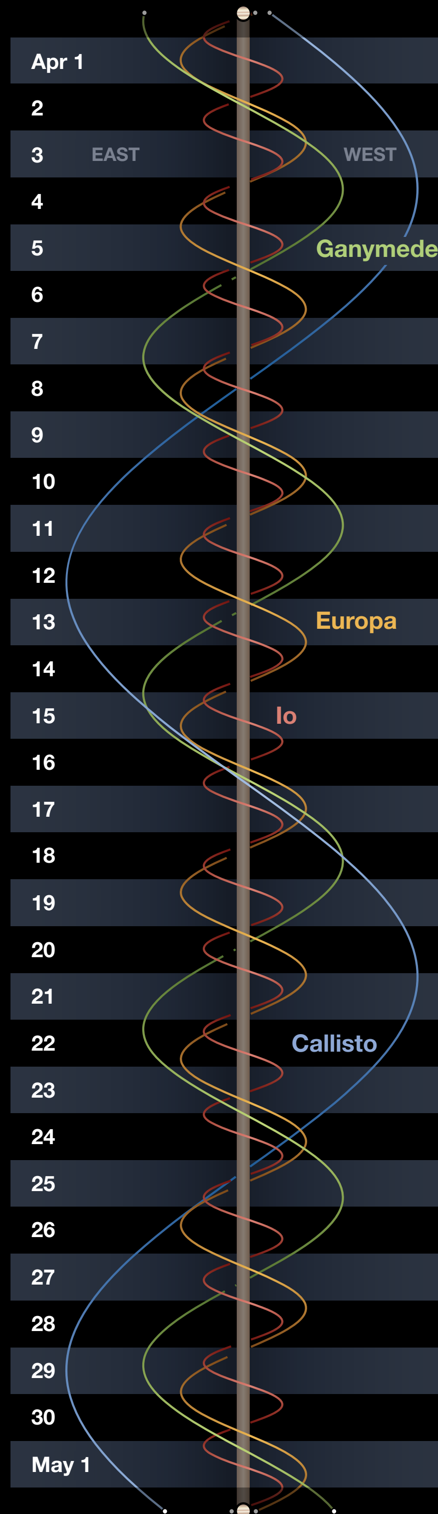
These times assume that the spot will be centered at System II longitude 72° on April 1st. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 72° and $1\frac{2}{3}$ minutes later for each degree more than 72°.

## Phenomena of Jupiter's Moons, April 2025

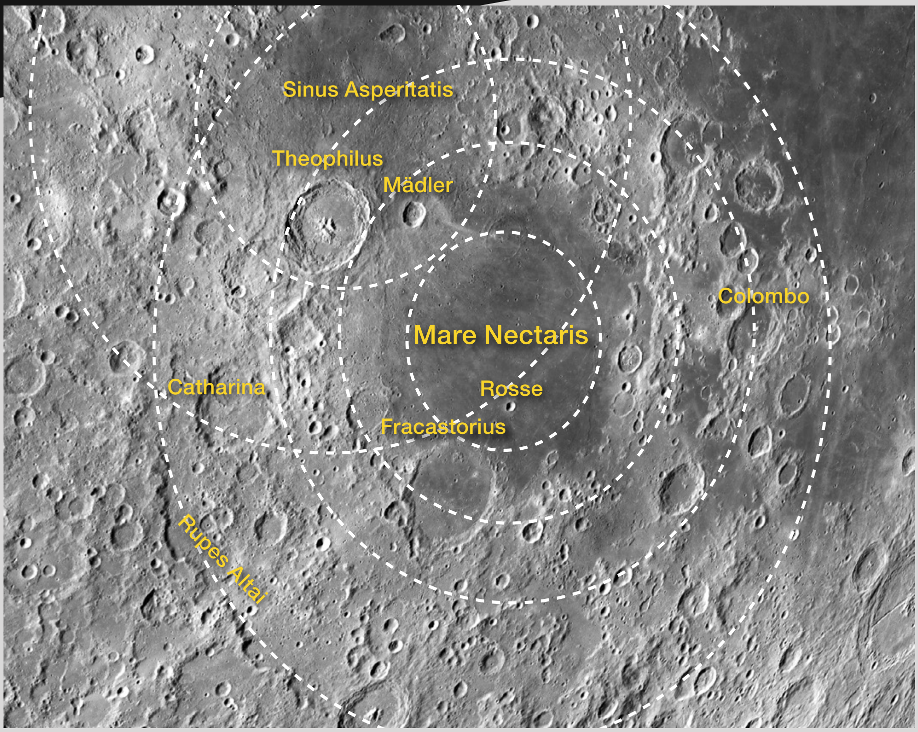
| | | |
|---|---|---|
| **Apr. 2** | 6:47 | I.Oc.D |
| | 7:40 | II.Tr.I |
| | 9:59 | II.Sh.I |
| | 9:59 | III.Tr.I |
| | 10:11 | I.Ec.R |
| | 10:16 | II.Tr.E |
| | 12:27 | III.Tr.E |
| | 12:36 | II.Sh.E |
| | 14:45 | III.Sh.I |
| | 17:17 | III.Sh.E |
| **Apr. 3** | 4:04 | I.Tr.I |
| | 5:14 | I.Sh.I |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

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

## Jupiter's Moons




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




◀ The Nectaris Basin contains several prominent craters, including Theophilus and Fracastorius. The rings mark its four basin rings that overlap the smaller rings of the Asperitatis Basin to the northwest.

NASA / GSFC / ARIZONA STATE UNIVERSITY

# Nectarian Nocturnes

Spend some time exploring this lava-filled basin.

It's easy to get lost in the details while exploring images from NASA's Lunar Reconnaissance Orbiter (LRO). This often happens to professional lunar scientists because such hyper-resolution data (the LRO Narrow Angle Camera resolves down to 5 meters) depict previously unknown features and offer clues to geologic processes. But some of the most glorious lunar sights are of broad regions seen at the eyepiece of a telescope. Such views provoke questions about our understanding of the events that formed large-scale lunar landscapes such as the Nectaris Basin.

Although most amateurs are familiar with **Mare Nectaris**, the 340-km-wide (210-mile-wide) patch of dark mare lavas, the key to understanding this region's geology is the multi-ring Nectaris impact basin that encircles the mare. Between each ring is a relatively flat zone called a *moat*. Part of the basin's 885-km-diameter outer ring is defined by the **Rupes Altai** (the Altai Scarp), a fault that drops some 3 to 4 km from its crest to the first flattish moat region. The second ring is about 625 km wide and partially circles the mare from the craters **Catharina** to **Colombo**. A third ring spanning some 440 km is defined by the shore of the dark mare lavas. This is the dense mantle material that's responsible for the basin's mass concentration. Finally, curved ridges within the mare's eastern expanse surround a 500-meter (1,640-foot) elevation drop toward the mare center and mark the basin's 270-km-wide inner ring.

The Nectaris Basin is like many near-side basins in that nearly half appears to be missing. The Altai Mountains majestically rise 7 km above the maria from the northwest to the south, similar to the way the Imbrium Basin is clearly defined only at its east and south sides, and Mare Humorum's rim is distinct only to the west and south. In these half-basins — and others like Serenitatis, Tranquillitatis, and Australis, which lack strong evidence for basin rims — there's a common reason for the missing rims. These basins tilt toward lower terrain that's often a pre-existing basin or mare. East of Nectaris are the lowlands of **Mare Fecunditatis** and to the northwest is the small basin associated with **Sinus Asperitatis** — the flat, eastern semicircular region with few rim peaks is about 1,900 meters lower than the similar flattish moat below the Altai rim. Did a rim fail to form along the basin's low east side, or were the ring's low parts covered by lava?

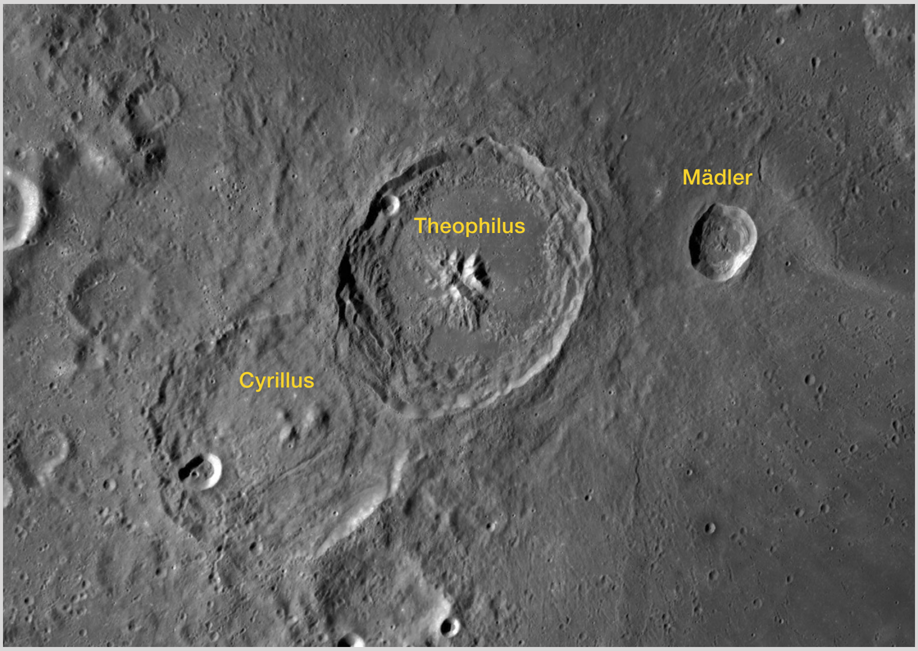
Mare Nectaris itself doesn't contain a lot for telescope users to look at. It lacks sinuous rilles, domes, and volcanic cones. The mare is mostly bland with hundreds of very small secondary craters from the formation of **Theophilus**. Hidden in the middle of Mare Nectaris is a lava-covered crater that's 65 km wide and 150 to 200 meters deep and only visible with very low-angle illumination. Only two notably fresh craters adorn the mare. One is 11-km-wide **Rosse**, which resides within rays from Tycho and Theophilus. The other is **Mädler**, a 27-km-wide, complex crater featuring a wide swath of faint rays to the south and east and a dark triangular area lacking rays to the northwest. This may look like an oblique impact with a zone of avoidance to the northwest, but read on!

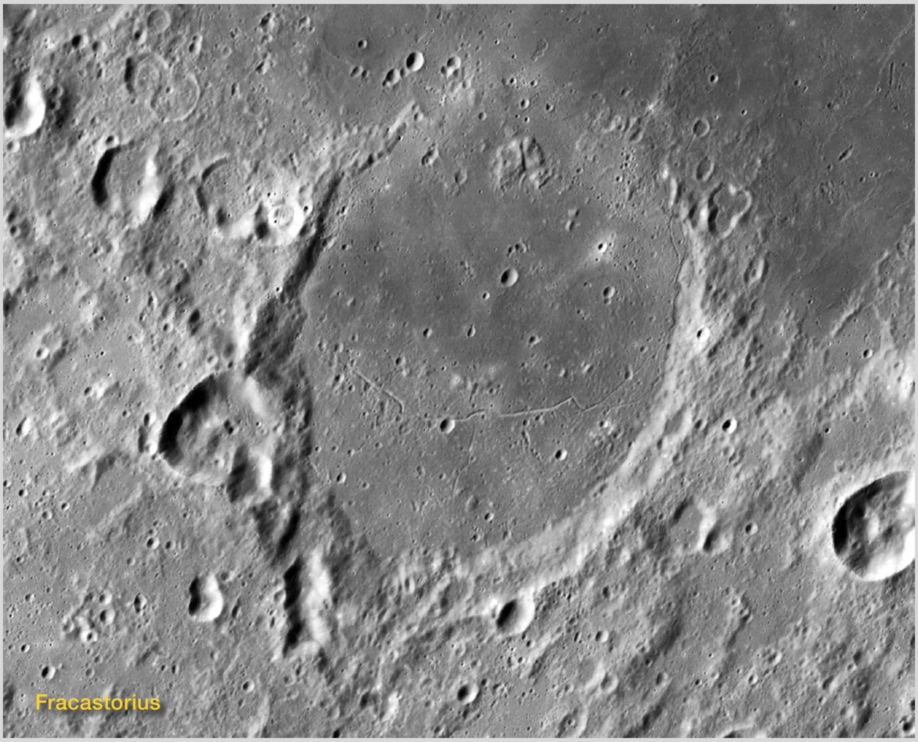
The morphological star of Nectaris is the 100-km diameter, 4.4-km-deep Theophilus crater. Theo, as I call it, is famous for its terraced walls, broad floor, and massive group of central mountains. But standing on its rim, it would look a lot less impressive since it's very shallow: The crater is 23 times wider than it is deep. Theo is a saucer, not a cup. The crater also has a very faint ray system, pockmarked with a few 2-to-3-km wide dark-halo craters formed by impacts that excavated dark maria from beneath the bright rays.

Observers often miss the smooth patches filling low spots that extend from due north of Theo's rim to Mädler to the east. These are ponds of impact melt ejected during Theo's violent formation. The ponds are concentrated to the crater's north and northeast, implying that it was formed by an oblique impact with the projectile coming from the southwest. This interpretation is supported by the very uneven height of Theo's rim. The crater's northeast rim is about 1,200 meters lower than the northwest rim, reflecting the pile up of ejecta on the projectile's incoming side and the blasting away of rim ejecta on the opposite side. Darkish impact melt covers the western third of Mädler's interior, rim, and surroundings. Mädler didn't form by an oblique impact but the area just northwest of Mädler is covered by impact melt from Theophilus, indicating that it's younger than its neighbor.

The second most interesting crater in the Nectaris Basin is 120-km-wide **Fracastorius**, which lies across the basin's third ring. Fracastorius was blasted into the sloped terrain of the basin ring. The south half of the crater's floor is light-hued, similar to the smooth terrain found within the inter-ring-basin moats, while the northern portion of the floor is buried under mare lavas. The crater's rim gently decreases in height by 3,000 meters to the mare floor. A narrow, jagged rille marks where the crater crosses the basin peak ring, which is also near where the gray-hued floor gives way to the mare surface. Since this third ring steps down toward the basin center, it makes sense that a fault at that location caused the floor to fracture. However, there's also a second explanation for the rille's location: The southern, gray portion of Fracastorius's floor is a 12-km-wide, 300-meter-high swell, with the rille slicing through the highest part of the laccolith-like elevation.

The most uncertain aspect of Nectaris Basin and its associated craters are their ages. Although Apollo 16 astronauts collected hundreds of samples from a location 150 km west of the Altai Scarp, there's no certainty which rocks date to the formation of the basin, the lava flows, or any of the craters. Some scientists argue that specimens dated at 3.92 billion years are the basin's age, while other researchers give evidence that 4.26-billion-year-old samples mark the basin's birth. Similarly, the age of Mare Nectaris lavas is uncertain. As for Theophilus, crater counts suggest it has an age of around 2 billion years. Fifty years of lunar exploration have established the basic facts about the Moon, and now as a second golden age of lunar exploration begins, we are on the cusp of understanding more of our nearest neighbor. What could be better?

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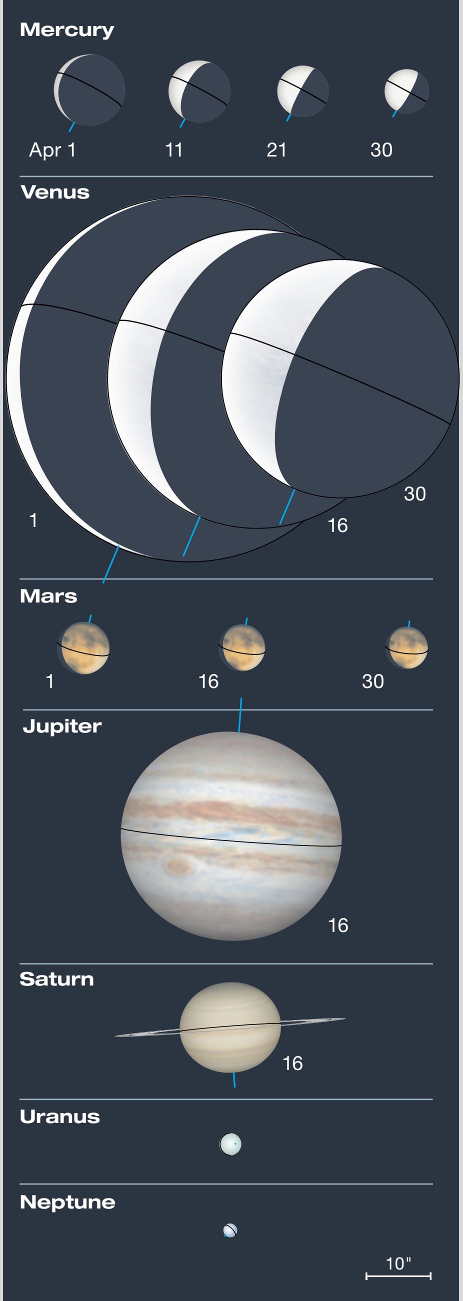
■ Contributing Editor **CHUCK WOOD** enjoys deciphering the visual clues that hint at the history of the Moon's formation.




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

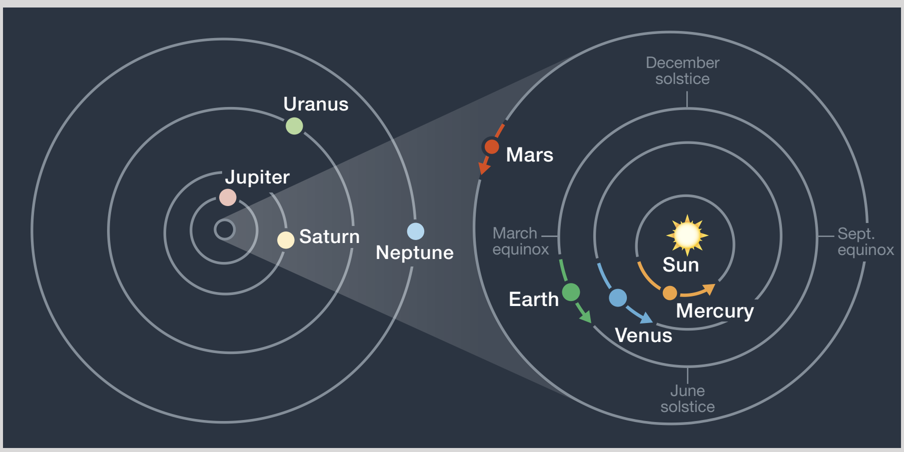
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during April. The outer planets don't change position enough in a month to notice at this scale.

**PLANET VISIBILITY** (40°N, naked-eye, approximate) **Mercury** is hidden in the Sun's glare all month • **Venus** visible low in the east at dawn all month • **Mars** visible at dusk and sets in the predawn • **Jupiter** visible at dusk and sets around midnight • **Saturn** emerges at dawn on the 18th.

## April Sun & Planets

| | Date | Right Ascension | Declination | Elongation | Magnitude | Diameter | Illumination | Distance |
|---|---|---|---|---|---|---|---|---|
| Sun | 1 | $0^h$ $41.1^m$ | +4° 25′ | — | –26.8 | 32′ 01″ | — | 0.999 |
| | 30 | $2^h$ $28.6^m$ | +14° 40′ | — | –26.8 | 31′ 46″ | — | 1.007 |
| Mercury | 1 | $23^h$ $51.6^m$ | +0° 51′ | 13° Mo | +3.0 | 11.1″ | 7% | 0.607 |
| | 11 | $23^h$ $50.5^m$ | –1° 59′ | 24° Mo | +1.0 | 9.6″ | 27% | 0.701 |
| | 21 | $0^h$ $16.8^m$ | –0° 50′ | 27° Mo | +0.3 | 8.0″ | 44% | 0.840 |
| | 30 | $0^h$ $55.3^m$ | +2° 48′ | 26° Mo | 0.0 | 6.9″ | 58% | 0.977 |
| Venus | 1 | $23^h$ $38.1^m$ | +5° 31′ | 16° Mo | –4.3 | 56.9″ | 4% | 0.293 |
| | 11 | $23^h$ $31.2^m$ | +2° 27′ | 27° Mo | –4.6 | 50.3″ | 11% | 0.332 |
| | 21 | $23^h$ $38.7^m$ | +0° 54′ | 35° Mo | –4.7 | 42.9″ | 20% | 0.389 |
| | 30 | $23^h$ $55.3^m$ | +0° 52′ | 40° Mo | –4.7 | 37.1″ | 28% | 0.450 |
| Mars | 1 | $7^h$ $42.3^m$ | +24° 04′ | 102° Ev | +0.4 | 8.2″ | 90% | 1.139 |
| | 16 | $8^h$ $05.6^m$ | +22° 40′ | 93° Ev | +0.7 | 7.3″ | 90% | 1.281 |
| | 30 | $8^h$ $30.6^m$ | +21° 01′ | 85° Ev | +0.9 | 6.6″ | 90% | 1.412 |
| Jupiter | 1 | $4^h$ $57.7^m$ | +22° 21′ | 64° Ev | –2.1 | 36.1″ | 99% | 5.464 |
| | 30 | $5^h$ $20.1^m$ | +22° 53′ | 41° Ev | –2.0 | 33.8″ | 100% | 5.837 |
| Saturn | 1 | $23^h$ $41.6^m$ | –4° 06′ | 17° Mo | +1.2 | 15.7″ | 100% | 10.553 |
| | 30 | $23^h$ $53.6^m$ | –2° 52′ | 42° Mo | +1.2 | 16.1″ | 100% | 10.317 |
| Uranus | 16 | $3^h$ $31.4^m$ | +18° 50′ | 29° Ev | +5.8 | 3.5″ | 100% | 20.405 |
| Neptune | 16 | $0^h$ $02.9^m$ | –1° 04′ | 26° Mo | +7.9 | 2.2″ | 100% | 30.793 |

**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**.



# Maxing Out Your Exposure

A handy rule of thumb and some experimentation can help you create memorable night-sky shots.

I love shooting nightscapes. My favorite subject is the summer Milky Way, and I'll even set an alarm for 4 a.m. if I need to capture it floating above an interesting landscape or landmark. While a star-tracking platform undeniably opens up all kinds of options, nothing beats the simplicity of just a camera on a tripod. But you might wonder if such a basic setup can make exposures long enough for good images? The answer is yes! You'll need a fast lens, however. The recommended minimum is typically f/2.8, but I'll admit that I've been spoiled with an f/1.4 — a focal ratio readily available from several manufacturers. The difference might sound small, but it represents an increase of two full stops. To put it in practical terms, where you might need a 60-second exposure at f/2.8, the f/1.4 lens requires only 15 seconds to get the same result! Rent one and try it — you'll never go back.

But here's why keeping your exposure times short is important: Without tracking, a long-exposure photo will show Earth's rotation manifesting as stars trailing across your camera's sensor. The effect can be quite appealing, and I've even written about how to create these kinds of images (*S&T:* Aug. 2024, p. 55). But for most nightscapes we try to avoid star trails. However, we don't want to err in the other direction either. When exposures are too short, they appear noisy unless we go through the extra steps of taking multiple exposures, stacking them, aligning them with the landscape, and so on. This additional effort defeats the simplicity we are after with a basic one-shot set up. So, what we want to do is figure out how long a single exposure can be before star trails start to become obvious.

▼ **HAPPY CAMPER IN FLORIDA** A fast, wide-angle lens on a tripod can create stunning nightscape images without the extra complication of a star-tracking platform. This 10-second exposure at ISO 3200 showing the Milky Way arching above the 2020 Winter Star Party was captured using a full-frame Canon EOS Ra camera fitted with a 20-mm f/1.4 Sigma Art lens.

ALL IMAGES COURTESY OF THE AUTHOR

◀ **MAGNIFICENT MILKY WAY** This untracked, 13-second exposure taken at Mather Point in Arizona's Grand Canyon National Park shows some slight trailing, which doesn't really diminish the appeal of the photo. Some distortion is visible in the corners due to shooting a Sigma 20-mm f/1.4 Art lens wide open. Still, even with these minor shortcomings, it's a photo most people would be happy with.

## The Rule of . . . Whatever

Chances are, when you first learned to ride a bicycle, you took advantage of training wheels to ensure that you didn't tip over when you lost your balance. Training wheels are great for building confidence. When attempting anything new, it's helpful to make things as easy as possible as your skills improve. And that's true whether you're learning to ride a bike or taking photos of the night sky.

The Rule of 500 is one set of training wheels often bandied about for astrophotography. The rule simply states that by dividing 500 by the focal length of your lens you get the number of seconds you can expose with a stationary camera before star trails start to appear. This means that for a 20-mm wide-angle lens fitted to a full-frame camera, you should be able expose for up to 25 seconds (500 ÷ 20). With so-called crop-sensor cameras, the guideline is often modified to the Rule of 300, ostensibly because of how a crop factor increases a lens's effective focal length. The Rule of 300 dictates shorter maximum exposure times. For example, the same 20-mm lens would now yield a maximum exposure time of only 15 seconds.

Okay, let's pause here for a moment to address an annoyingly persistent myth. The size of your camera's sensor in no way, shape, or form alters the focal length of your lens — it only changes the *field of view*, that is, how much sky you capture. In fact, it's the size of the pixels on your camera's sensor that really matters; the larger the pixels, the more time it takes for a star to traverse enough of them to register as a short streak. In other words, the Rule of 300 works because of smaller pixels, not the the overall dimensions of the sensor. Geometry — it's a thing.

While it's true that typical full-frame sensors once had larger pixels than their crop-frame cousins, that's no longer the case. Today, cameras sporting the latest full-frame sensors have much smaller pixels than they did a decade ago. And so, the Rule of 300 is really the one to use as a starting point regardless of which camera model you have.

Training wheels certainly have their place. I helped a friend who was teaching a Milky Way photography class at the Grand Canyon Star Party a few years ago. We had some students who just needed a few tips to get up and running, but others who needed more help. "How do I set the exposure time on my camera again?" There's no shame in this — everyone starts somewhere, and rules of thumb are a great aid. But eventually you reach the point where your equipment is so familiar that you can operate it with your eyes closed (or in the dark). So, when you're ready to take off the training wheels and move beyond basic guidelines, you can refine your approach.

▶ **AVOIDING STREAKS** Exposing too long yields tiny dashes (top image) instead of dots for stars. On a camera viewscreen, these little streaks can create a misleadingly bight and rich image. It's only when you inspect the photo at high magnification or on a computer monitor that you'll discover your error.

## Losing the Training Wheels

The Rule of 300 is useful, but applying it precisely is a bit pointless. That's because stars don't all move at the same rate across the sky. How's that? If you remember what star-trail pictures look like, you'll quickly realize what's going on. Notice that the North Star, Polaris, appears essentially stationary. Indeed, stars near the north celestial pole appear to move very little while those closer to the celestial equator seem to move quite far. I'll spare you the rigors of spherical geometry — all you have to remember is that the farther a star is from the pole, the greater the span of sky it traverses in a given amount of time.

In practical terms, what all this means is that when you take a very wide-field image, stars in one area may drift across enough pixels to create a streak in 15 seconds, while in other areas of your image it may only take 10 seconds. Trying to calculate an optimal exposure based on your pixel scale, where you are pointing in the sky, and how the trailing varies across your entire field of view is more trouble than it's worth. A quick and easy rule of thumb is certainly easier to apply when you're just getting your feet wet. The main thing to note is that the Rule of 300 may be too strict when it comes to shooting near the pole, and perhaps too lenient for images of the sky near the celestial equator. That's why it's merely a starting point.

▲ **CONCENTRIC CIRCLES** As Earth rotates, the stars appear to arc across the sky, as illustrated by this hour-long star-trail image. For nightscapes, the trick is to shoot as long an exposure as possible without trailed stars. Note how the trails lengthen the farther from the pole the stars are.

## Experimentation is Key

The approach I use and recommend is surprisingly simple and assumes you are using a modern camera with a viewscreen that has a zoom feature so you can inspect the stars in your image. Mount your camera on a tripod and take a quick, well-focused shot of a star field using the Rule of 300 to calculate your exposure and with the ISO set to 1600. (You can read my December 2021 article to learn why I suggest this setting as a good place to start.) Zoom in, and if the stars are trailing, shorten the exposure. If they're not, try pushing it a little longer and add a few seconds. That's not so hard, is it? You'll also want to pan around your image on the viewscreen to ensure that there are no trailing stars near the edges of the frame. Inspecting the edges is also important to ensure that optical aberrations in your lens aren't distorting the stars. You may wish to stop down the lens if you notice problems, bearing in mind that the more you do the longer your exposure needs to be to retain the same image brightness. Some creative cropping in post-processing might be the better approach.

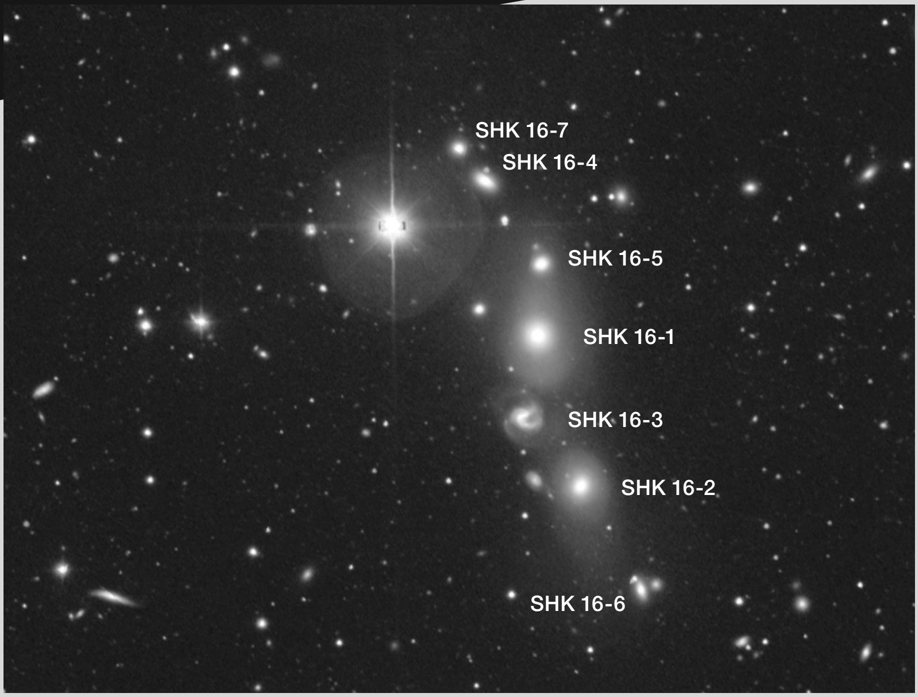
There's one more reason to carefully inspect the stars in your images. Sometimes a shot may look impressively bright on the viewscreen because the stars are trailed. More illuminated pixels mean a brighter image that could trick you into thinking you've gotten a fantastic shot. That is, until you zoom in and discover that what looked like a brilliant Milky Way nightscape is actually just bright stars streaked across many pixels. You've sacrificed all that glorious detail for an image composed of small dashes of light.

It really just takes a few minutes of experimentation to discover how long you can typically go with your particular camera and favorite lens. And the results for this modest effort can be immensely gratifying.

Now get out there and give basic nightscape photography a try!

■ Contributing Editor **RICHARD S. WRIGHT, JR.** has been shooting nightscape scenes with just a tripod since 2003 when he got his first DSLR, a Canon Digital Rebel.


▶ **STELLAR LENS** This Sigma 20-mm f/1.4 Art lens was the author's favorite for wide-field Milky Way photography for some years. Its fast focal ratio makes tripod nightscape photography fun and easy. He now favors a Tamron 35-mm model (also f/1.4) for its superior optics.




◀ **SHAKHBAZIAN 16** You'll want to get your bigger telescopes out and make sure you have ideal observing conditions to snag the targets outlined here, including SHK 16.



# The Shakhbazian Challenge

These compact galaxy groups will test your observing skills and equipment.

Many deep-sky enthusiasts are fans of Canadian astronomer Paul Hickson's list of compact groups of galaxies (HCG), which includes Stephan's Quintet (*S&T:* Sept. 2024, p. 28). Count me in the club — my first article in the March 1999 issue of *S&T* is titled "Quintets, Sextets, and Septets: Exploring Hickson Compact Groups." However, Hickson's 1982 catalog was neither the first nor the largest compilation of compact groups of galaxies. In the 1970s, astronomers at the Byurakan Astronomical Observatory (BAO) in Armenia conducted a lesser-known but more extensive survey.

The story began in 1957 when BAO astronomer Romela Karapet Shakhbazian (also spelled Shahbazian) discovered a small group of a dozen faint red objects in southern Ursa Major. Based on their stellar appearance on plates in the *National Geographic Society – Palomar Observatory Sky Survey* (*POSS*), she thought it was a cluster of faint stars at a distance of 425,000 light-years. The following year, American-Canadian astronomer Helen Sawyer Hogg announced the globular cluster candidate "Shak" in the *Journal of the Royal Astronomical Society of Canada*. But deeper images taken in 1962 with Lick Observatory's 120-inch reflector suggested the group was an accidental assembly of stars and background galaxies rather than a star cluster.

That's where things stood until 1973 when Lick astronomers Lloyd Robinson and Joseph Wampler captured the spectra of five group members. These galaxies were all luminous red ellipticals with a redshift of $z = 0.117$, indicating a distance of 1.6 billion light-years! With 17 galaxies squeezed into a 1′ circle, Robinson and Wampler concluded, "Shakhbazian I is one of the densest galaxy clusters known."

This study prompted a systematic search at the BAO for similar groups on more than 200 *POSS* prints. An Armenian and German collaboration published 10 papers between 1973 and 1979. They listed 377 compact groups using several criteria involving, among others: number of members (five to 15); magnitude (between 14th and 19th on red *POSS* images); and that all galaxies should be extremely red with a high surface brightness and no diffuse border.

Later photometric and spectroscopic studies established the vast majority are gravitationally bound groups (several in chainlike configurations) and not chance alignments. However, due to the limited resolution of the *POSS* images, some of the original members turned out to be faint Milky Way stars. Furthermore, the Shakhbazian groups (SHK) encompass a range of spatial densities, with many individual galaxies being standard ellipticals.

In comparison to HCGs, the SHK groups are dimmer, more distant, and richer in early-type galaxies (E and S0). To snag more than a few members, I suggest using an 18-inch or larger scope in preferably Bortle-2 skies and good transparency. Employing high magnifications enhances the visibility of the nearly stellar members. Patience is also crucial — each group contained phantom glows that teetered on the edge of perception in my 18-inch and 24-inch scopes.

## Chains in Draco and Ursa Minor

Let's start with a few of the more accessible groups. **SHK 16** is a remarkable north-south chain of compact galaxies in southern Draco. Before Shakhbazian cataloged the chain in 1973, Russian astronomer Boris Vorontsov-Vel'yaminov included several individual members in the 1962 *Morphological Catalogue of Galaxies, Part 1*. Halton Arp added the group (Arp 330) to his 1966 "*Atlas of Peculiar Galaxies*" and described, "Five galaxies in chain quite compact; 6th of low surface brightness." The latter object is a blue spiral showing evidence of tidal distortion.

## Armenian Astronomer

Romela Shakhbazian was born in 1925 in the southern Russian city of Rostov-on-Don. She was a member of the BAO staff from 1953 until her retirement in 1995. Shakhbazian defended her PhD thesis in 1970 under the supervision of Viktor Ambartsumian, the observatory's founder and one of the leading astrophysicists of the 20th century. As well as compact galaxy groups, she also researched stellar associations in nearby galaxies and extragalactic supernovae. Shakhbazian passed away in 2012 at the age of 87.

To find SHK 16, hop 2° east-northeast of 16 and 17 Draconis, an easy 5.4-magnitude binocular pair. The galaxy chain spans 5′ in length and passes just west of the 9.2-magnitude star HD 234352. Once you've identified the field, I'd recommend using at least 250× to spread the members away from this stellar signpost. I've observed this delightful chain at least a half-dozen times over the years. My favorite view, though, was through my 18-inch from the 8,500-foot-elevation trailhead to Lassen Peak in Northern California.

Using 328×, I spotted **SHK 16-1** just 2′ southwest of the bright star. Despite a magnitude of 14.6, the galaxy has a compact diameter of 18″ and a relatively high surface brightness. Two fainter companions, **SHK 16-5** and **SHK 16-3**, bracket the galaxy north and south by 0.8′ and resemble bloated stars. **SHK 16-2** marks the southern end of the chain, and I could hold it steady. By scanning 1′ northwest of the star, I caught **SHK 16-4**, a droplet of light near the glare. I also noticed PGC 2817454 just 3′ north of SHK 16-4. It displayed a 2:1 elongation and was comparable in visibility to SHK 16-1 and SHK 16-2.

**SHK 166** is a similar 8′ linear chain, conveniently located only ½° south-southeast of 4.2-magnitude Epsilon (ε) Ursae Minoris, one of the handle stars of the Little Dipper. The group comprises several featureless elliptical and lenticular galaxies queued up from southwest to northeast.

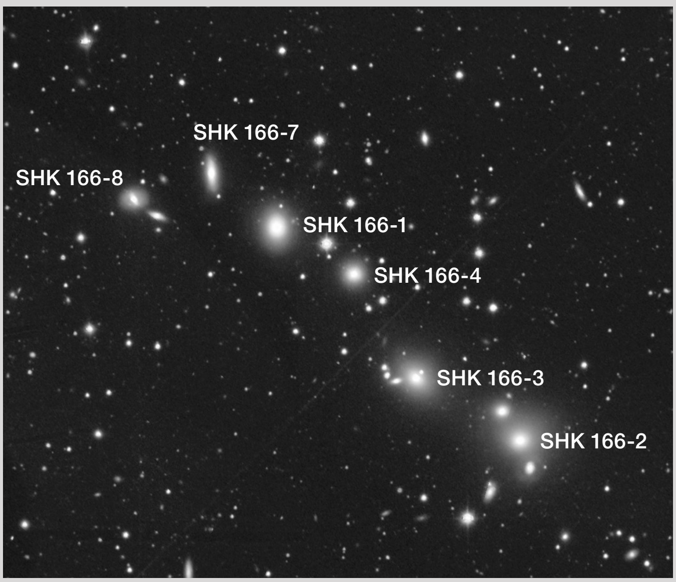
At 281×, I first spied **SHK 166-1**, an easy 20″ fuzzball just 50″ northeast of a 13th-magnitude star. I find this star helpful to orient the group members. Three galaxies, **SHK 166-4**, **SHK 166-3**, and **SHK 166-2**, line up to the southwest of SHK 166-1. The closest is SHK 166-4, an intermittent glow just 40″ southwest of the star, while SHK 166-3 is comparable in brightness to SHK 166-1. Two feeble smudges lie close to the northeast of SHK 166-1: **SHK 166-7** is a miniature oval angling north-south with the terribly elusive **SHK 166-8** to its east. By taking my time and focusing on each member individually, I managed to tally seven galaxies including PGC 59182, a 12″ speck about 5′ south of the chain. Although not assigned an SHK designation, it has the same redshift as the chain.

### Pileups in Coma and Leo

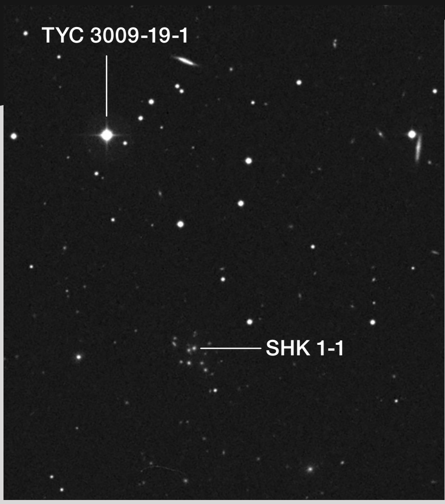
**SHK 202** is one of the nearer and brighter of the Shakhbazian groups, but there's a spoiler. The members huddle near the 6.6-magnitude star 10 Comae Berenices, whose brilliance may overwhelm their anemic glows.

Before exploring SHK 202, let's take a peek at NGC 4251, a 10.7-magnitude barred lenticular located ½° southwest of 10 Com. It spans 3.6′ × 1.5′ from east to west and features a bright, bulging core and a star-like nucleus. Shift 18′ to the northeast, and you'll arrive at 14th-magnitude IC 777. Through my 18-inch, this foreground galaxy tilts 2:1 northwest to southeast and outshines the nearby members of SHK 202.

Since SHK 202-1 lies a mere 5′ south of 10 Com, I used 390× and nudged the stellar nuisance outside the field of view. SHK 202-1 appeared as a 20″ × 15″ oval patch with a decent surface brightness. The similarly fuzzy SHK 202-3 floats just 2′ north. If you're successful with this pair, SHK 202-5 is a tiny toughie squeezed in between! SHK 202-6 is the lone member on the northwest side of 10 Com, while SHK 202-2 is 6′ southeast of the star. Both match SHK 202-1 in size and brightness. Want one more challenge? I barely glimpsed SHK 202-4 in




▲ **SHAKHBAZIAN 166** The galaxies in this pleasing chain are sprinkled from northeast to southwest. German amateur Uwe Glahn sketched it using his 27-inch f/4 telescope at 419×.




◀ **SHAKHBAZIAN 1** The first galaxy group Romela Shakhbazian identified lies between the hind paws of the Great Bear. It's the most challenging collection described here — Glahn sketched the four brightest members using his 27-inch under pristine conditions.

my 18-inch — a ghostly bead of light less than 3′ southeast of 10 Com.

Next up is **SHK 352**, which occupies a cramped 2.5′ × 1.5′ plot of celestial real estate nearly 700 million light-years away. To locate our target, point towards Tau (τ) Leonis, also known as 84 Leonis, in the southeastern corner of the constellation. Tau consists of a wide pair (1.5′ separation) of 5.1- and 7.5-magnitude stars tinted light yellow and blue. It forms a binocular "double-double" with 83 Leonis, a neighboring pair 20′ northwest of Tau and consisting of 6.6- and 7.5-magnitude stars 29″ apart. From Tau, scoot 1.7° to the west-northwest, and you can't miss 10.4-magnitude NGC 3640. SHK 352 lies just 22′ to its south-southwest.

Through my 24-inch Dob at 380×, I found a clump of four petite galaxies. SHK 352-1 appeared as a faint, gray stain measuring at most 20″ × 15″. Three smaller and dimmer spots, SHK 352-2, SHK 352-3, and SHK 352-4, adjoin its north and east. Moving 5′ south of SHK 352-1, NGC 3644 is a brighter 14th-magnitude spiral, but it's a foreground imposter at half the distance. When I examined SHK 352 through Jimi Lowrey's jumbo-size 48-inch in west Texas, four new members (numbers 5 through 8) joined the heap.

## Challenges in Ursa Major

**SHK 5** is better known as HCG 50 and is considered the most difficult of the 100 Hickson groups. Locating the field is easy — just head 20′ east-southeast of M97, the Owl Nebula. But SHK 5's five members are stuffed into a minuscule 40″ circle, with daunting magnitudes ranging from 17.2 to 18.7.

The key to pinpointing the group is an isosceles triangle formed by two 13th- and 15th-magnitude stars separated by 2.7′ east to west. A fainter 16th-magnitude star 2′ south completes the triangle. You'll need to spot this star easily, as the members of SHK 5 are much dimmer. Using my 24-inch scope at 200×, I navigated to the field and centered the star. I bumped the magnification up to 450× and bingo! SHK 5-1 (HCG 50A) popped into view just 20″ northeast of the dim star. The subtle, very compact glow was quite satisfying, considering the ancient light was emitted 1.9 billion years ago!

What about **SHK 1**, the prototype? Detecting any of its members requires large optics, dark and transparent skies, and an experienced eye. I've only observed the cluster through Jimi's 48-inch and McDonald Observatory's 82-inch Otto Struve Telescope. However, German amateur Uwe Glahn sketched the four brightest members in superb conditions using his 27-inch reflector at 419× to 586×. To locate this formidable target, steer 50′ west of 5th-magnitude 47 Ursae and 5′ south-southwest of a 10.3-magnitude star.

When I peered into the 48-inch at 375×, I noticed a faint, lumpy patch 1′ in diameter with a 15th-magnitude star 1.5′ to its northwest. Increasing to 488×, 17.2-magnitude **SHK 1-1** resolved, along with several other gossamer spots. The closest is 18th-magnitude SHK 1-2, barely off its east edge. Using 813×, I was amazed to see SHK 1 fracture into seven teensy galaxies down to magnitude 18.5!

If you have a large telescope and enjoy viewing galaxies in bunches, the SHK compact groups could be your next observing project. Alvin Huey provides an observing guide with finder charts and images at **www.faintfuzzies.com** to help you get started.

## Shakhbazian Galaxy Groups

| Object | Brightest Member | Mag(v) | Size | RA | Dec. |
|---|---|---|---|---|---|
| SHK 16 | PGC 59049 | 14.6 | 5.2′ | $16^h 49.2^m$ | +53° 25′ |
| SHK 166 | PGC 59174 | 14.9 | 7.8′ | $16^h 52.8^m$ | +81° 38′ |
| SHK 202 | PGC 39737 | 14.6 | 9.5′ | $12^h 19.9^m$ | +28° 23′ |
| SHK 352 | PGC 34794 | 14.6 | 2.7′ | $11^h 21.5^m$ | +02° 53′ |
| SHK 5 | PGC 34447 | 17.2 | 0.7′ | $11^h 17.1^m$ | +54° 55′ |
| SHK 1 | PGC 32808 | 17.2 | 1.2′ | $10^h 55.1^m$ | +40° 27′ |

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

■ Contributing Editor **STEVE GOTTLIEB** enjoys viewing galaxy groups of all sizes from northern California. For more of his favorite observing projects, see **adventuresindeepspace.com**.

# Inspirational Stargazing

## **STAR GAZERS:** *Finding Joy in the Night Sky*

**David H. Levy**
**The University of Arizona Press, 2024**
**174 pages, ISBN 9780816554645**
**$19.95, paperback**

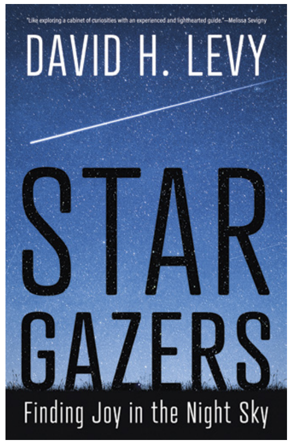
**WHEN'S THE LAST TIME** you read a book about astronomy that simply celebrated the wonder of a dark night, looking up at the sky? What was the last one you read that reminded you of why you love the cosmos so much?

David H. Levy's new book *Star Gazers: Finding Joy in the Night Sky* might just be the book you're looking for. Levy, known for his discovery of 23 comets (including Shoemaker-Levy 9), has compiled a collection of his essays from the last 10 years or so that examine the stories of people who've made a difference in his life or an impression on him in some way. He explains in the introduction to Part One, "Not all these people are astronomers. What unites them is not the sky itself, but their ways and feelings about the sky. Moreover, not all these people are people. Some are telescopes. Some are constellations. Some are comets."

> Levy's prose invites the reader to linger, and the ideas he brings up often make one stop and think.

The book is divided into various sections, with titles like "Not How to Watch the Sky, But Why," "Comets," "The Night Sky Experience," and "Joining the Sky With Life." Along with writing about astronomy, Levy brings in pop culture, history, literature, religion, relationships, and love, presenting a thoughtful and cerebral approach to astronomy that sits comfortably alongside the science. Everything works in harmony, and at the start of each section, he writes a short introduction alluding to what the reader can expect in the coming pages and what it means to him.

Chapters within each part are what bring the book to life, and though each one is brief, the book is not a fast read. Levy's prose invites the reader to linger, and the ideas he brings up often make one stop and think or propel one to look for more information. Chapters like "Go Webb!," "Join Your Local Astronomy Club," "Teachings of an Eclipse," "The Christmas Star," and "When Poetry Reaches the Stars" contain practical advice, nostalgic musings, and lessons learned.



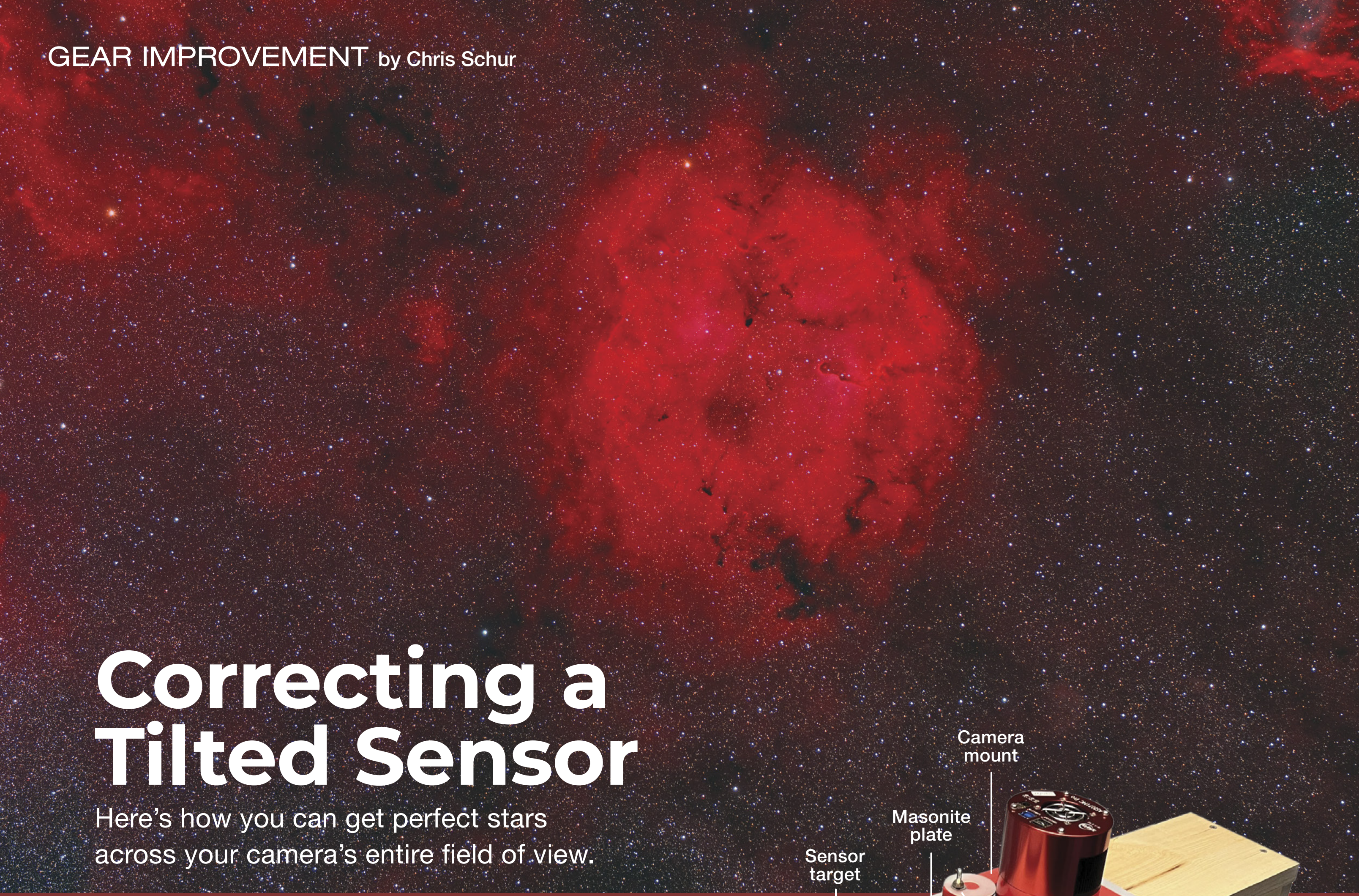

The last chapter, "Goodbye, Wendee," is a beautiful tribute to his late wife and illustrates how even in grief, the cosmos was there. He describes the night before Wendee's funeral, when he and his grandson Matthew were in the observatory. Matthew saw a meteor, and as Levy asked about it, he saw a faint one as well. Levy writes, "I like to think that this minor outburst of the October Cygnid Meteor shower — three meteors within a period of about five minutes — was Wendee's goodbye."

Those interested in the story of his discovery of Shoemaker-Levy 9 won't be disappointed, as he has a chapter on that, as well as a touching one on the friendship he and Wendee had with co-discoverers Gene and Carolyn Shoemaker. Although Levy is always aware of and observing the skies above, it's clear that he doesn't let things on Earth pass him by unnoticed. While he shares plenty on astronomy and his own experiences in these pages, there's also an intimacy that builds with the reader that allows us to get to know him. We learn about the formative events that nudged Levy into astronomy and the relationships with the people who encouraged him to keep working toward his goals. By the end of the book, it feels as if we know *him*, and not just his work or his thoughts on the stars.

*Star Gazers* is a deceptively thin volume that, at first glance, looks like you could knock it out in a night. But what you find inside is much deeper, much richer. Alongside pictures of eclipses, stars, observatories, and nebulae, there are photos of the Levys and Shoemakers together, a photo of the viewing site used by the author's local astronomy club, a sketch of the Moon he drew in 1964, and more.

This collection feels like a labor of love: Levy's love of the stars, his work, the people he met, and his family — and how all of this came together for him in his life. It is a book to savor, and share with a fellow stargazer, and then maybe sit outside and together look up.

■ **JAIME HERNDON** is a writer and editor. Her love of astronomy was reignited as an adult, and she finally got to experience the magic of Space Camp (a NASA-led program designed to inspire the next generation of explorers) when she accompanied her son in the summer of 2024.



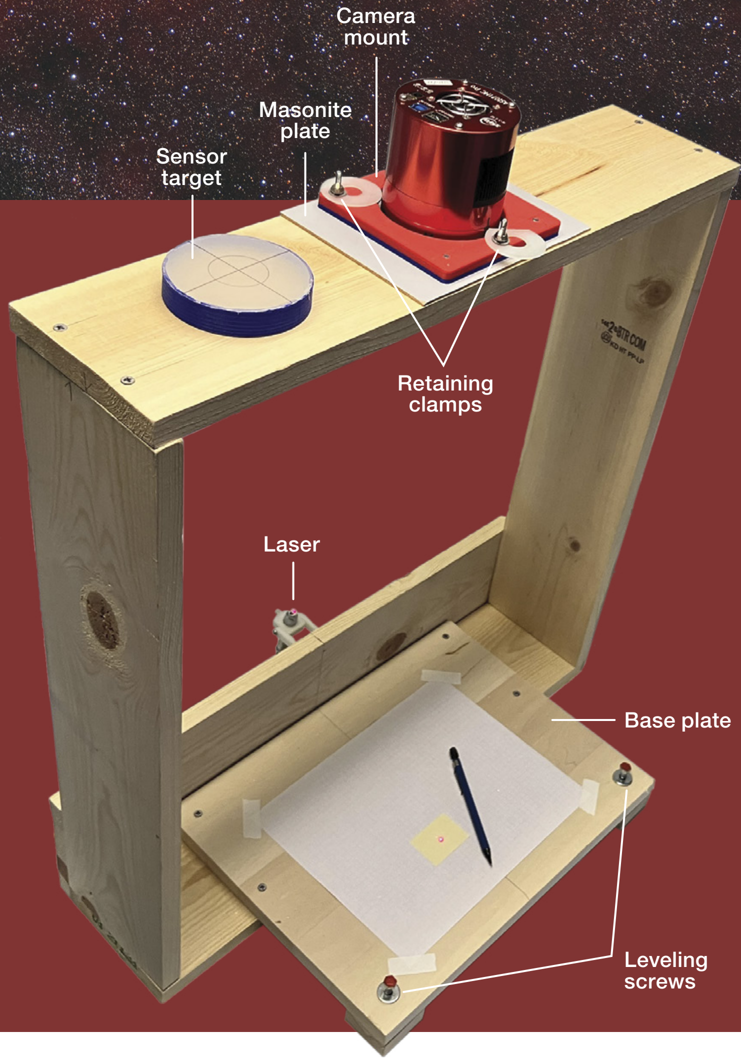
# Correcting a Tilted Sensor

Here's how you can get perfect stars across your camera's entire field of view.

Astronomy cameras with large CMOS detectors are very popular these days. Such cameras have higher sensitivities and lower noise characteristics than their CCD predecessors and cost less, too. Astrophotographers pairing them with fast Newtonians, apochromatic refractors, or camera lenses are producing the deepest astronomical images ever. However, many imagers soon discover that shooting with a large detector comes with its own set of challenges. High on that list is a tilted sensor causing focus variation and distorted stars across the image frame.

Fortunately, nearly all astronomy cameras with an APS-C or larger sensor include an adjustable tilt plate on the front of the camera to compensate for this. Correcting the tilt using the manufacturer's procedure can be a daunting and frustrating experience often doomed to failure. Here's a method I developed to diagnose and fix sensor tilt indoors. It requires a simple testing rig made using common hand tools to achieve the sharpest deep-sky images your equipment is capable of producing.

▲▶ **PERFECT STARS** After removing the tilt of the author's camera sensor using the rig he devised, this portrait of the emission nebula IC 1396 displays sharp stars right to the corners of the field.



## Diagnosing The Problem

There are two common sources for a tilted focal plane. The first source is due to poor collimation of an optical system. This often is caused by the misalignment of the focuser relative to the optical axis. With a Newtonian reflector, I can shim the focuser and laser-align the optics to bring this under control (*S&T:* March 2024, p. 60). Some premium refractors include a push-pull adjustment cell for aligning the objective lens with the central axis of the focuser.

But there's also a less well-known reason why the focal plane could be tilted: The camera's sensor could be installed incorrectly. While the plane of the electronic sensor's surface should be parallel to the front plate of the camera, often it is not.

With either cause, the only way to narrow down the source of misalignment in your system is to align the camera's tilt plate before you can diagnose if your instrument's collimation needs more critical alignment. Recently, I purchased a new camera for use in our f/4 Newtonian astrograph and found that right out of the box the sensor was tilted by a small amount. This triggered our pursuit of a simple and fail-safe method to square up any sensor misalignment.

## Standard Technique

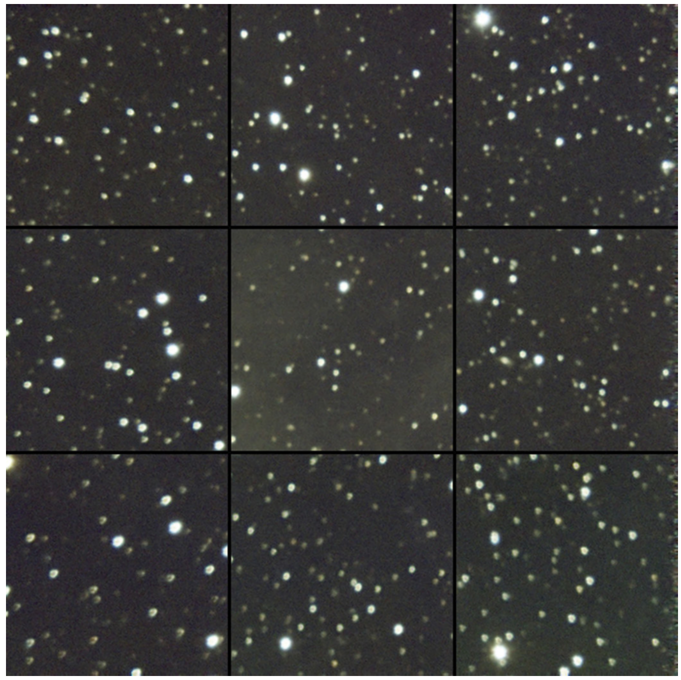
Ever since large detectors became widely available to amateurs, manufacturers have struggled to ensure they were installed in the camera bodies correctly. This proved a challenging task that likely added significant cost to the final product. A more effective solution was to add an alignment plate to the front of the camera body to give users the ability to correct the tilt themselves.

The recommended fix for sensor tilt is to install your camera on the telescope and then use tiny wrenches and a flashlight at night to tweak the tilt plate adjustment screws on the camera while taking test exposures to see the results of the adjustments. Having tried this procedure myself, I found it extremely difficult to correct the tilt with my fast optical systems under such conditions. If only I could make the tweaks in the daytime, in my workshops with full access to all the adjustment screws and without the camera being installed on the scope!

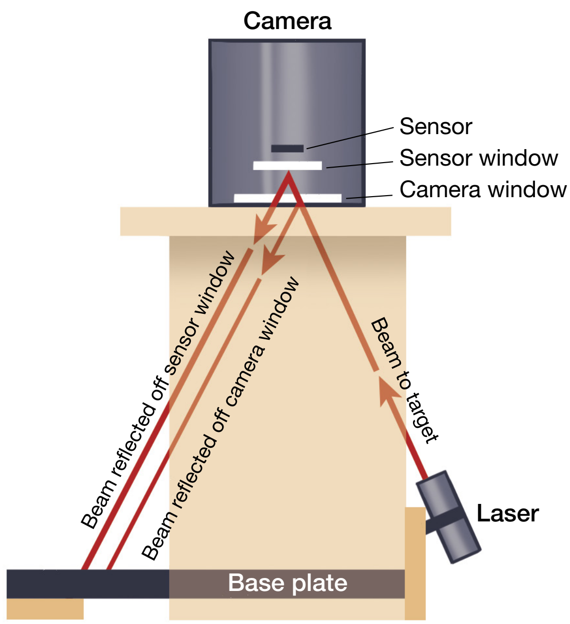
After a great deal of thought, I came up with a solid, easy-to-use and accurate testing rig that's simple to build using readily available materials and hand tools. The resulting tester allows rapid alignment of many cameras regardless of body shapes.

## A Simple Rig

The basic concept is to mount your camera facing down over a properly sized hole, and shine a low-powered laser up at an angle to reflect off of the sensor cover glass, which then reflects back down to produce a pattern on the base of the fixture for evaluation. By rotating the camera slowly, your sensor will reflect a stationary dot if it's parallel to the camera front plate. More often than not, this motion traces out



▲ **TINY TILT** This array shows nine areas from a single wide-field image and reveals uneven focus from upper right to lower left due to a tilted sensor in a ZWO ASI071MC camera. The camera was paired with the same 135-mm f/2.8 lens used to image IC 1396 on the facing page.




▲ **TESTING WITHOUT OPTICS** This side view shows how the test rig works. The user aims a laser pointer at the center of the camera's sensor. The beam is then reflected onto the tester base where it remains stationary as the camera is rotated provided that the sensor is mounted parallel to the camera's front plate. The reflected dot from the optical window on the front of the camera is dimmer due to anti-reflection coatings and should be ignored. Reflections from the sensor are omitted for clarity.

UNLESS OTHERWISE NOTED ALL IMAGES ARE COURTESY OF THE AUTHOR; DIAGRAM OF ALIGNMENT RIG: LEAH TISCIONE / S&T

a small circle revealing imperfect sensor alignment. You would then incrementally adjust the camera's tilt plate until the reflected pattern converges on the smallest area. This test is quite sensitive and can detect tilts of less than a fraction of a degree with ease.

◀ **LASER ROCKER** The laser mount should allow you to precisely aim its beam at the test target or camera sensor. The author 3D-printed this part, but it can also be made from thin aluminum flashing or wood.

Constructing the test rig is straightforward. I built mine from a few 1-by-6 pine boards along with wood screws, three 2½-inch machine screws with wing nuts, three large nylon washers, Elmer's carpenter's glue, and a small piece of Masonite to be used as a smooth rotation surface. I made our rig 24 inches (61 cm) tall, but you can increase the accuracy of the rig by making it even taller (though this was more than adequate for my testing). You'll also need a pen-style laser pointer clamped to a small aiming yoke. Finally, some sticky backed note paper for tracking the dot's rotation is really handy.

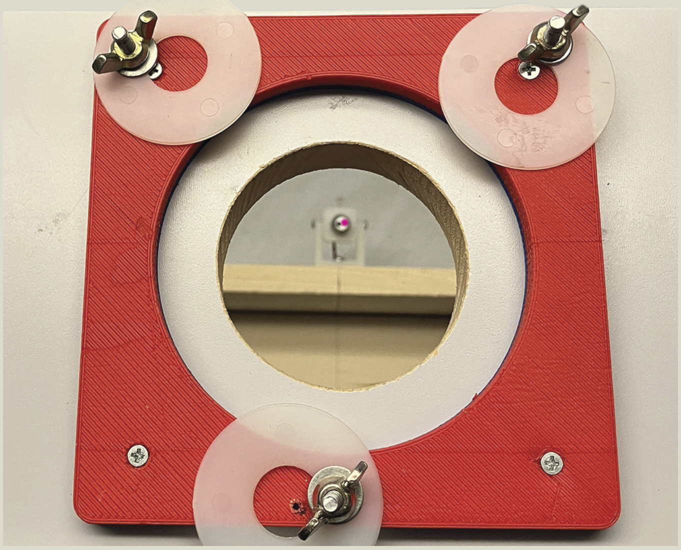
While many of the small parts could be made of metal or wood, I found that highly accurate 3D-printed parts worked exceptionally well. The three parts I printed using standard PLA filament were the camera holder, a fork mount for the laser, and the simulated camera back-focus tube for initial laser alignment. A low-tech clothespin is handy for clamping the lasers button down while testing.

After assembly, the laser must be aligned so that it strikes the sensor approximately at its center. To do this, make a target that simulates the position of your camera's sensor. You can do this by taking a tube of roughly the same diameter as your camera's with a depth equal to the back focus of the camera under test. Next, glue a piece of tracing paper or frosted plastic to the top of the tube with an X marking its center. This is where you'll aim the laser. Insert this fixture into the camera mounting plate, then adjust the laser until it's aimed at the center of your target's frosted screen. This ensures that when the camera is installed in place of the target, the laser dot will strike the sensor in its center. We're now ready to start testing!

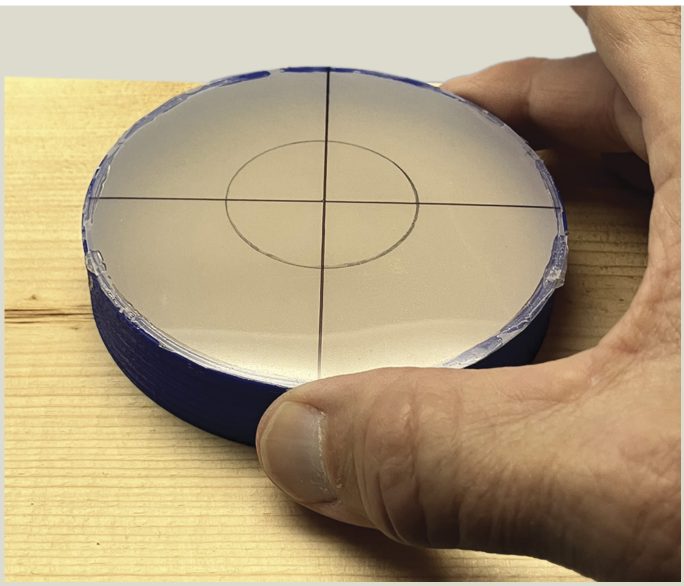
## In Action

Once the camera is installed in place of the target and the laser switched on, examine the reflected laser dot on the tester's base. The reflected laser beam has multiple components — understanding what they are and how they move as the camera is rotated is critical to achieving optimal tilt alignment. The brightest spot is the reflection from the front and back of the sensor cover glass window mounted on the sensor chip. They are merged into one slightly elongated dot because of the size of the laser beam and the thinness of the cover glass. This spot is the one to monitor during testing. Ignore all the other reflections.

Once you understand the projected patterns, testing is very straightforward. In most cases, the camera's front plate



▲ **CAMERA PLATE** The camera is dropped into the recess of the camera mount sensor-side down, and the nylon washer clamps are pivoted and tightened to keep the camera centered while it's being rotated.



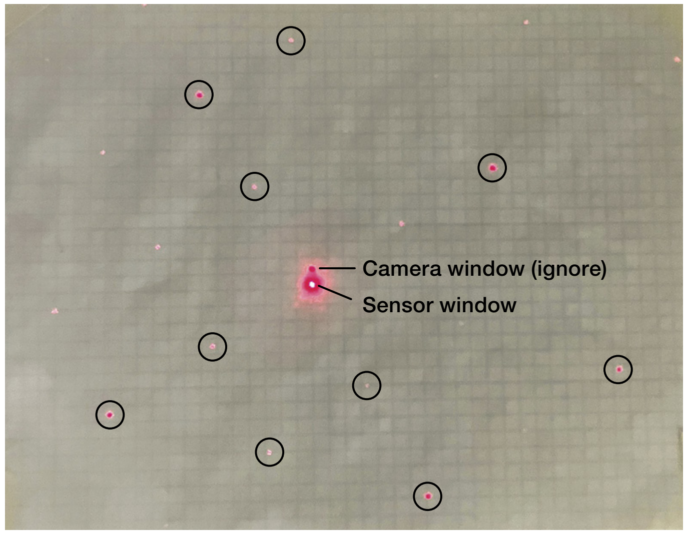
▲ **DUMMY SENSOR** Make an alignment target the same depth as the distance between the camera's detector and the front plate of the camera body. Every manufacturer provides this information to permit the proper spacing of coma correctors and field flatteners.

is manufactured to be flat enough to ensure parallelism for f/6 and slower optical systems. With faster optics, however, some small adjustments may be required. To test a round camera, remove its 2-inch nosepiece and install the camera face down into the camera mount on the top of the tester.

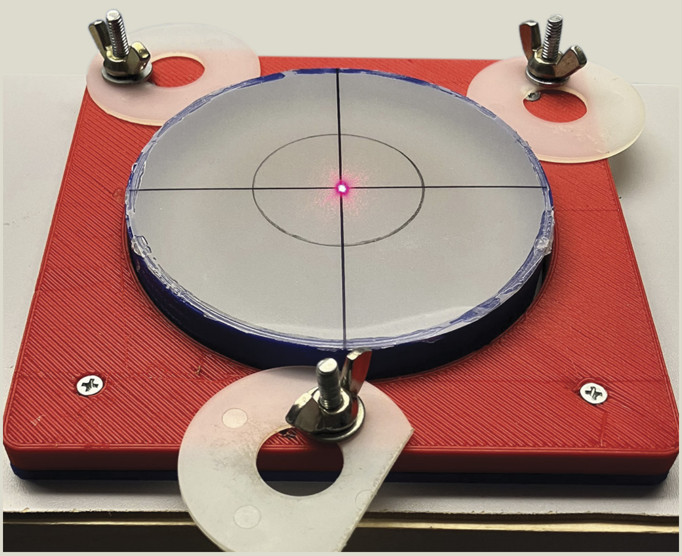
Most camera tilt plates include three or four sets of push-pull screws. Since most cameras come from the manufacturer with the adjustment plate flush against the front of the camera, you'll have to loosen the pull screws half a turn and rotate the push screws ¼ turn or less to get a bit of adjustability.

Approximately center the camera in the rig and rotate the three nylon washers until they are touching the camera body. Then refine the camera's centering by rotating it by hand. Be sure to mark the side of the camera so you have a starting-point reference for the coming measurements. Next, turn on the laser (which you pre-aligned to strike the center of the sensor) and examine the projected pattern. Rotate the camera slowly while pushing down on it a bit to keep it flush to the Masonite plate. If the beam traces out a small circle, then the sensor is tipped, and adjustments are needed. The goal is to confine the circle it traces to less than ⅛-inch. When the traced circle is closest to you (as you're standing in front of the fixture), it's farthest along the base plate from the laser.

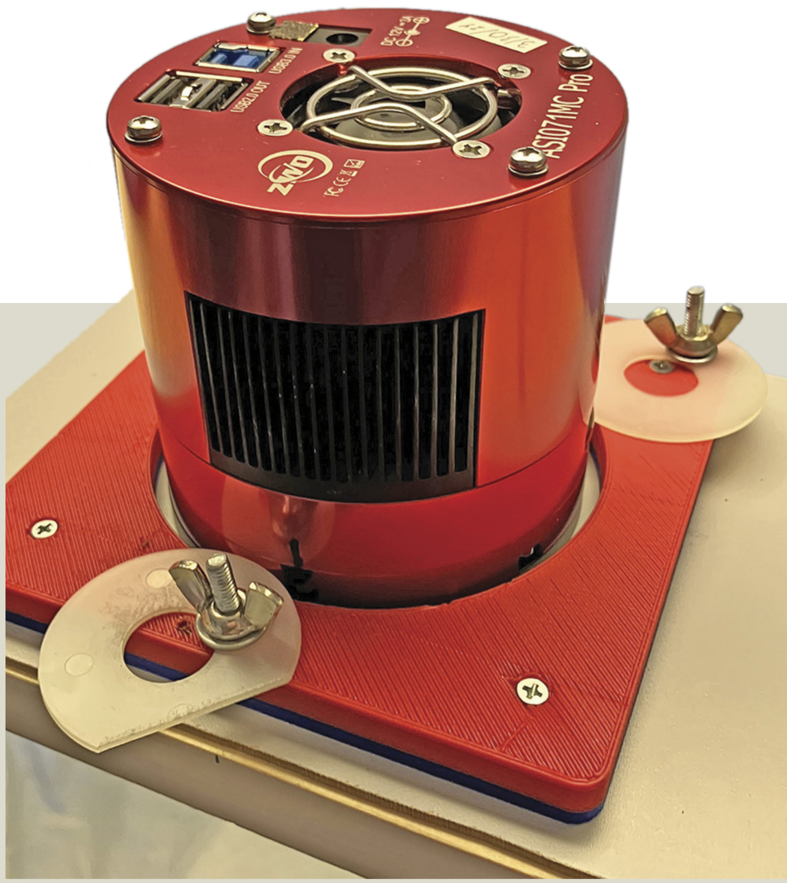
At this point, put a sticky backed note on the base plate and use a fine-tip marker or pencil to plot the laser dot's position at six different angles separated by about 60°. Remove the camera and adjust the push-pull screws to decrease the spacing of the plate on the side closest to you, or raise the opposite side, whichever is best aligned with the side facing you. Use increments of ⅛-to ¼-turn to avoid overcorrection. Return the camera to the test fixture and check again.




▲ **FOLLOW THE BRIGHTEST DOT** The brightest reflection is from the window over the sensor and is the one to watch. You should ignore all the others (like those circled in the above photograph).



▲ **TAKE AIM** When in place, the target makes it easy to aim the laser at the exact center of your camera's detector.




▲ **CENTERED DETECTOR** The camera shown is mounted and ready for testing. Swivel the nylon washers to secure the camera in the center but still allow it to rotate freely. Note the black arrow on the camera body that's used as an indexing point as you turn the camera during testing.

Most cameras I've tested started out with a ½-inch to 1-inch circle, and then after adjustment, I was able to get the circle of projected beams to less than ¼-inch pretty easy, and with some care less than ⅛-inch. Repeat the six-point camera rotation slowly, and keep adjusting the screw pairs until the size of the circle is minimized. The first time you do this process, it may take some time, but with repetition the routine becomes more intuitive.

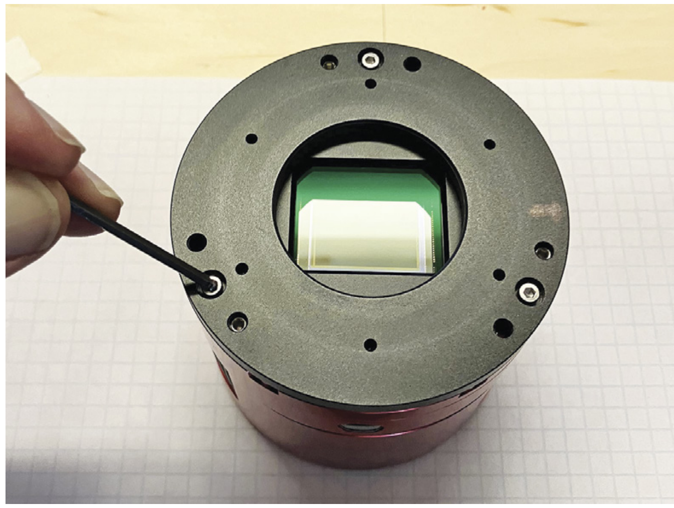
## Testing Square and Non-symmetrical Cameras

Some newer astronomy cameras today come in square housings, and some have a sensor offset from the center of the camera housing. Some older CCD cameras had more exotically shaped bodies. To test these, mount a 2-inch focuser tube on the top of a camera holder that's either 3D-printed or scavenged from an extension tube or old Barlow. The camera is then installed with its 2-inch nosepiece in place and rotated in the focuser tube to perform the testing. Be sure to include this additional offset when creating your sensor simulator so that the laser is properly aimed.

If your camera has a built-in shutter, you'll need to connect the power and USB to a computer to open the shutter during testing. It's also advisable to remove external filter wheels or off-axis guiders because they can introduce their own tilt errors. If you trust your filter wheel to be machined accurately, then move it to an empty filter slot with no filters for the test. By routing the cables up and over the top you can spin the camera about a full turn without twisting the wires too much.

## Final Testing at the Telescope

After aligning the sensor as best you can indoors, install the camera on your telescope or camera lens to do a final check by imaging a rich starfield and reviewing the result on screen. Zoom in on the corners of the frame to have a critical look at the shapes of the stars there. While field flatness can also be measured by software such as *PixInsight*, or *CCDInspector*, it's really what you can see at full resolution in your images that matters the most.

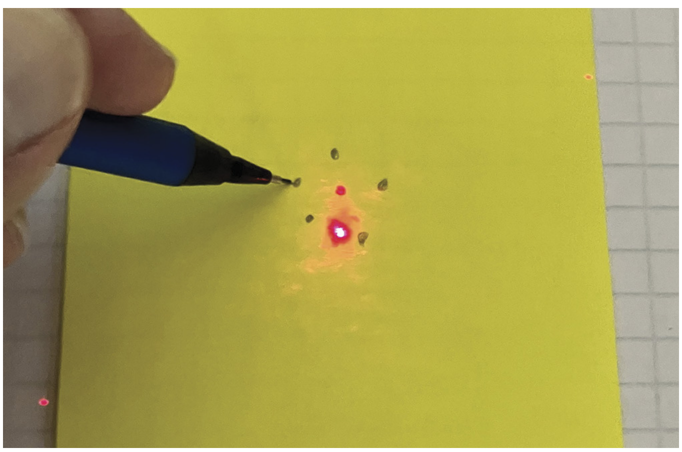


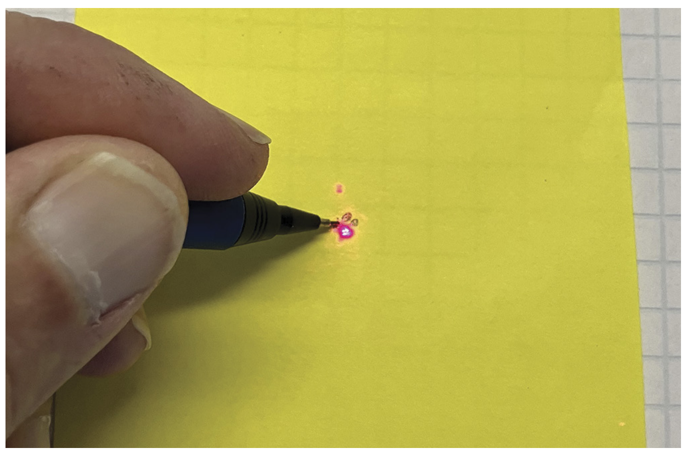
▲ **COLLIMATING ADJUSTMENTS** Nearly all recent astronomy cameras include three or four sets of push-pull screws to allow adjustment of the tilt of the camera. Here the pull bolt is a larger cap screw than the push bolt next to it.

With this simple, home-built alignment rig, you can ensure your camera is going to give you the sharpest possible images as long as your astrograph or camera lens is well collimated. And if you do have an issue with a tilted focuser, you can be certain you've at least eliminated the camera as the problem and can address that issue separately.

It's a good idea to retest your cameras annually since adjustments can loosen in normal use. With some practice, you can test a camera and adjust it in less than 10 minutes. The sharp images possible with a properly aligned camera can be quite dramatic, resulting in photos that can inspire awe and admiration from your family and astro-imaging friends.

■ **CHRIS SCHUR** operates a pair of high-altitude observatories in northern Arizona where he routinely pushes the limits of his equipment. Visit his website at **schursastrophotography.com**.





▲ **SHRINKING CIRCLE** *Left:* The first round of testing produces a wide circle, revealing sensor tilt. *Right:* After a few rounds of adjustments, the circumference of the laser's path should become very small. At this point, your sensor should be parallel to the front plate of your camera.

# Airy Disk's 106-mm Triplet Refractor

*We test an apochromat from a new Canadian manufacturer. Does it live up to its marketing?*


◀ The Airy-Disk APO 106mm f/6.6 Triplet ED FCD-100 refractor includes tube rings, and two Vixen-style dovetails — one to mount the scope, the other for carrying additional accessories up top. Also included is a 2-to-1¼-inch eyepiece adapter.

ALL PHOTOS COURTESY THE AUTHOR.

## Airy Disk APO 106mm f/6.6 Triplet ED FCD-100

U.S. Price: $1,890
airy-disk.com

### What We Like

High-quality machining

Excellent focuser

### What We Don't Like

Field coverage insufficient for full-frame cameras

Optical defects visible in corners of images

**EVERY INDUSTRY GOES** through fads. Currently, I'd argue that refractor telescopes seem to be the hottest thing going. Everyone wants one, and everyone is making them. I ran into a new player in this market niche at the Texas Star Party eclipse event last April. Cleverly named Airy Disk, their wares consisted exclusively of apochromatic refractors. I didn't have time to get a closer look at the star party, but fortunately I encountered them again at their booth at the annual Northeast Astronomy Forum (NEAF) where I had a chance to learn more. They weren't quite as "new" as I thought, as they've been making telescopes for years, but recently they launched their own branded line of refractors. While at NEAF I arranged loan of the company's APO 106mm f/6.6 Triplet ED FCD-100 along with two focal reducers.

## In the Box

A few weeks later, the scope arrived in a foam-packed cardboard box. The build-quality of this refractor is impressive. The 106-mm (4.17-inch) objective is protected with a threaded aluminum lens cap — a nice touch. I can't tell you how many times I've had push-fit caps fall off and roll away down the driveway in the dark. The dew shield extends easily and is secured by a single polymer screw.

The focuser is one of the better focusers I've seen without paying a premium for an upgrade. It has knobs for both coarse and fine focus and a locking screw. The drawtube rides along three linear bearings for added stability and rigidity. Initially, the focuser was smooth and without any backlash that I could feel, nor did the view shift as I racked in and out of focus. I made use of that locking screw for heavier loads, but shortly after beginning the review I added an Optec DirectSync focus motor made specifically for this scope. Motorized, the focuser held any load I tried without issue. The focuser accepts 2-inch accessories and includes a 2-to-1¼-inch adapter as well. The field-flattener / reducers thread directly onto the focuser after the eyepiece adapter is removed.

The tube's matte-white finish gives the scope a clean feel that doesn't look cheap. Even the two flatteners show a nice attention to detail as each comes with threaded metal caps and an adjustable spacer. Also included are a pair of machined tube rings and a set of Vixen-style dovetail bars — one on the bottom for attaching to a mount and another on top for accessories.

The heart of the scope is its air-spaced-triplet objective lens featuring Hoya FCD-100 ED glass — a material prized for its color-correction capabilities. The telescope I received was a display model, and the first night out I found the optics a bit out of alignment. Since the scope doesn't allow collimation adjustment, Airy Disk quickly sent me a new objective assembly. At first, I was a bit taken aback by the idea of having to replace the lens, but my fears were unfounded. The lens cell screws off easily, allowing me to replace the objective without difficulty. Star testing showed the new objective to be in collimation.

Airy Disk provides analyses of each scope they ship, which is unusual in an instrument at this price. However, the documentation proved a bit confusing. One report showed an overall Strehl ratio of 0.976, which is surprisingly good for a scope at this price. A second, more detailed report was also provided but gave a Strehl of 0.894 instead. I'm not sure how to account for the different values.

## Visual Performance

After replacing the objective lens, I spent a few days with the scope evaluating its visual capabilities. Bright stars in the middle of the field showed no color to my eye, and the views of the Sun with a Herschel wedge displayed crisp details in sunspots and granules across the solar disk. I also tried the scope with a Daystar Quantum Chromosphere filter and found the background did show a bit of haze. The appearance of a black background when solar observing is a very high bar to attain in scopes that aren't designed specifically for that kind of work. I've seen few scopes that could achieve this feat.

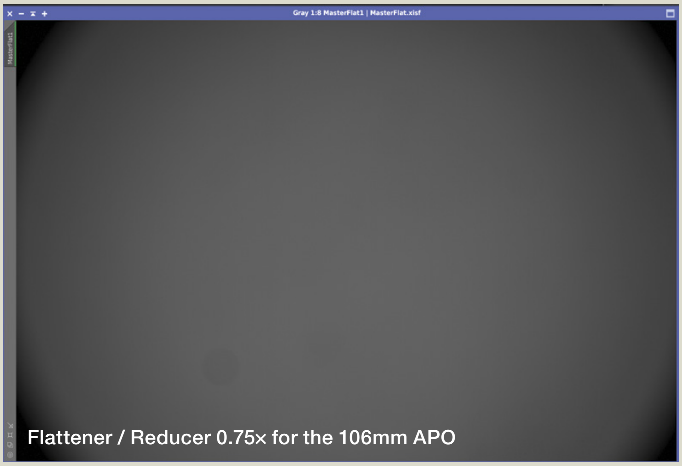
Views of the Moon were contrasty and sharp, with the lunar disk surrounded by black sky and a few stars. I used the bright limb as a critical color test and only at high power could I just catch some hints of red/yellow/orange against the dark of space. So far so good.

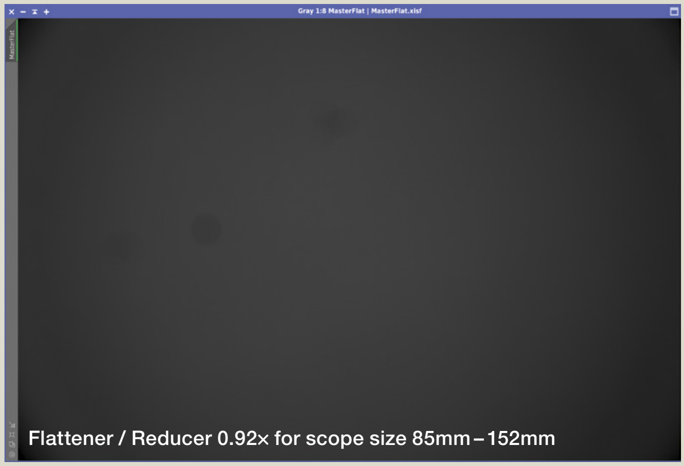
Next, I performed a star test, which revealed a small amount of spherical aberration. During my visual tests


▲ *Left:* The scope includes two ring baffles to reduce internal reflections. A threaded aluminum lens cap protects the objective when not in use. *Right:* The heavy duty, 2-inch dual-speed focuser has a bracket for mounting a finderscope or guidescope, though neither are provided. The focuser and its 2-to-1¼-inch adapter use non-marring brass compression rings to secure eyepieces and star diagonals.

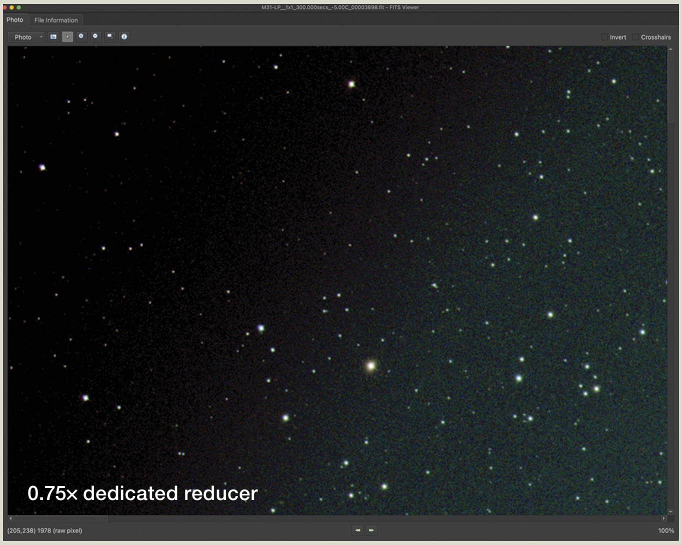
▲ *Left:* The rack-and-pinion focuser rides along three linear bearings that produce excellent rigidity. *Right:* a knurled thumbscrew located on the bottom of the gearbox locks the focuser in place.

▲ *Left:* The focuser's 2-inch adapter unscrews to reveal M63 threads that accept the company's optimal focal reducers (right).




▲ Both optional reducers produce slight vignetting that was easily corrected in post-processing with flat-field calibration frames.





▲ Stars in the images taken using both focal reducers appear round on a full-frame detector except in the extreme corners. While the stars were still acceptable with the 0.75× model, they appear unacceptably astigmatic with the 0.92× reducer. Users with APS-C cameras won't see these issues.

I didn't need to tighten the focuser's tension screw for just a diagonal and eyepiece.

## Astrophotography Tests

To assess the scope's photographic capabilities, I used the supplied optional accessory optics, starting with the awkwardly named "Flattener / Reducer 0.92× for scope size 85mm - 152mm." It's made with two extra-dispersion (ED) glass elements and is priced at $250. This adapter takes the scope's native focal length of 700 mm down to 644 mm, changing the effective focal ratio to f/6. The back focus is listed as 55 mm. The second adapter is a 3-element 0.75× Flattener / Reducer made specifically for the 106mm APO ($280). It brings the focal length down to 525 mm and the focal ratio to f/4.95. The back focus requirement for this adapter is listed as 55 to 60 mm, which I found rather odd, as corrective optics typically require a very precise spacing to do its job properly. Performance certainly wasn't acceptable within this entire range, which brings me to an interesting feature integrated into both corrective lenses. They each have adjustable spacers built right into them. You can dial the space between the correctors and your camera from 0 to 5 mm in increments of 0.05 mm steps, and the motion is quite smooth. After some adjustments, I established 57.5 mm as the best spacing. Of course, your milage may vary.

Your camera attaches directly to either reducer with T-threads, and both units accept 2-inch filters (another nice touch). If you have a color camera, you can connect a UV/IR filter or a light pollution filter directly to the reducer. The 0- to 5-mm adjustment seems like an ideal benefit as well because putting one of these filters in line changes the back focus by the thickness of the filter's glass, usually about 1 mm or more.

All this sounds like it would be quick to dial in and start imaging, and I had a full-frame color camera on hand that I was anxious to try with this scope. In practice I found that I had to experiment quite a bit to find the optimal spacing with both adapters. I made sure I started with the minimum recommended spacing of 55 mm between the camera and the reducers. I anticipated adjusting the spacing by as much as 1 mm when using with an UV/IR blocking filter or a light pollution filter. However, I had to spend a good bit of time adjusting the spacing, refocusing, and then evaluating the corners of images to see how the change affected the star shapes. Corner stars showed significant distortion initially, looking bloated and cross-like rather than round. The goal was to minimize these to acceptable levels. With each spacing change, refocus was necessary and, just like finding focus, I could clearly see the correction in the corners of the images get progressively better, and then start getting worse.

This brings me to the performance of the scope with a full-frame sensor. The scope is described as capable of illuminating a full-frame (24 × 36 mm) detector, but marketing being what it is, you may not get quite what you expect. I would say the scope's corrected field coverage is closer to full frame than to a cropped sensor, but it's no match for any of my premium refractors. I could adjust the spacing such that stars at the edges of the field were close enough to being round that they could be corrected with software in post processing or cropped out after stacking. This level of performance was the same with both reducers, although the 0.75× flattener was substantially better than the 0.92× model, most likely because it was designed specifically for this scope rather than for a range of optics. The stars in particular degrade quite rapidly at the very corners where you can see chromatic aberration and distortion. Again, this is only in the extreme corners of the field of view.

I also tried the scope with a monochrome sensor, though not a full-frame unit. I used the Player One Poseidon-M with an APS-C-size detector and did some imaging with a Chroma 3-nanometer hydrogen-alpha filter. The 28-mm wide field was well-corrected from corner-to-corner. No optical distortions were visible at all in this smaller field.

## Final Thoughts

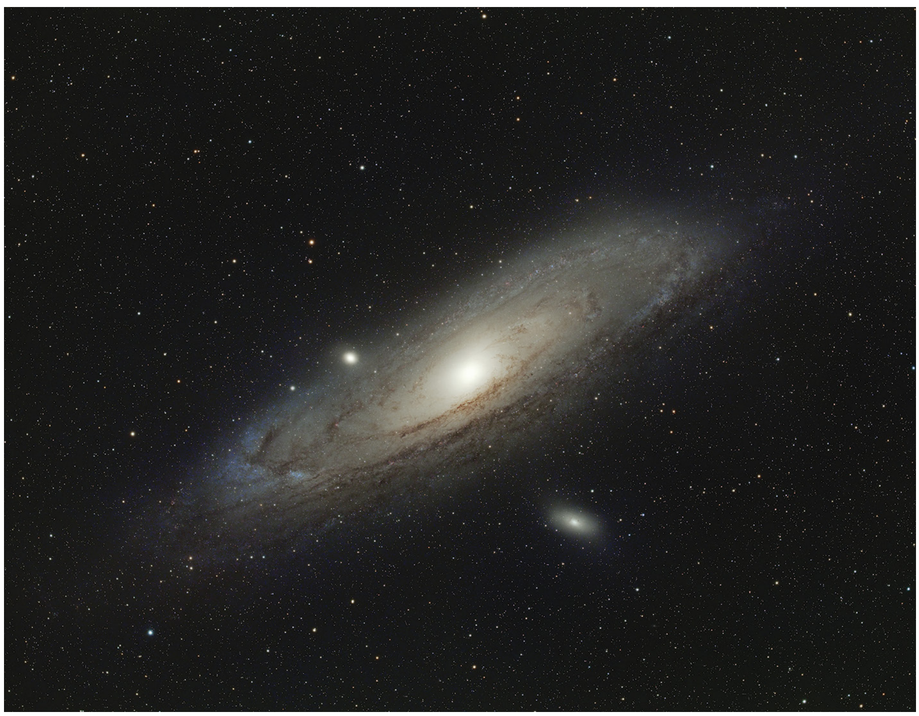
For visual use, the Airy Disk 106mm is a fine scope. The build quality and the focuser are excellent, and the instrument looks and feels like a high-quality telescope. The views were quite satisfactory to me as well, and better than many refractors I've tried at this price. For twice the money, the next tier of refractor quality will give you a solid and noticeable incremental improvement, but certainly not twice as good.

As an astrograph, I did find the "full frame" claim to be a bit of a stretch, particularly with the 0.92× flattener. The horizontal and vertical edges from such a sensor were decent enough and can be easily corrected in processing.

▲ Both the optional 0.92× flattener / reducer (left) and 0.75× (right) have built-in extensions with index marking that allow precise adjustment of the spacing between your camera and the rear element of the corrector.

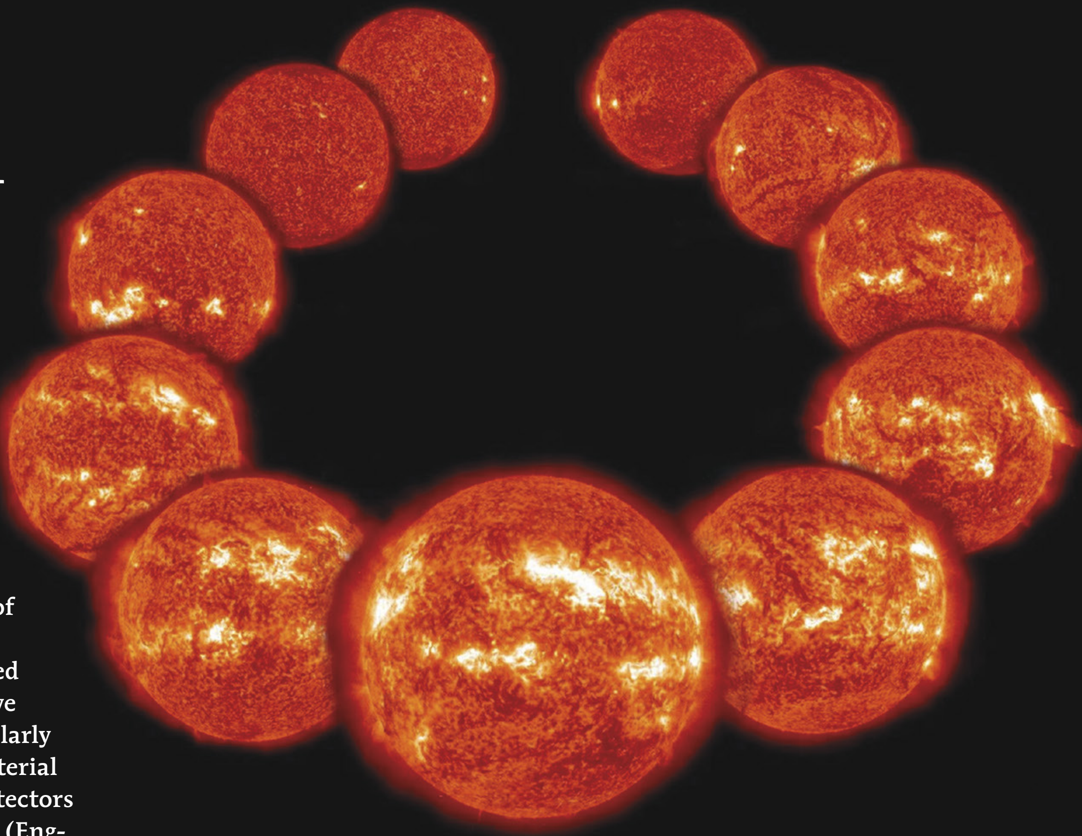
The corners, however, were truly bad on the 0.92× flattener, showing badly distorted stars. Corners with the 0.75× reducer were much better but not perfect. On the other hand, if you typically work with smaller sensors, this is an excellent scope even with these limitations. Given that it's one of the lower-cost refractors of this size on the market, I'd consider it a great value.

■ If Contributing Editor **RICHARD S. WRIGHT, JR.** could only keep one telescope, it surely would be a high-quality refractor.



▲ This image of The Andromeda Galaxy, M31, was captured with the Airy Disk 106mm and dedicated 0.75× reducer and a full-frame Player One Zeus camera. With this combination the outer 1/8 of the field required some cropping to remove distorted stars in the corners of the frame.

# What Is the Solar Cycle?



**OUR SUN IS NOT** a constant star. It changes on a roughly 11-year cycle, waxing and waning in activity that includes sunspots, flares, and eruptions of energetic subatomic particles.

Much of this activity remained invisible until the Space Age — we couldn't know that the Sun regularly emits X-ray flares and ejects material until we had the space-based detectors for those photons and particles. (English astronomer Richard Carrington famously recorded a *visible* flare in 1859, however.) But long before satellites offered us access to the Sun in parts of the spectrum we can't see with our eyes, observers found another way to monitor solar cycles as they unfolded.

For more than 400 years, astronomers have kept watch on solar activity by means of *sunspots*. Within these regions, strong magnetic fields inhibit the movement of gas in the Sun's *photosphere*, or surface layer. Magnetically trapped gas cools by more than 1,000 degrees and appears dark in contrast with the surrounding hotter gas.

German amateur astronomer Heinrich Schwabe started observing sunspots nearly daily in 1825. After more than a decade, he realized that the sunspot count exhibited a roughly 10-year period of variation — close to the modern average of 11 years.

Sunspots wax and wane in number because they are a marker of magnetic activity. A quiet Sun is an orderly Sun, its magnetic field arranged similar to a bar magnet (that is, with a north and south pole). But the Sun isn't a solid body, and its equator rotates faster than its poles. This *differential rotation* interacts with interior flows of plasma that create the magnetic field, tangling the field lines. And where field lines tangle, sunspots crop up.

Sunspots are only the most obvious indicator of the solar cycle. As spot counts peak, the Sun's limb is more likely to sport magenta arcs of gas known as *prominences*. This phenomenon becomes visible during total solar eclipses or at any time when observing the Sun through hydrogen-alpha filters. Likewise around the peak of the solar cycle, sudden flares of high-energy radiation become more likely. There may also be huge blasts of material from the Sun's outer atmosphere, usually from above sunspots, known as *coronal mass ejections*. Sometimes, these streams of energetic solar particles head straight for Earth — bringing on the geomagnetic storms that both threaten satellites and delight aurora chasers.

▲ **A CYCLE** Photos of the lower solar corona taken between 1996 and 2006 show the evolution of the Sun's magnetically driven activity during Solar Cycle 23.

NASA / GODDARD SPACE FLIGHT CENTER

These activities associated with sunspots release the energy of the tangled magnetic fields, weakening them. Eventually, the Sun's magnetic poles flip and, as an orderly field reasserts itself, the sunspot count decreases again — for a while.

Right now, we're in the maximum phase of the current solar cycle, as noted by the National Oceanic and Atmospheric Administration last fall. The peak may continue for several more months. The activity we've seen thus far — including two strong aurora shows in May and October of 2024 — indicates that this cycle has shown unexpected strength compared to the exceedingly weak cycle that preceded it (*S&T:* Nov. 2013, p. 10). Once the current solar fervor fades, we'll have to wait until 2035 or so to see its like again. So enjoy it while it lasts! ■

## ▶ BUDGET ASTROGRAPH

Apertura now offers a high-quality, 6-inch astrograph. The Apertura CarbonStar 150 Imaging Newtonian with 0.95× Coma Corrector ($999.95) is a 5.9-inch f/4 reflector designed for astrophotography with crop-sensor cameras. The carbon-fiber optical tube is 50.8 centimeters (20 inches) long and weighs just 4.7 kilograms (10.4 lbs). Its dual-speed, 2-inch linear bearing focuser can hold heavy cameras and additional accessories and accepts most third-party automation motors. The included 0.95× Coma Corrector produces a fully corrected image circle of 28 mm. Both primary and secondary Borosilicate mirrors feature enhanced aluminum coatings with a $SiO_2$ overcoat boasting 96% reflectivity. Each scope also comes with CNC-machined aluminum tube rings, both Vixen-style and Losmandy-D-style dovetail mounting bars, a 2- to-1¼-inch eyepiece adapter, a dust cap, and a pair of hex keys.

**Apertura**
Available in North America from **High Point Scientific**
442 Rt. 206, Montague, NJ 07827
highpointscientific.com

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## ▶ TINY OBSERVING STATION

Chinese manufacturer ZWO announces its newest entry into the "Smart Telescope" market with the Seestar S30 ($349). The device is built around two lenses: a 30-mm f/5 apochromatic triplet refractor, and a wide-angle lens. The larger optic is paired with a Sony IMX662 CMOS color camera having a 1,920 × 1,080 array of 2.9-micron-square pixels, while the wide-angle lens is paired with a smaller sensor. The telephoto lens includes bult-in, selectable filters to combat light pollution and enhance nebulosity. The optics and internal electronics ride along in a compact alt-azimuth Go To mount that weighs 1.65 kilograms (3.6 pounds). The Seestar S30 is controlled with a smartphone or tablet using the *ASIAIR* app and connects with either Wi-Fi or Bluetooth. Images are saved on 64GB of internal memory. The device is powered by an internal, rechargeable lithium-ion battery that can run the device for up to six hours. Each purchase includes a field tripod, USB-C charging cable, a solar filter, and a carrying case.

**ZWO**
6 Moon Bay Rd., Suzhou Industrial Park, Jiangsu Province, China
Phone: +86-512-65923102; zwoastro.com

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## ▶ SOLAR SCOPE

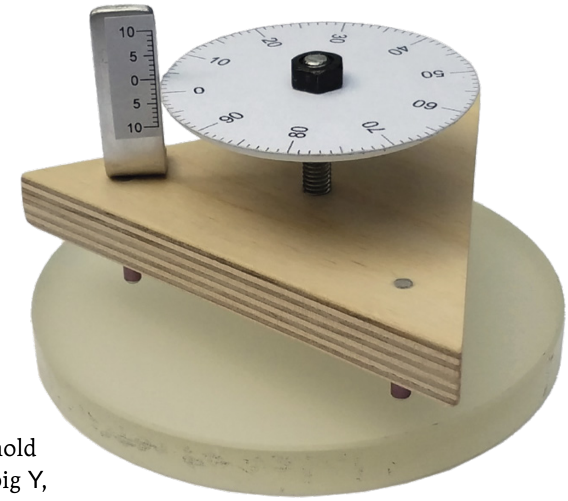
Sky-Watcher USA introduces its first telescope designed for observing the solar chromosphere. The Heliostar 76mm H-Alpha Solar Telescope ($2,995) is a 3.1-inch f/8.3 doublet refractor with a built-in, tunable Solis Etalon that passes 0.55 angstroms of the solar spectrum. The scope weighs 3.8 kilograms (8.4 lbs) and comes with a 1¼-inch blocking-filter diagonal having 11.5-mm clear aperture, together producing high-contrast views of the chromosphere. Its 2-inch, dual-speed Crayford-style focuser can hold heavy eyepieces and accessories. Each scope comes with mounting rings, a V-style dovetail mounting bar, a Heliostar solar finder, a 2- to-1¼-inch eyepiece adapter, a 20-mm eyepiece, a smartphone camera adapter, and a hard-shell carrying case.

**Sky-Watcher USA**
475 Alaska Ave., Torrance, CA 90503
310-803-5953; skywatcherusa.com

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

# Make Your Own Spherometer

*This precision tool is surprisingly easy to build.*



▲ The spherometer rests on a blank with the central screw just touching. The depth of the screw is accurate to a hundredth of a millimeter.

**IT'S ALWAYS FUN** to build your own telescope, but there's a special kind of joy in making your own tools with which to build that scope. A tool can be used again and again, bringing satisfaction every time you use it. When you're grinding a mirror or a lens, one very useful tool is a *spherometer*, which lets you measure the curvature of your blank as you go. At first glance spherometers look pretty elaborate, but they're really just a screw and a set of legs sticking out of a base plate. You can build one in your sleep. Here's how, based on a flat tester designed by professional optician Ed Jones.

Start by making a three-legged base. Why three legs? Because three legs will always rest solidly on any surface. Plus, three points of contact define a circle, and that circle is important for the math to work out. Note: The diameter of the circle needs to be smaller than the mirror or lens you're measuring! (Ask me how I know.)

I made a triangular platform to hold the legs, but you can use a circle, a big Y, or any shape that will hold three legs in an equilateral triangle. The legs should be made of something relatively soft so they don't scratch the glass you're measuring. I used an aluminum knitting needle. Round the ends so there's only a single, centered point of contact for each leg.

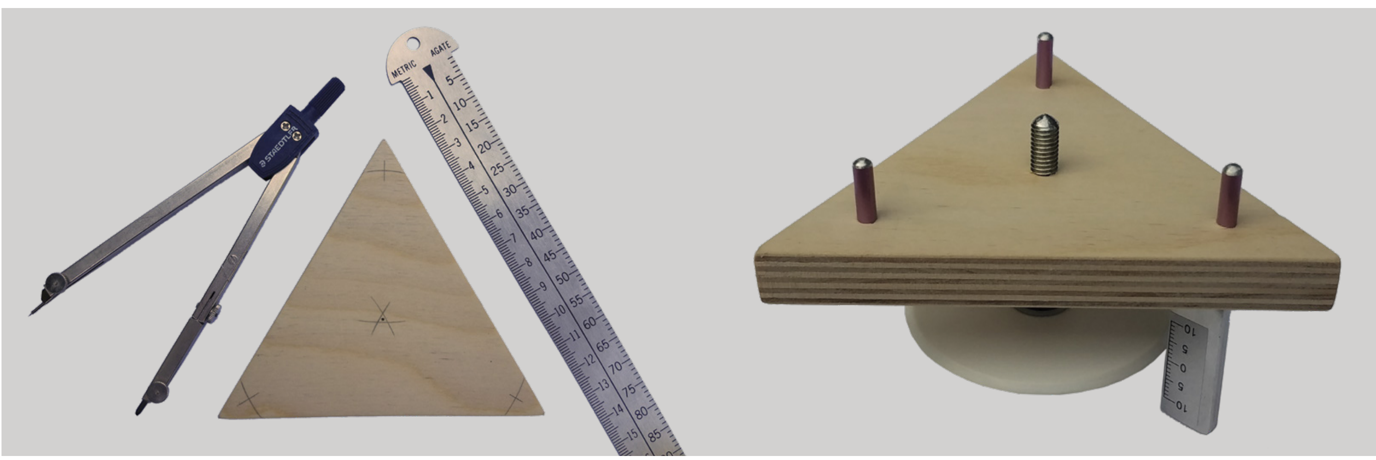
The legs should be as close to defining the points of an equilateral triangle as you can make them, and close to the same height, too. The center screw should be of a known thread pitch. Most spherometers read in millimeters, so it makes sense to use a metric bolt with a 1-mm thread pitch. Drill the hole for it as exactly centered between the legs as you can and as perfectly straight up and down as you can. (A drill press helps immensely here.) Tap threads in the hole to accommodate the screw. You can tap all the way through to make the screw run loosely, as on a commercial spherometer, or you can leave the hole partially untapped, so it grips the threads and leaves the screw snug.

Round the end of the screw, too.

Cut out a circular disk a couple inches across to use as your measuring wheel. Mark the disk in 100 increments. (You can save yourself a lot of trouble by searching online for "circle with 100 divisions" and scaling the result to match your disk size.) Mount the disk to the top of the center bolt.

Now make a post that stands up beside the disk. With the screw extended down to just touch the surface on something nice and flat, mark the post even with the top of the disk and

▼ *Left:* Mark where the legs and central screw will go with a compass and a straightedge. Getting it exact is great, but close is good enough. *Right:* The ends of the legs and the central screw are rounded to provide a single point of contact with any surface.



ALL IMAGES COURTESY OF THE AUTHOR

make marks upward and downward every millimeter for about a centimeter in each direction. That's your rough gauge to count complete turns of the screw (1 mm per turn), while the 100-increment disk counts hundredths of a millimeter.

That's pretty much your spherometer. So how do you use it? You start by setting it on something really flat. A commercial countertop or a thick piece of window glass will do. Back the screw off a bit and set the spherometer on the flat surface, then turn the screw downward until it just makes contact. If your screw is loose (ha ha), you can feel it snug up when it hits bottom. If your screw is tight, you won't feel it hit bottom, so the way to tell when it has is to give the spherometer a little tangential nudge each time you lower the screw. When it spins on the central screw rather than skids on the outer legs, you've hit bottom.

Once you've evened out on a flat surface, take note of the dial reading. It probably won't be zero, but that doesn't matter. Just note what it reads, then move to your work piece and do the same. Count up how many millimeters you moved the screw. Then plug it into the formula below to get your radius of curvature.

And there's your new tool to be used again and again.

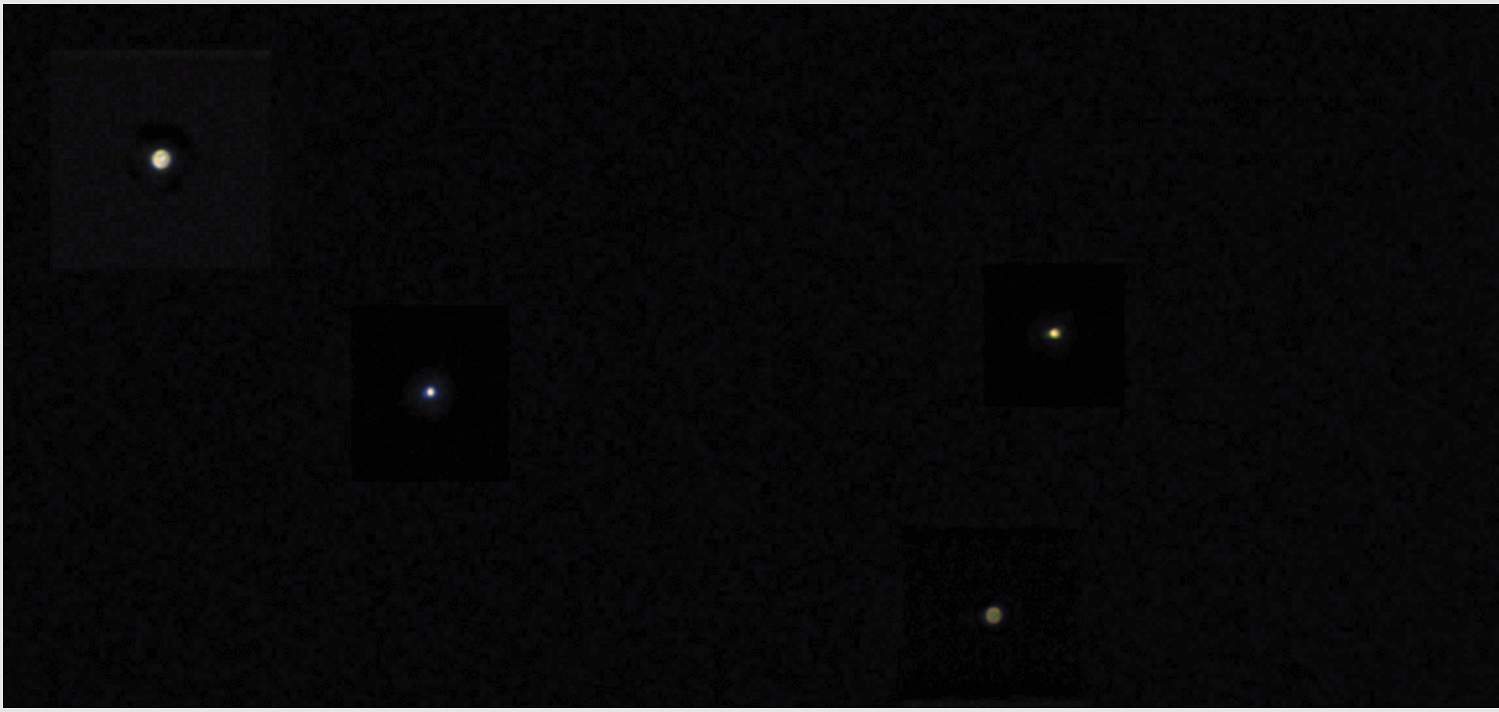
■ Contributing Editor **JERRY OLTION** now knows the radius of curvature of his barbecue lid, his desk lamp shade, and the lens he's grinding.

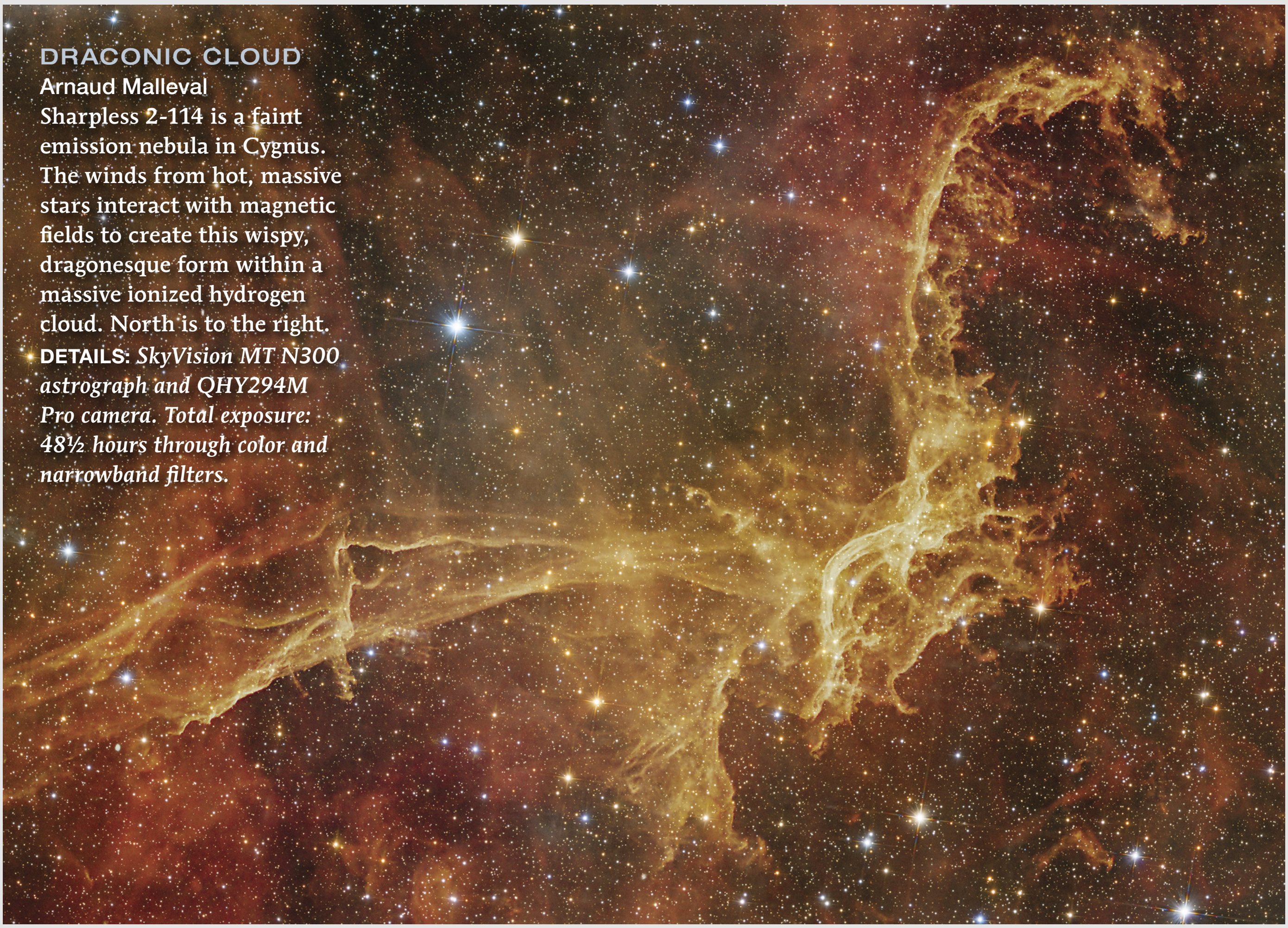
### HOW CURVED IS YOUR SURFACE?

The formula for radius of curvature is

$$R = \frac{h}{2} + \frac{a^2}{6h}$$

where $h$ is the spherometer reading and $a$ is the average distance between the three outer legs. So if your spherometer has a leg spacing of 69 mm and you measure a depth of 0.39 mm, you've got a surface with a radius of curvature of 2,035 mm, or 80 inches.



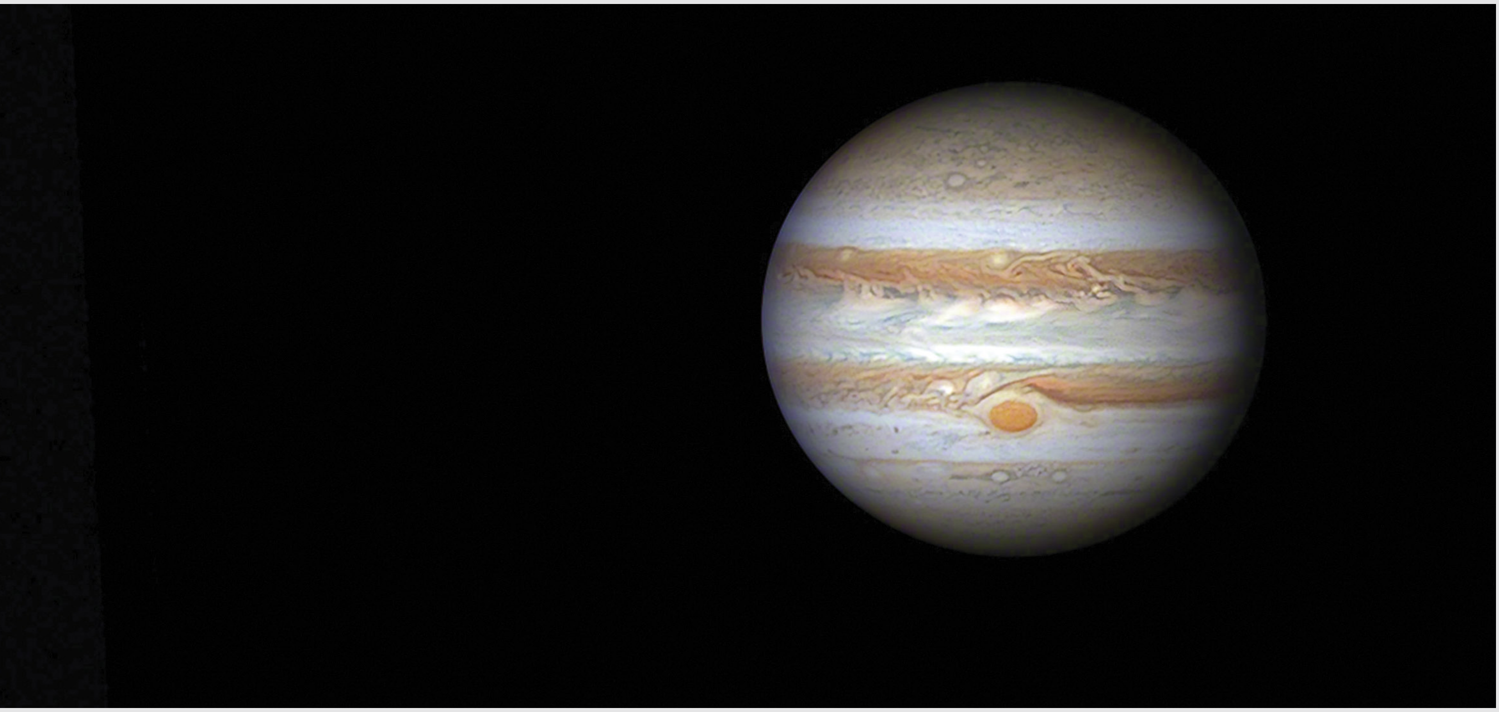


DRACONIC CLOUD

Arnaud Malleval

Sharpless 2-114 is a faint emission nebula in Cygnus. The winds from hot, massive stars interact with magnetic fields to create this wispy, dragonesque form within a massive ionized hydrogen cloud. North is to the right.

**DETAILS:** *SkyVision MT N300 astrograph and QHY294M Pro camera. Total exposure: 48½ hours through color and narrowband filters.*



### △ JOVIAN PARADE

Oleg Bouevitch

In addition to detail visible within Jupiter's Great Red Spot, Ganymede, Europa, Callisto, and Io (left to right, respectively) are also well resolved, with albedo features visible on both Ganymede and Callisto.

**DETAILS:** *Celestron 14-inch EdgeHD Schmidt-Cassegrain and ZWO ASI290MM camera. Stack of multiple frames through color filters on September 11, 2024.*

### ◁ ROBIN'S EGG

Vikas Chander

NGC 1360 is a planetary nebula originating from a binary system of white dwarf stars. Its vivid turquoise color is due to the presence of emission from doubly ionized oxygen atoms, while the reddish material at the upper left and lower right was expelled at an earlier stage.

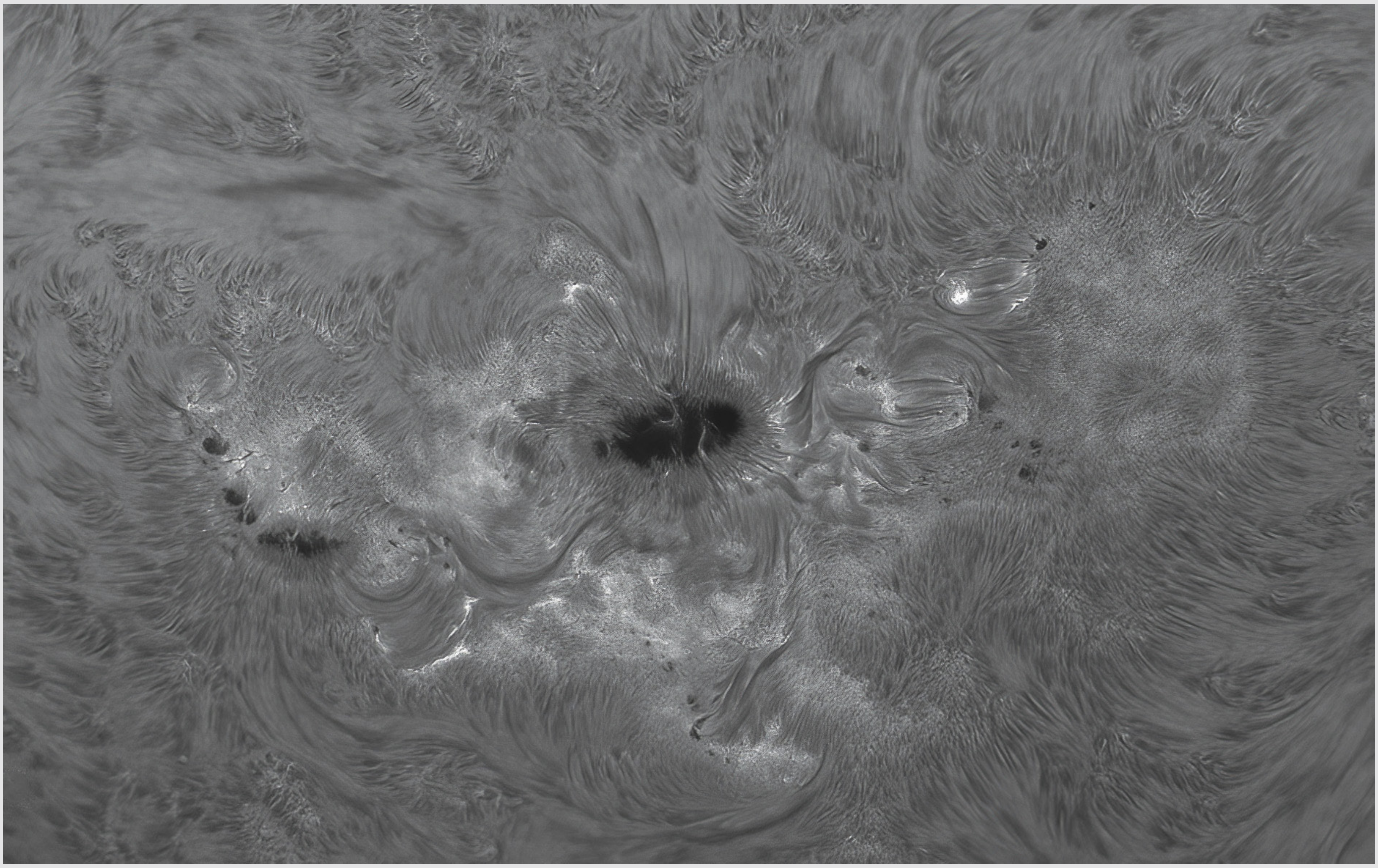
**DETAILS:** *PlaneWave CDK24 telescope and Moravian Instruments C5A-100M camera. Total exposure: 27½ hours through narrowband and color filters.*

### ▷ FATIN PEAK
Tunç Tezel
Comet Tsuchinshan-ATLAS (C/2023 A3) adds additional flair to this fisheye view of the Milky Way seen above Fatin Peak in Turkey on October 20, 2024.

**DETAILS:** *Canon 6D camera and 24-mm lens. Mosaic of 25 panels, each exposed for 10 seconds or less at f/3.2, ISO 6400.*

### ▽ CHAOTIC CROMOSPHERE
Daniel Brousseau
Frothing plasma surrounds the dark umbra of sunspot AR 3780 in this exquisitely detailed, high-resolution image from August 8, 2024. The wispy filaments of AR 3780's penumbra appear to bridge this dark gap in several places.

**DETAILS:** *iStar Optical Phantom FCL 140-6.5 refractor and ZWO ASI174MM camera. Stack of several video frames through a Daystar Quark Chromosphere filter.*



**EVENING VISITORS**
Osama Fathi
Comet Tsuchinshan-ATLAS (C/2023 A3) cuts between Ophiuchus and Serpens Caput above Egypt's Black Desert on October 18, 2024. Blazing Venus hovers just above the horizon at bottom just left of center.
**DETAILS:** *Nikon Z6 camera and 14-to-24-mm lens. Stack of 8 exposures at f/2.8, ISO 200.*

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# From Lahore to Toronto

*A Toronto-based artist recounts his astronomical journey alongside his global journey.*

▲ The author's paintings, such as the one above depicting the surface of the Sun, have appeared in numerous astronomical articles and publications.

JULIAN SAMUEL

**MY GRANDMOTHER** Virginia Hem Raj Kahan Singh, born in 1902 in Lahore (then British India), inspired my love for astronomy. During the hot Lahore summers, my brothers and sister and I used to sleep on the flat roof of my grandparents' house. It felt like a party, with owls hooting in the trees below. Under those coal-black nights, my grandmother would point out the constellations and planets. We'd giggle when she tried to pronounce Sputnik.

Later, from Karachi, Pakistan, we sailed to the United Kingdom, where the starry night skies were extinguished. However, my need to see stars wasn't. In both Glasgow, Scotland, and later Warlingham, England, I fabricated telescopes with cardboard tubes and magnifying glasses. My scopes didn't work, except for once when I saw the Moon jiggle into view and then abruptly float away. That two-second view of the Moon stayed with me for years. It was only much later that I discovered tripods.

At Trent University in Peterborough, Canada, I started taking Astronomy 101. One evening, our professor brought the class to a dark field on campus. Flashlight in hand, he pointed to various objects we couldn't see. We were charmed by him, even though he looked incurably eccentric. But I had no background in math. I feared numbers and dropped the course. That semester in English class, I read Bertolt Brecht's play *Life of Galileo*.

Decades passed. I didn't look through a telescope until I moved back to Toronto from Montreal. My partner lives in an apartment that has a vast view of our badly damaged urban sky. That view, along with adult high-school courses in math, physics, and chemistry, brought astronomy back into my life. My "numerophobia" evaporated . . . almost.

I began hunting for telescopes *and* tripods. Online, I came across Ken, at the time an astrophotographer at Orion Telescopes & Binoculars in California, who did a convincing sales pitch for linear binoviewers. But which pair of eyepieces would work best? I phoned Tele Vue Optics in Chester, New York, to consult their experts. My call was transferred to a man who said, "Al Nagler speaking, how can I help?" Had the receptionist really connected me with *the* Al Nagler? This internationally renowned maker of telescopes and wide-field eyepieces kindly spoke with me for 30 minutes. We discussed the clear aperture on my newly purchased binoviewers, and in his Bronxonian accent, Nagler recommended a pair of 15-mm Delite eyepieces.

My partner and I became members of the Royal Astronomical Society of Canada, which is brimming with supportive astronomers. In general, astronomers are a welcoming bunch. One of the places we observe from is the RASC's E. C. Carr Astronomical Observatory, about 175 km (110 miles) northwest of Toronto. And, yes, I inducted my partner into math and astronomy. She now teaches me integrals and derivatives while collimating our 10-inch reflector.

Observing the night sky from the Canadian Shield, I imagine myself back in Lahore on that rooftop under the blackest sky. I speak to Virginia: "Grandma, thanks for the sky tour, now please take a look through this Dobsonian. Can you see the Double Cluster in Perseus?" To me, one cluster represents Lahore, the other Toronto.

■ **JULIAN SAMUEL** is an artist and author of the romantic-comedy novel *Muskoka*, in which an amateur astronomer discovers love under the stars in Canada's oldest and best-known cottage resort.