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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

JUNE 2023

Photograph the Summer Milky Way

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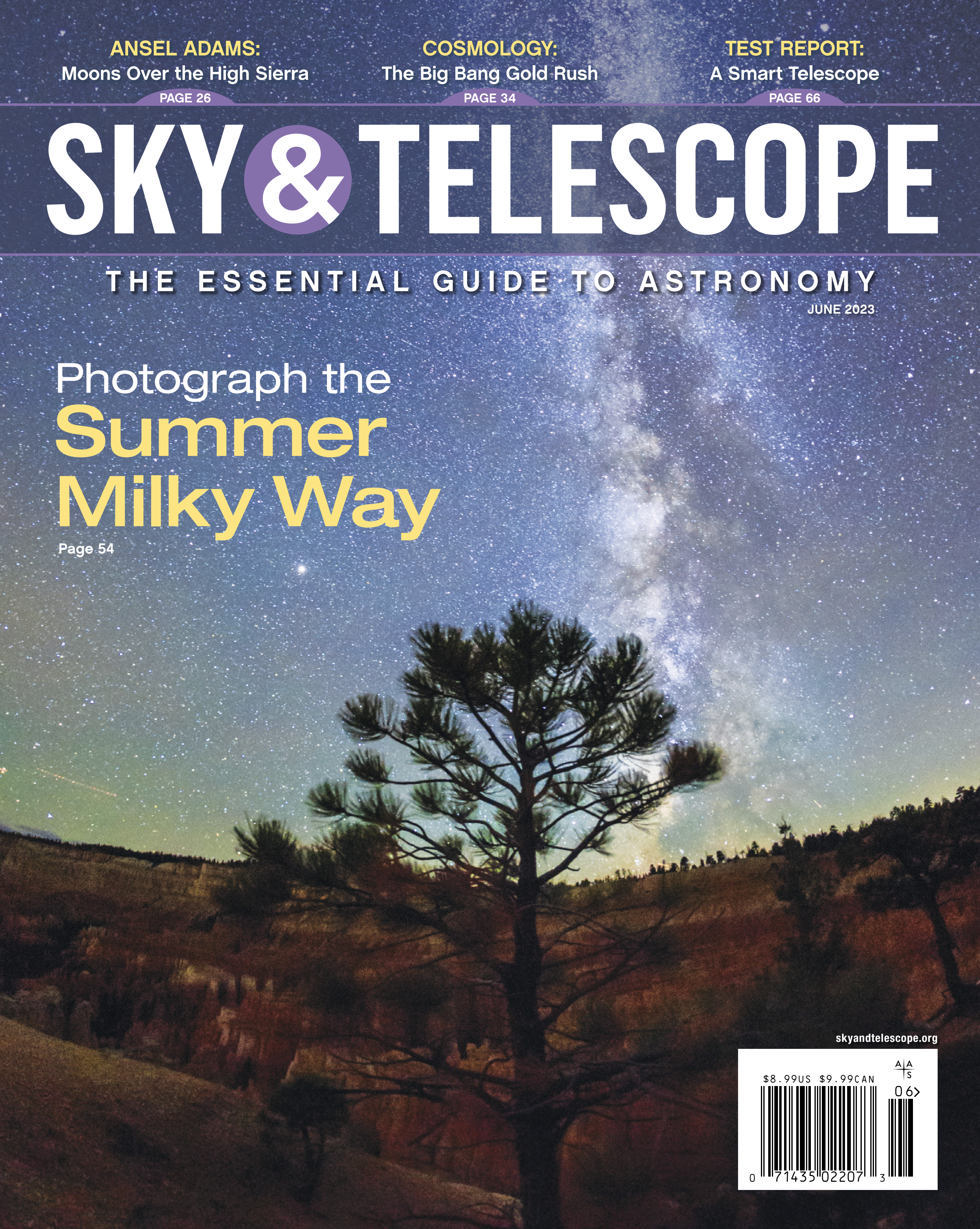

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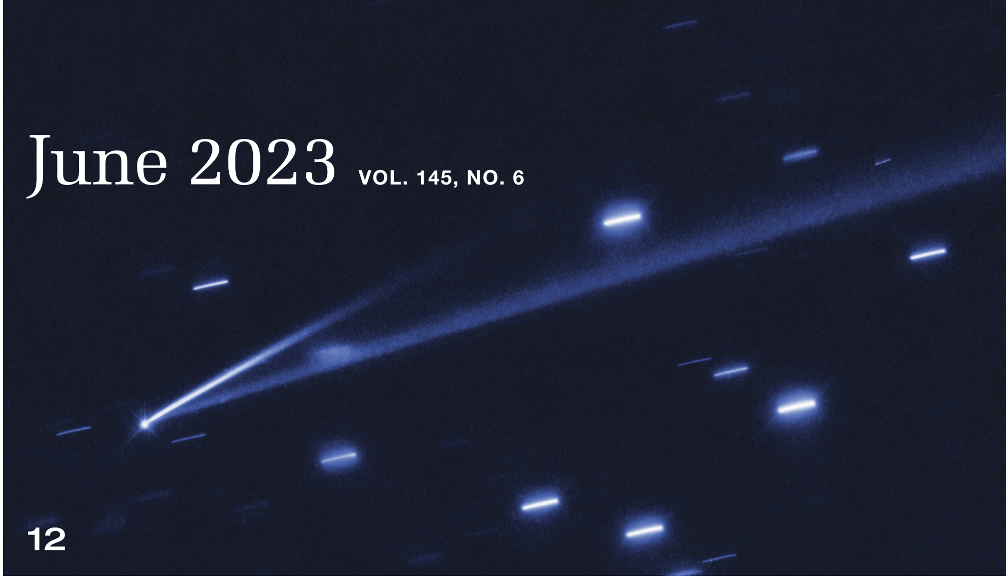
THE ESSENTIAL GUIDE TO ASTRONOMY

June 2023 VOL. 145, NO. 6



NASA GODDARD SPACE FLIGHT CENTER

ON THE COVER

The Milky Way sets behind a bristlecone pine in Utah.
PHOTO: TONY PUERZER

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Mark Our Words

THROUGHOUT EVERY ISSUE OF *S&T*, you'll find terms in italics — that cursive, right-tilting typeface first introduced around 1500 in Italy (hence the name). I'm not talking about those words slanted just to give them a little more oomph, like *awfully* or *sharp*, nor about book titles or other elements italicized as a matter of style. I'm talking about technical terms, usually followed by brief definitions.

In Beginner's Space, we underscore even relatively common terms, like *wavelength* and *electromagnetic spectrum*, as that department is for newcomers to our hobby. Elsewhere in an issue, we might give a term emphasis largely in passing. That's in case those relatively new to astronomy, or some area of it, are not entirely sure about the meaning, as when we flag *sublimation* or *lunar libration*.

Primarily, though, we highlight terms that might be novel, or at least less familiar, to *all* our readers (see what I did there?). Occasionally, astronomers researching a new discovery or phenomenon have recently coined the term.

▲ Letters that lean: Italics have specific duties in *S&T*.

So, you've likely heard of gravitational waves, but what of *primordial gravitational waves*? How about *active asteroids* or *main-belt comets*? These terms sound vaguely oxymoronic: Asteroids are inanimate hunks of rock or metal, you say — how can they be active? And comets come from the outer solar system, not from the asteroid belt near Jupiter, right?

If a simple-sounding term catches you up, you might have to pivot mentally when you learn what it means in the context. In astrophotography, for example, *stretching* isn't what you do before a workout, and *plate solving* isn't how best to unload the dishwasher. Seriously, at the other extreme certain technical terms might seem downright scary to certain readers. Take the $m^2\varphi^2$ *model* — heck, that one even scares me.

Altogether, as a popular-science magazine we do our best to avoid jargon. But we're also committed to expanding our readers' horizons. So if a scientific term is crucial to a story or some aspect of it, we'll call it out and define it, explain why we're using it, and move on. Italicizing important terms arguably helps readers focus their attention on — and retain — key concepts in the increasingly complex yet endlessly fascinating field of astronomy.

We try not to overdo it — as one style manual cautions, overusing italics can come across as "affected and patronizing." For us, it's about keeping the right balance for the reader between enjoying a clear, easygoing read and learning something new or challenging oneself just a little bit.

Incidentally, all the italicized terms above appear in this issue. Happy hunting — if you're so inclined.

Peter

Editor in Chief

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SKY&TELESCOPE
The Essential Guide to Astronomy

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A classic spiral: NGC 6814 in Aquila

Decaying Spirals

I found Monica Young's "Where Do Spirals Come From?" (*S&T:* Mar. 2023, p. 14) informative and thought-provoking. Whether the cause is long-lived swing amplification or self-propagating groove modes, some questions come to mind: First, what causes these features to eventually decay and go away as spiral galaxies evolve into ellipticals? Second, why are these features missing in lenticular galaxies?

It makes me wonder if there could be a measure of the strength or robustness of the spiral structures that perhaps weakens as the galaxy ages. Also, could the distribution of tangential velocities of gas clouds, as a function of distance from the core, be an indicator of that parameter? Again, thanks for the high-quality, thought-provoking articles that you publish every month!

Dave Billesbach
Lincoln, Nebraska

Monica Young replies: *Indeed, there are disk galaxies without spiral structures (lenticulars), and elliptical galaxies have no spiral structure either, so why don't they have spirals if the pattern is so ubiquitous elsewhere?*

One of the biggest differences between spiral and non-spiral galaxies is that spiral galaxies have lots of gas and non-spirals have very little gas. Stars by themselves are collision-less — space is big, and stars will rarely collide directly, so their primary way of interacting with each other is via gravity. As these interactions occur, stellar motions become more random over time, and stars become less responsive to the gravitational force from the spiral. Gas provides fuel for new stars, which can then start afresh in their interactions with the spiral's gravity.

As long as a spiral galaxy has gas, it will maintain its spiral pattern. Once it runs out of gas, it will have a spiral only a little while longer, transitioning gradually to a lenticular galaxy, a disk with no spiral. And if galaxies collide in a way that removes most of their gas, the end result can be an elliptical galaxy. That's not to say lenticulars and ellipticals are necessarily the end stage of all galaxies, though, since gas can still flow into galaxies via the cosmic web.

Hunting for Lunar Meteors

"Appreciating Earthshine" by Tom Dobbins and Bill Sheehan (*S&T:* Mar. 2023, p. 22) and Dobbins' "Hunting for Venusian Fireballs" (*S&T:* Mar. 2023, p. 52) were very nice articles. Both pieces remind me of Walter Haas, founder of the Association of Lunar and Planetary Observers, and his Lunar Meteor Search Project in the 1950s and '60s. I participated in that effort for many years while in high school using my "new" home-built 3-inch refractor with war-surplus optics, looking in vain for momentary meteoric flashes on the unilluminated side of the very young and very old Moon.

Though conceptually not a bad idea, in practice the odds of success were astronomically low. As we now know, far more powerful sensors than the naked eye are required to detect such transient events on the airless Moon. Still, it was fun and rewarding in those days thinking we were actually doing important work, as Sir Patrick Moore assured us that amateurs could do then.

Klaus Brasch
Flagstaff, Arizona

Tracking Comet ZTF

I would like to congratulate the editors and authors for the content of *S&T*'s website and magazine. It's always interesting, with a nice mix between scientific data and amateur astronomy.

Recently, I read the article "See Comet ZTF (C/2022 E3) Dash Between Big and Little Dippers" (**https://is.gd/CometZTFDippers**) by Bob King, which I enjoyed very much.

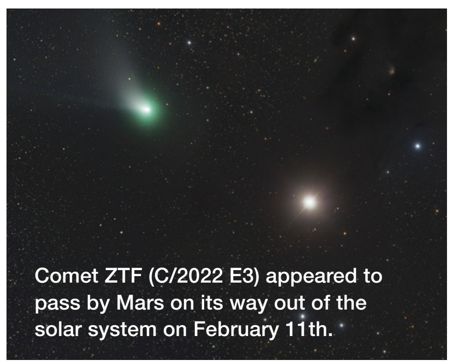
A phrase in the article reads: "While its *inbound* period was 53,000 years, due to perturbations by the planets ZTF is now headed out of the solar system altogether." By any chance, do you have any technical reference on this point?

I now work in industry, but I do have a background in professional astronomy and research. I sometimes teach a course on classical mechanics and simulations, and I think that this would be an interesting project for my students. It would help to have a paper or official reference with the comet's orbital parameters.

Gerardo Ramón Fox
Monterrey, Mexico

Bob King replies: *Thank you for writing in and for your kind words about* Sky & Telescope. *I received the information I used in the article from Dan Green, who is Director of the Central Bureau for Astronomical Telegrams out of Cambridge, Massachusetts. He said:*

"We now have a 1.5-year arc of good astrometry (July 2021 to Dec 2022) that Syuichi Nakano used to produce original and future orbits, meaning using solar system barycenter when the comet is far outside the orbits of the major planets. These indicate that the comet had a semimajor axis of 1,414 astronomical units before it became perturbed by the major planets on its way into perihelion now, and that it will be ejected from the solar


Comet ZTF (C/2022 E3) appeared to pass by Mars on its way out of the solar system on February 11th.

NGC 6814: ESA / HUBBLE / NASA, ACKNOWLEDGEMENT: JUDY SCHMIDT; COMET ZTF: SEAN WALKER / MDW SKY SURVEY *system due to planetary perturbations at its current return."*

If you would like to do your own calculations, here is a link to the comet's orbital elements posted on Gideon van Buitenen's comets page: **https://is.gd/VanBuitenen**.

Comparing Detectors

Congratulations on your fantastic article "Stepping Up to CMOS" by Ron Brecher (*S&T:* Mar. 2023, p. 58). I thoroughly enjoyed the very clear side-by-side comparison of both types of imaging chips.

CMOS detectors have indeed come a long way, including that their issues with amp glow are now practically resolved, as the article explained.

One question keeps puzzling me, though. How does binning compare between CMOS and CCDs? Due to the different read-out systems, I suspect CMOS does lose some advantage because binning averages are made after the data are read-out, not on the chip beforehand as with a CCD. On the other hand, CMOS has better read noise to compensate.

Tom Alderweireldt
Schilde, Belgium

Sean Walker replies: *CMOS binning occurs after the sensor is read out and thus simply doubles the read noise. But it is very low in the first place. There's not as big a gain compared to CCDs, but it's still useful for over-sampled systems. Here is an article one manufacturer published on the matter:* ***https://is.gd/Binning***.

Blast From the Past

As I perused my February issue, I did a double-take when I saw the cover from 50 years ago showing Nicolaus Copernicus, in Roger Sinnott's 75, 50 & 25 Years Ago (*S&T:* Feb. 2023, p. 7). The February 1973 issue was the first issue I received as a new subscriber when I was 13 years old. Back then, I was observing with a 2.4-inch Unitron refractor. Now my primary telescope is a 17.5-inch Dobsonian. I still have that original issue — and the 2.4-inch Unitron! Thank you for your wonderful magazine, which has been part of my exploration of the cosmos for the past half century.

David Hasenauer
Monrovia, California

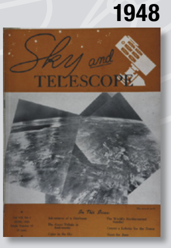
FOR THE RECORD

- In "What Is Opposition?" (*S&T:* Mar. 2023, p. 72), the interior planets achieve eastern elongation as they catch up with us in our orbit, and western elongation occurs after each has passed us by.
- In "Comet Prospects for 2023" (*S&T:* Feb. 2023, p. 48), 1.9 astronomical units is equal to 280 million kilometers and 180 million miles.

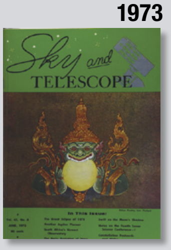
SUBMISSIONS: Write to *Sky & Telescope*, 1374 Massachusetts Ave., 4th Floor, Cambridge, MA 02138, USA, or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1948



1973



1998

June 1948

Compound Reflectors "Another combination of conic curves has lately received notice among amateurs. It consists of an ellipsoidal primary mirror and a spherical secondary. The favorable qualities of this combination, such as its relative simplicity of manufacture, were recognized and advocated some years ago by [Horace E.] Dall, who made several telescopes of that design. A few years later, Alan R. Kirkham published formulas for computing the aberration of the spherical secondary . . .

"Albert G. Ingalls [of *Scientific American*] has proposed the name 'Dall-Kirkham' for this telescope, as a merited and more dignified one than the misnomer 'modified Cass.'"

Allyn J. Thompson, author of Sky Publishing's Making Your Own Telescope*, had just begun a series of articles on Cassegrain-type reflectors. Unfortunately, Thompson's sequel has never been released.*

June 1973

Old Eclipse Site "A few years ago, on a short spring vacation, my family and I set out to find Separation, [Wyoming,] to see what remained of a day 90 years past. In the hope of finding the stone telescope piers, we carried with our camping equipment the Naval Observatory volume on the eclipse, . . . which contains Sampson's and Newcomb's description of their site. . . .

"An 1882 map showed us roughly where the town and the original railbed had been . . . For a day or so we searched along this desolate road, looking in particular for the semicircular sand dune, which had given protection to Sampson and Newcomb. [We] were just about to give up when my wife Marjorie found a small and unusual stone [that was] soft, like old mortar. Perhaps the piers lay buried beneath us . . ."

The excitement of reading about that 1878 eclipse, and John A. Eddy's successful hunt for the expedition site, has never left me.

June 1998

Asteroid Impact? "On March 11th, Brian Marsden (Central Bureau for Astronomical Telegrams) announced what seemed like the scariest [potentially hazardous object] yet — a 19th-magnitude asteroid designated 1997 XF_{11}. It had been discovered last December . . . He found that it would pass a scant 40,000 kilometers above Earth's surface on October 26, 2028. This was deep within the orbit's estimated margin of error of about 180,000 km!

"[The] issue became moot within one day of the [announcement when prediscovery images greatly reduced the chance of an impact.]"

As Stuart Goldman explained, this whiplash news was a public-relations nightmare for astronomy. It sparked big changes in how alarming discoveries were handled. Nowadays, for example, NASA's Sentry risk page at ***https://cneos.jpl.nasa.gov/sentry/*** *gives up-to-date details on all known hazardous minor planets.*

SOLAR SYSTEM

Amateurs Use Occultations to Monitor Asteroid Impact

▲ This image, taken from 920 km (570 mi) away, shows the asteroid Didymos (bottom right) and its moonlet, Dimorphos, about 2.5 minutes before the impact of NASA's DART spacecraft.

AMATEUR ASTRONOMERS around the globe have chased down the shadows of the Didymos-Dimorphos asteroid system as it passed in front of, or *occulted*, distant stars, thereby helping scientists evaluate the effects of NASA's Double Asteroid Redirection Test.

The DART mission intentionally ran into Dimorphos, the moon of near-Earth asteroid 65803 Didymos, on September 26, 2022 (*S&T:* Jan. 2023, p. 8). The collision was designed to test planetary-defense strategies by changing the moonlet's orbit.

The DART team has measured the change in Dimorphos' orbit around Didymos using ground- and space-based telescopes. But stellar occultations enable measurements not yet possible by other means.

One of the groups following up on the impact is a French-Greek collaboration known as the Asteroid Collaborative Research via Occultation Systematic Survey (ACROSS), initiated with the support of the European Space Agency (ESA). ACROSS ties together the professional and amateur communities in the hunt for stellar occultations by the Didymos system. While professionals predict when and where to observe, volunteers across continents conduct most of the observations. Every time this asteroid system blocks a background star, observers gather to watch — sometimes traveling hundreds of kilometers to the narrow path of the pair's shadow. Their data help trace the shadow and pin down the asteroids' orbits.

Calculating the path along which the asteroids' shadow falls can be tricky. Sometimes amateurs see nothing at all. Bad weather and orbital uncertainties plagued early attempts, starting in mid-June last year. Such misses can serve to rework the orbital model.

Soon after the DART impact, Didymos began crossing the Milky Way's galactic plane, which meant it was passing in front of many brighter stars. Observers used mobile stations to successfully record 19 occultations between October 15, 2022, and January 21, 2023, with multiple detections for most of these events. In three of these, observers even detected Dimorphos, which spans only 160 meters (520 feet), making it the smallest object observed during an occultation.

The background stars involved ranged from magnitude 9 to 13.5, visible to telescopes between 4.5 and 14 inches in aperture. In each case, the background star blinked out for less than half a second; observers used high-speed cameras and GPS to accurately time the disappearances.

ACROSS observations have enabled a measurement of the impact's effect on the system's orbit around the Sun, a valuable constraint for ESA's Hera mission, which will rendezvous with the asteroid system in 2026. The team found that the impact changed Didymos' velocity by 1 to 3 meters per day.

As the first occultation season has come to an end, the ACROSS team, led by Paolo Tanga (Observatory of Côte d'Azur, France) and Kleomenis Tsiganis (Aristotle University of Thessaloniki, Greece), is now preparing for the next one, which starts in April 2024.

■ **DAMYA SOUAMI**

SOLAR SYSTEM

A Dozen More Moons for Jupiter

THE BIGGEST PLANET in the solar system now has the largest family of moons. The International Astronomical Union's Minor Planet Center has published orbits for 12 previously unreported moons of Jupiter, based on observations from Scott Sheppard (Carnegie Institution for Science).

The newest additions bring the list of Jovian moons to 92, a hefty 15% increase from the previous tally of 80. The new finds put Jupiter's lunar family well ahead of Saturn's 83 confirmed moons, at least for now.

All the new moons are small and far out, taking more than 250 days to orbit Jupiter. Nine of the 12 are among the 71 outermost Jovian moons. Jupiter probably captured these moons, as evidenced by their *retrograde* orbits.

Three of the new moons are among 13 others that orbit Jupiter in a *prograde* direction, between the orbits of the large, close-in Galilean moons and the far-out retrograde moons. The new discoveries add to two known prograde groups: Two additions go to the Himalia group between 11 and 12 million km from Jupiter, and one to the more distant Carpo group at 17 million km.

But searches for prograde moons outside these groups turned up nothing. In the yawning gap between the Galilean moons and the Himalia group, there's only one moon, and it's already known: the 9-kilometer Themisto. "We have searched very deeply for objects near Themisto and have found nothing else to date," says Sheppard. He says glare from Jupiter is strong enough to hide anything smaller than 3 km across.

Stay tuned for more, as Sheppard still has observations awaiting approval.

■ **JEFF HECHT**

DIDYMOS ASTEROID SYSTEM: NASA / JOHNS HOPKINS APL

SOLAR SYSTEM

An Unexpected Ring Around Quaoar

THE DISTANT DWARF PLANET 50000 Quaoar appears to have a ring that spans far beyond where it ought to be stable.

"That is not where it was supposed to be," says Bruno Morgado (Federal University of Rio de Janeiro, Brazil), who led a team of 59 astronomers in reporting the discovery in the February 9th *Nature*.

Inside the theoretical *Roche limit*, a world's tidal forces exceed the gravitational force holding together any would-be moon, pulling material apart into a ring instead. Outside that limit, though, any dust particles or debris ought to coalesce under their own gravity — either that, or drift away over time.

The Roche limit has served as a good rule of thumb in the solar system. Most rings around planets, and even around dwarf planets such as 136108 Haumea and 10199 Chariklo, lie close to or within the Roche limit.

But the ring around Quaoar breaks that rule. The material orbits 4,100 kilometers (2,500 miles) out, far beyond the world's Roche limit of 1,780 km.

Morgado's team observed *stellar occultations*, in which Quaoar passed in front of a distant star and momentarily blocked its light. After finding hints of a ring, the researchers went back through previous occultation records, including those obtained by amateur astronomers Jonathan Bradshaw, Renato Langersek, and John Broughton, who had detected the ring in August 2021.

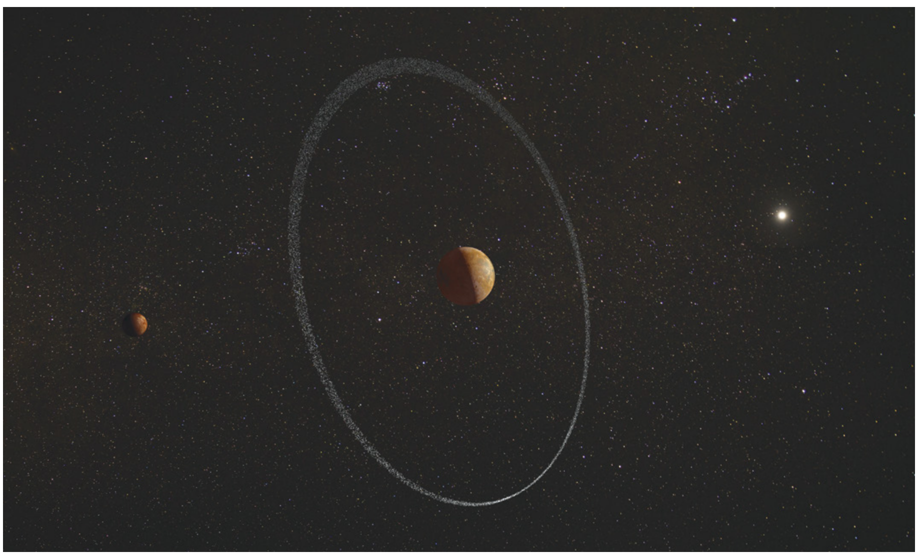
"We saw the ring in nine different regions from observations taken between 2018 and 2021," Morgado summarizes.

The ring is irregular, spanning just 5 km in some parts and wider than 300 km in others. If its material were collected into a moon, it would be about 10 km in diameter — less than a tenth the size of Quaoar's moon, Weywot.

A few thin, lightweight rings exist beyond the Roche limit elsewhere in the solar system — like the tenuous rings beyond Saturn's F ring — but nothing so massive as the ring around Quaoar.

Amanda Sickafoose (Planetary Science Institute), who wasn't involved with the study, notes that the team hasn't yet demonstrated a full ring system. Nevertheless, she calls the find "intriguing," adding that it "calls into question our basic understanding of how ring systems form and evolve."

■ JEFF HECHT



▲ An artist's impression of the ring around dwarf planet Quaoar. Quaoar's moon Weywot is at left and the distant Sun at right. (Note that the nine occultations observed showed only pieces of this ring, which appears to vary greatly in width.)

IN BRIEF

Amateur Discovers Dwarfs

In 2020, amateur astronomer Giuseppe Donatiello was poring over images made public by the Dark Energy Survey (DES), which had recorded the southern sky from Chile. Amid the smattering of stars, gas, and dust, he noticed three new satellites near the Sculptor Galaxy (NGC 253). Dwarf-size and spheroidal in shape, they had been overlooked by the algorithm set up to spot them. The dwarf galaxies were dubbed Donatiello II, III and IV. A previous quest to photograph the satellites of the Andromeda Galaxy (M31) had already led Giuseppe to unearth Donatiello I. Including two others in the Local Group, his total count is now six. A paper detailing the newest discoveries was published in collaboration with David Martínez-Delgado (Institute of Astrophysics of Andalusia, Spain) and others in 2021. More recently, a different team headed up by Burçin Mutlu-Pakdil (University of Chicago), also in search of satellites of NGC 253, used the Hubble Space Telescope to obtain images of a number of them. Among them was Donatiello II, now independently corroborated. Hubble, with its precise distance measurements, was moreover able to conclusively demonstrate Donatiello II's association with NGC 253.

■ KIT GILCHRIST

Read more: https://is.gd/Donatiello.

Asteroid Adventure

On February 12th, astronomers detected a 1-meter (3-foot) asteroid roughly 7 hours before it impacted Earth's atmosphere. Astronomer Krisztián Sárneczky spotted the asteroid, now known as 2023 CX_1, as he was working at the GINOP KHK observatory in Hungary. Observatories in Croatia and Italy confirmed the detection and pinned down the orbit, determining that 2023 CX_1 would head for a terminal point off the northern coast of France. Observers across Europe tracked the rock until it flamed harmlessly over the English Channel. Afterward, the Vigie-Ciel group of the Fireball Recovery and Interplanetary Observation Network (FRIPON) scoured the strewn field in Normandy, France; 18-year-old art student Loïs Leblanc spied the first fragment in a field near Saint-Pierre-le-Viger. The palm-size, 100-gram (3.5-ounce) stone represents the third recovery of fragments of an asteroid that was discovered before impact. Additional fragments have since been found.

■ DAVID DICKINSON

BLACK HOLES

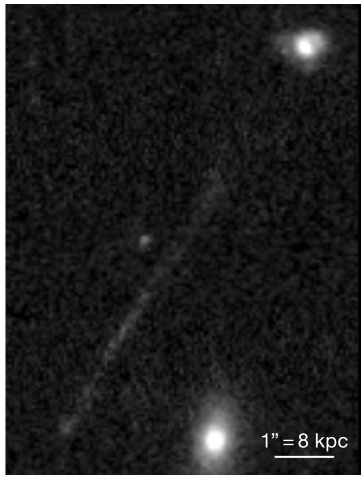
Have Scientists Found a Rogue Supermassive Black Hole?

SCIENTISTS MIGHT HAVE spotted a runaway supermassive black hole, according to a study of Hubble Space Telescope images that will appear in the *Astrophysical Journal Letters*.

In this image, Pieter van Dokkum (Yale) and colleagues noticed a narrow streak of light 200,000 light-years long that appears to be emerging from a small, star-forming galaxy. At first glance, the feature resembles a black hole–powered jet. But unlike a jet, the light shows clear signatures of starlight rather than plasma. And the trail's shape is also the opposite of what's expected: pencil-sharp at the tip and somewhat wider close to the galaxy.

The team suggests that a runaway black hole is racing through the gas surrounding its galaxy at some 1,600 kilometers per second (3.6 million mph). The black hole's passage shocks the gas, prompting star formation in its wake.

"It's really quite uncanny how similar it looks like our pictures," says Marta Volonteri (Institute of Astrophysics of Paris), whose team has studied simulated collisions of supermassive black holes and predicted similar trails. (Volonteri wasn't involved in the new study.)



◀ A narrow streak of light appears to emerge from a small galaxy (upper right). The streak is broader toward the galaxy and narrower at the tip.

Intriguingly, closer scrutiny revealed a second, much fainter trail on the opposite side of the galaxy. Again, the bipolar jets from black holes come to mind as an obvious explanation, but according to the team, the evidence argues against it.

Instead, the team suggest that the galaxy might once have harbored three black holes, the result of a recent galactic collision (evidenced by the galaxy's irregular shape and enthusiastic star-birth). As the galaxies came together, so too did their central black holes. The lightest of the three was ejected to create the bright trail, while the other two merged before being kicked out in the opposite direction with somewhat lower velocity. This ejection scenario would also explain why the galaxy doesn't host an active nucleus — because any supermassive black hole(s) at the center have left.

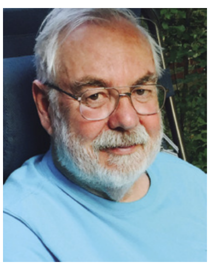
It's too early, though, to claim the discovery of a runaway supermassive black hole. The team is working on obtaining X-ray observations, which could give smoking-gun evidence of a black hole at the tip of the trail of stars.

■ **JURE JAPELJ**

OBITUARY

Terence Dickinson (1943–2023)

CANADIAN ASTRONOMER and author of numerous popular books on astronomy Terence Dickinson passed away February 1, 2023, at age 79, after a long battle with Parkinson's. He is survived by his wife, Susan Dickinson, and his sister, Dianne Dickinson.



Terence's interest in astronomy began when he was only five years old, when he saw his first shooting star. His professional career took off in 1968 when he joined the staff at the McLaughlin Planetarium in Toronto. In 1970, he became assistant director of the Strasenburgh Planetarium in Rochester, New York.

Terence served as contributing editor and later executive editor of the then-new *Astronomy* magazine from 1973 to 1975. Then, from 1995 until 2016, he was co-owner and editor of *SkyNews*, Canada's magazine of stargazing.

Terence is perhaps best known in the amateur astronomy world as the author of *NightWatch: A Practical Guide to Viewing the Universe*, which has been in print for 40 years. Terence authored many other popular books, among them *The Universe and Beyond* and *Hubble's Universe: Greatest Discoveries and Latest Images*. Most recently, he coauthored *The Backyard Astronomer's Guide*.

From 1981 until 2004, Terence wrote a weekly astronomy column for *The Toronto Star*. Terence also appeared frequently on the radio and TV, including the Canadian Discovery Channel.

Among his numerous awards are the New York Academy of Sciences' Children's Book of the Year (1988), the Royal Canadian Institute's Sandford Fleming Medal (1992), and the Astronomical Society of the Pacific's Klumpke-Roberts Award (1996). He was the recipient of honorary doctorates from Trent University and Queen's University. In 1995, he was invested as a Member of the Order of Canada for his contributions to public outreach.

The asteroid 5272 Dickinson is named in his honor.

Terence Dickinson's ability to explain the universe gained him a huge international audience, inspiring thousands of people. "Terry was also a mentor to many of us in the astronomy-writing world," says *S&T* Consulting Editor Gary Seronik. "He gave me my first big break and through example showed me how to convey the wonders of the night sky in an engaging and friendly style."

Terence once said, "I want to do what I'm doing for as long as I can. . . . I'll never run out of things to write about — I'll just run out of time."

■ **ALAN DYER**

HUBBLE IMAGE OF GALAXY AND STREAK OF STARS: VAN DOKKUM ET AL. / *ASTROPHYSICAL JOURNAL LETTERS* 2023; DICKINSON: SUSAN DICKINSON

COSMOLOGY

The Universe Is Too Smooth by Half

RESULTS FROM A COMPLEX new analysis support cosmologists' suspicions that something is missing from our understanding of the universe.

For the most part, our standard theory of cosmology fits observations like a glove. With just a handful of ingredients, scientists can explain the patchiness of the *cosmic microwave background* (CMB) — the relic radiation from the universe's primordial age — and how the nearly uniform soup it came from transformed into the Swiss cheese of galaxy clusters and voids we see today.

But some nagging problems remain. The most touted is the Hubble tension (*S&T:* Mar. 2022, p. 14). But there's another, more subtle discrepancy: Today's universe is too smooth.

The CMB's patchiness reveals how lumpy the primordial soup was. Those little lumps grew into big ones, the biggest of which became galaxy clusters. Yet a decade's worth of studies have shown we only see half as many big galaxy clusters as cosmologists predict.

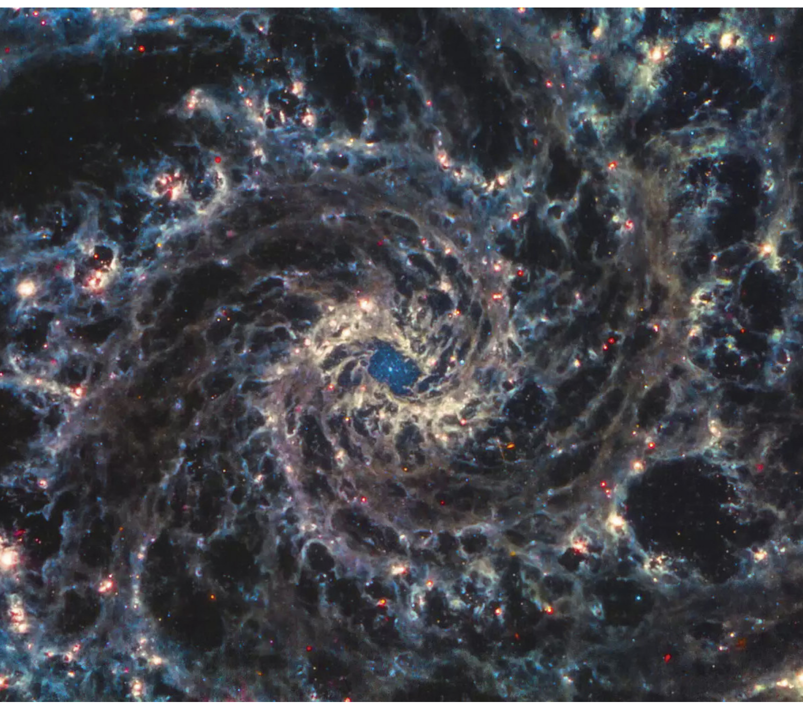
A new analysis, reported January 31st in three papers in *Physical Review D*, continues the trend. More than 150 scientists from the Dark Energy Survey (DES) and South Pole Telescope (SPT) collaborations joined forces in the work, adding data from the Planck spacecraft to study large-scale cosmic structure in a large section of sky.

Fornax galaxy cluster

The three instruments observe the universe in distinct ways: DES has imaged hundreds of millions of galaxies and other objects, while SPT and Planck have mapped the CMB. The researchers examined the gravitational-lensing distortions that intervening matter creates in the images of galaxies as well as in the CMB itself. The comparison gives scientists a unique look at the distribution of matter over the past 8 or 9 billion years. The discrepancy remains, albeit weakly.

Across all studies, there's a 1% to 15% chance the result is a fluke. The clumpiness tension is less pronounced than the Hubble tension, which has a flukiness potential much smaller than 1%. However, scientists haven't tracked down any errors in the measurements that can easily explain the lack of lumps. Furthermore, fixing the clumpiness parameter tends to exacerbate the Hubble tension, and vice versa. Accommodating both tensions within the cosmological model will be difficult.

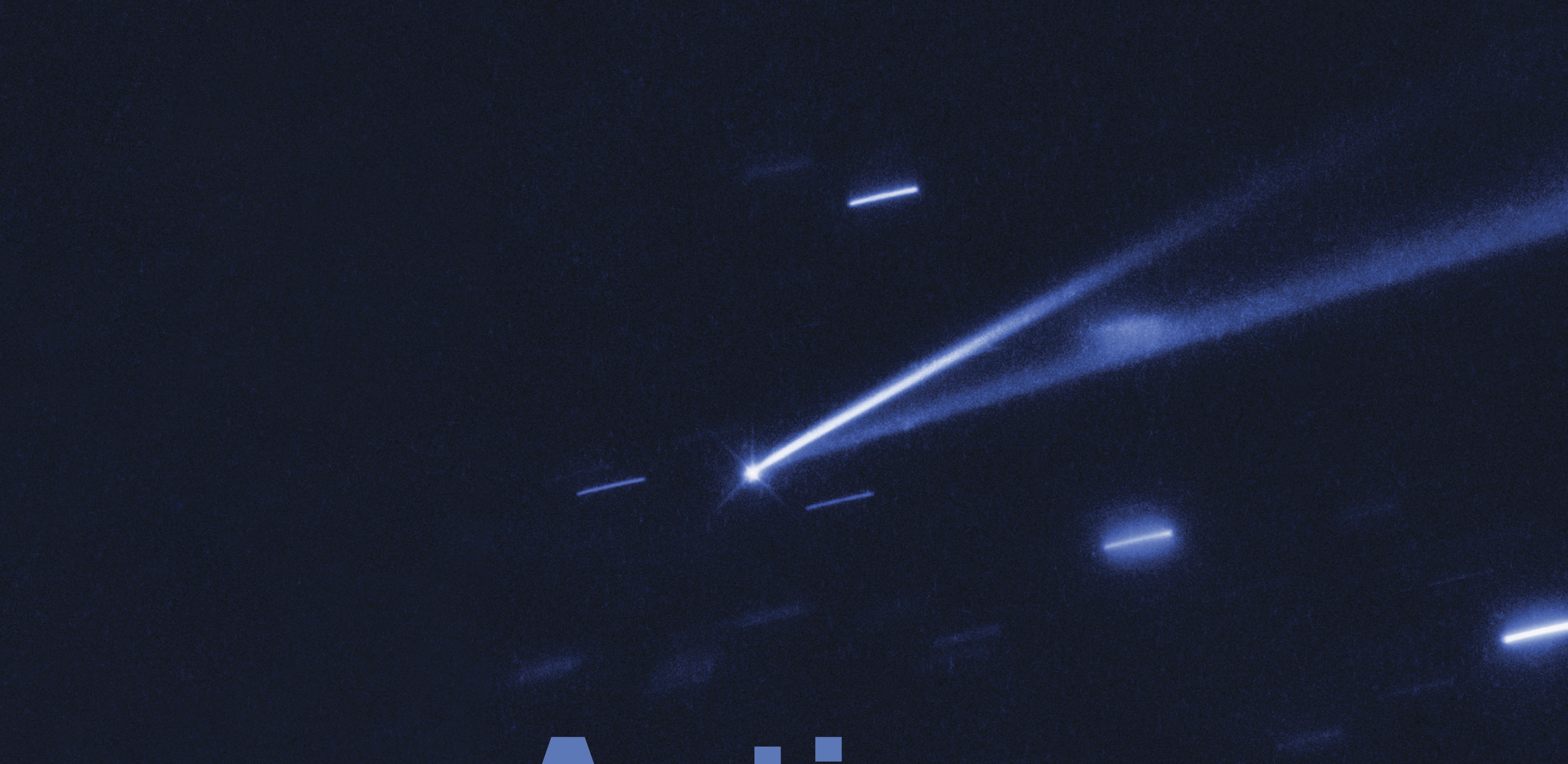
■ CAMILLE M. CARLISLE



Stars Shape Their Galaxies

An ambitious project to image the face of 19 stunning spiral galaxies is well underway. A special issue of the *Astrophysical Journal Letters* presents dramatic James Webb Space Telescope observations of four of these spirals: NGC 1365, NGC 7496, NGC 628 (M74; shown at left), and IC 5332. In these images, Webb showcases stellar embryos nested in an intricate jumble of filaments, shells, and bubbles. These structures are testament to the impact of previous generations of stars. The new images join an already immense — and still-growing — dataset known as the Physics at High Angular resolution in Nearby Galaxies (PHANGS) program. PHANGS operates across several major observatories, including the Atacama Large Millimeter/submillimeter Array, the Hubble Space Telescope, and the Multi Unit Spectroscopic Explorer on the Very Large Telescope. Webb observations have become a crucial piece of this story, enabling astronomers to examine star formation on scales from tens to hundreds of light-years. There's much more to come, as Webb is due to finish imaging all 19 galaxies by mid-2023.

■ MONICA YOUNG



Active Asteroids

Dozens of worldlets in asteroid-like orbits spout comet-like tails, challenging our understanding of small bodies in the solar system.

What's the difference between a comet and an asteroid? This seems like a simple question. Comets are familiar to most people as celestial objects with a fuzzy head and often one or more long, sweeping tails — features that astronomers collectively describe as "activity." Even those who have never seen a comet with their own eyes have probably seen this activity in glossy photos of comets in magazines like the one you are reading right now, or in depictions in popular media and apocalyptic movies.

In 1950, Fred Whipple described comets as "dirty snowballs," referring to the mixture of icy and non-icy material that makes them up — which still largely captures how astronomers view comets today. This view naturally and intuitively explains the "active" appearance of comets, which arises when, as the comet emerges from the cold outer solar system and approaches the Sun, ice in the nucleus (the "head") heats up and transforms into gas. This direct transition from ice to gas, called *sublimation*, can create geyser-like outflows that drag dust off the nucleus, forming different kinds of tails.

In contrast, asteroids are for the most part decidedly un-comet-like. Being mostly rocky or metallic and primarily found in the main belt between the orbits of Mars and Jupiter, astronomers long thought that asteroids orbit too close to the Sun to carry the ice that powers sublimation-fueled outbursts. They should therefore be inert — perpetu-

NASA / ESA / K. MEECH AND J. KLEYNA (UNIVERSITY OF HAWAI'I) / O. HAINAUT (ESO)

Rarities

Up to 2 million asteroids circle the Sun in the main belt of the solar system. Only 40 or so of these are currently known to be "active."

ally lifeless rocks or inactive rubble piles.

But the solar system, it turns out, is not so black-and-white. We now realize that asteroids can behave like comets and vice versa. What we thought were two kinds of bodies are in fact part of a single, sprawling family, their properties not always falling neatly into traditional asteroidal and cometary boxes.

Comets in the Main Belt

The classical view of asteroids as inert bodies and comets as active bodies rests on the presumption that activity requires ice, and asteroids don't have it. This presumption is tied to other long-held notions, such as that comets originate in the cold outer solar system beyond the orbit of Neptune — explaining their icy content and elongated orbits — while asteroids were formed where we see them today, at the distance of the present-day main belt. Here, it was too warm during the solar system's formation for significant amounts of icy particles to survive and be swept up into growing planetesimals (*S&T:* May 2020, p. 34).

▲ **COMING APART** The tiny asteroid 6478 Gault is spinning itself into pieces. The Hubble Space Telescope spotted tails from two separate dust-emitting events in October and December 2018. The longer of the two ensuing tails is roughly 4,800 km wide and stretches more than 800,000 kilometers (500,000 miles) — more than twice the distance between Earth and the Moon.

To be fair, this basic picture has for many years given us a reasonable working framework for understanding the properties of our solar system. Recently, however, ongoing advancements in telescope technology, wide-field surveys, computing power, and theoretical work have revealed exceptions to these rules, forcing us to revisit our assumptions and better understand their limitations.

For example, we now know that visible comet-like activity from a small solar system body might be produced by one or more of a multitude of mechanisms, not just sublimation. We have also learned that main-belt asteroids may not be ice-free as once believed, thanks to detections of possible surface ice and outgassing as well as theoretical work showing that near-surface ice might survive longer than previously thought. Even assumptions about an object's origin based on its orbit have had to change over time, as simulations now show that objects on asteroid-like paths can evolve onto comet-like ones, and vice versa.

One particularly intriguing population is the *active asteroids*. These objects have asteroid-like orbits but display comet-like dust clouds and tails. The modern era of active-asteroid research began in 1996, when Eric Elst and Guido Pizarro discovered the mysterious Comet 133P/Elst-Pizarro. Though originally known as an asteroid, the object appeared in new photos like a comet with a long dust tail. That would normally suggest that it contained near-surface ice. However, it orbits entirely within the main asteroid belt. There, temperatures should be too warm for ice to survive over the billions of years that we think this main-belt asteroid spent there.

Researchers considered alternate explanations to sublimation, but none really fits the observations. An impact from another asteroid, for example, could conceivably kick up enough material to form the dust tail. If this were true, though, one would expect the dust to be ejected in a single, short burst at the moment of impact. But computer simulations showed that the dust was ejected over a period of at least two months. This result is difficult for an impact to explain but is common for sublimation-driven activity in other comets.

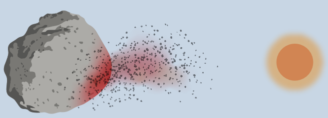
Further support for a sublimation-driven tail came from observations taken in 2002, which showed that the object had once again become active. On both occasions, the flare-ups occurred close in time to Elst-Pizarro's perihelion.

Portents

Comets appear in Chinese records as early as the 11th century BC — when they were known as "broom stars" — and also famously in the Bayeux Tapestry, where Halley's Comet foretells doom for England's King Harold II in 1066.

What Makes Asteroids Active

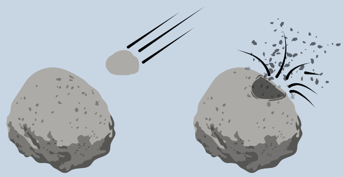
SUBLIMATION



HOW IT WORKS
Sublimation of near-surface ice during times of sufficiently high solar heating releases gas that drags away dust. The ice involved must be water ice, because other ices evaporate more easily and therefore are less likely to have survived to the present day.

WHAT WE SEE
- Prolonged dust emission
- Repeated activity near perihelion

IMPACTS



HOW IT WORKS
Impact of a smaller asteroid releases debris.

WHAT WE SEE
- Short-duration dust emission
- Activity can occur at any point along an object's orbit
- One-time active events for individual objects

ROTATIONAL DESTABILIZATION

HOW IT WORKS
An object rotates so quickly that gravity and internal structural forces can no longer counteract centrifugal forces.

WHAT WE SEE
- Short-duration dust emission (sometimes)
- Fast rotation
- Activity can occur at any point along an object's orbit
- Individual objects can have one-time active events or repeated activity

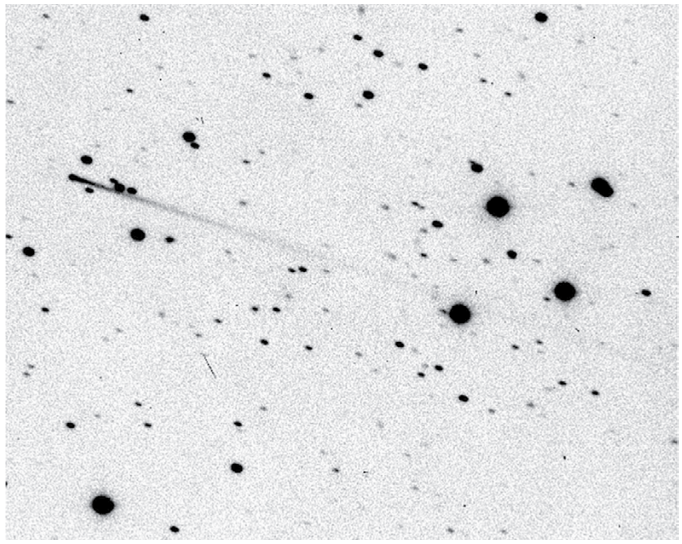
ASTEROID ILLUSTRATIONS: BEATRIZ INGLESSIS / *S&T*; SOURCE: HENRY HSIEH

Observations of repeated activity near perihelion clinched the sublimation argument, since this is exactly what we see in “normal” comets: Every time they approach the Sun, they become active, and when they move away, activity stops.

Since 2002, observers have found several more bodies in the asteroid belt that appear to show sublimation-powered activity. We now call these objects *main-belt comets*. As in Elst-Pizarro’s case, dust-emission events from these new comets last from weeks to months. In many cases, emission recurs near perihelion. Both of these are indications of sublimation. To date, researchers have identified 15 main-belt comets, and we expect this number to climb in the future. The currently known main-belt comets may be just the tip of the proverbial iceberg.

Disrupted Asteroids

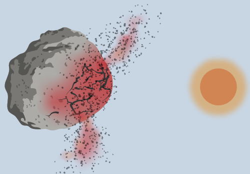
By 2010, main-belt comets were becoming better established as a new type of comet. But then something strange happened. In January and December of that year, respectively, astronomers found two additional active main-belt objects — the newly discovered 354P/LINEAR and the known main-belt asteroid 596 Scheila — that were different from the main-belt comets found before them. Besides just looking visually unusual compared to other comets, the objects had dust tails produced by short bursts of emission rather than extended outbursts. These short-lived eruptions indicated that the objects’ dust tails probably resulted not from sublimation but instead from debris ejected by impacts with other asteroids.



▲ **ASTEROID WITH A TAIL** A narrow dust tail pointing away from the direction of the Sun appeared in images taken at La Silla Observatory in 1996. Despite its cometary appearance, the object, now known as 133P/Elst-Pizarro, had an asteroid-like orbit in the outer part of the main belt.

Then in 2013, in yet another twist, astronomers discovered an active main-belt asteroid whose activity did not appear to be due to either sublimation or an impact event. Now called 311P/PanSTARRS, the object displayed at least six distinct

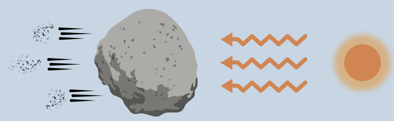
THERMAL DECOMPOSITION AND FRACTURING



HOW IT WORKS
Sunbaking might break apart hydrated minerals, and/or different parts of the surface expanding at different rates could fracture surface material.

WHAT WE SEE
- Mass loss during extremely high-temperature portions of an object’s orbit
- Mainly applicable to near-Earth objects

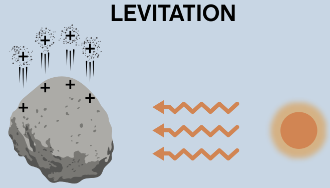
RADIATION-PRESSURE SWEEPING



HOW IT WORKS
Radiation pressure from solar photons accelerates dust particles already lifted from the surface by other means.

WHAT WE SEE
- Not thought to be a primary driver of activity but may enhance mass loss driven by other mechanisms, particularly for small asteroids close to the Sun

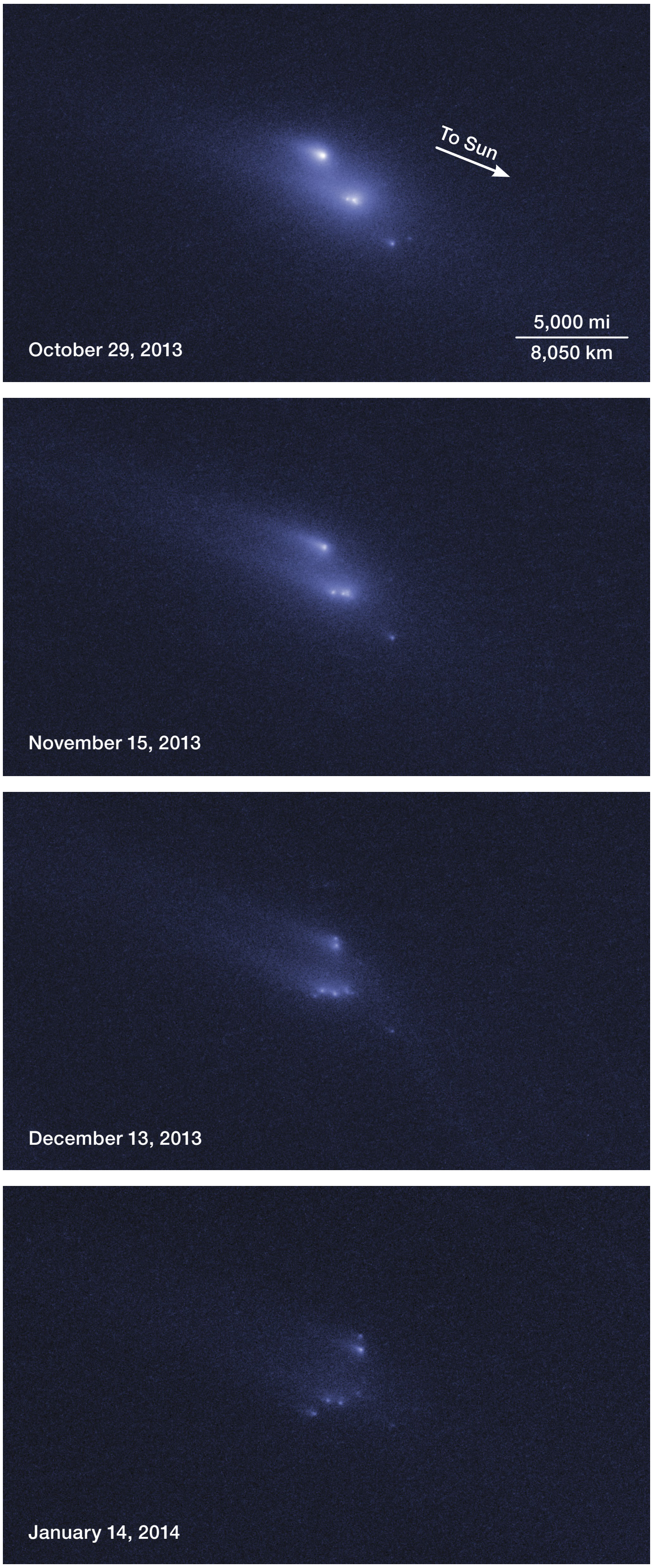
ELECTROSTATIC DUST LEVITATION



HOW IT WORKS
Solar radiation positively charges the asteroid exterior, mobilizing dust particles — also positively charged — above the surface. Apollo astronauts saw this on the Moon.

WHAT WE SEE
- Not thought to be a primary driver of activity but might work together with other mechanisms, such as radiation-pressure sweeping

ESO



▲ **DISRUPTION** Some asteroids spin themselves apart. Starting in late 2013, the Hubble Space Telescope captured the breakup of P/2013 R3 over a period of several months. Fragments of the asteroid showed tails of dust, pushed back by the pressure of sunlight.

NASA / ESA / D. JEWITT (UCLA) (4)

dust tails, each corresponding to an individual mass-ejection event. Researchers eventually determined that the asteroid's rotation was responsible: The body was spinning so fast that gravity and internal structural forces could no longer counteract centrifugal forces trying to tear it apart, and material was flying off the surface into space.

Astronomers had previously predicted that *rotational destabilization* could cause mass loss — or even the destruction of entire asteroids — based on both theoretical work and the scarcity of rapidly rotating objects in the asteroid population. (Their scarcity implies that such objects are structurally unstable and may systematically destroy themselves, leaving few such objects for us to find.) Until the discovery of 311P/PanSTARRS, though, we'd never observed such events occurring in real time.

Importantly, neither an impact nor rotational disruption requires an asteroid to possess ice in order to display dust emission mimicking cometary activity. Therefore, objects experiencing these events became known as *disrupted asteroids*, to set them apart from main-belt comets. Scientists have since adopted the term *active asteroids* as an umbrella term to encompass both categories.

What Activates Asteroids?

Yet other mechanisms may contribute to activity (see illustrations on pages 14–15). In many cases, multiple processes may work in concert. Comet Elst-Pizarro is a good illustration of the possible interplay. Although observations demonstrate that sublimation is the driving force behind Elst-Pizarro's activity, a collision could have been the trigger, excavating the inert surface to expose subsurface ice to sunlight. Elst-Pizarro also rotates quickly, which could assist with the outflow of dust particles that outgassing alone might not have been able to launch with enough speed to escape the object's gravity.

Meanwhile, there exist some active asteroids whose activity mechanisms remain unknown. Near-Earth asteroid 3200 Phaethon is well-known as the source of the Geminid meteor shower. Meteor showers are usually caused by passing comets, which leave behind streams of dust particles that burn up in Earth's atmosphere when our planet passes through them. However, Phaethon has an asteroid-like orbit and appeared completely inactive for decades after its discovery — until astronomers finally detected a faint, comet-like tail in 2009, and again in 2012. Phaethon travels within Mercury's orbit, making extremely close approaches to the Sun. The very high temperatures it experiences should destroy any ice that once existed there, ruling out sublimation-driven activity. Yet Phaethon's activity near perihelia suggest that those repeated cycles of solar heating must somehow still be involved.

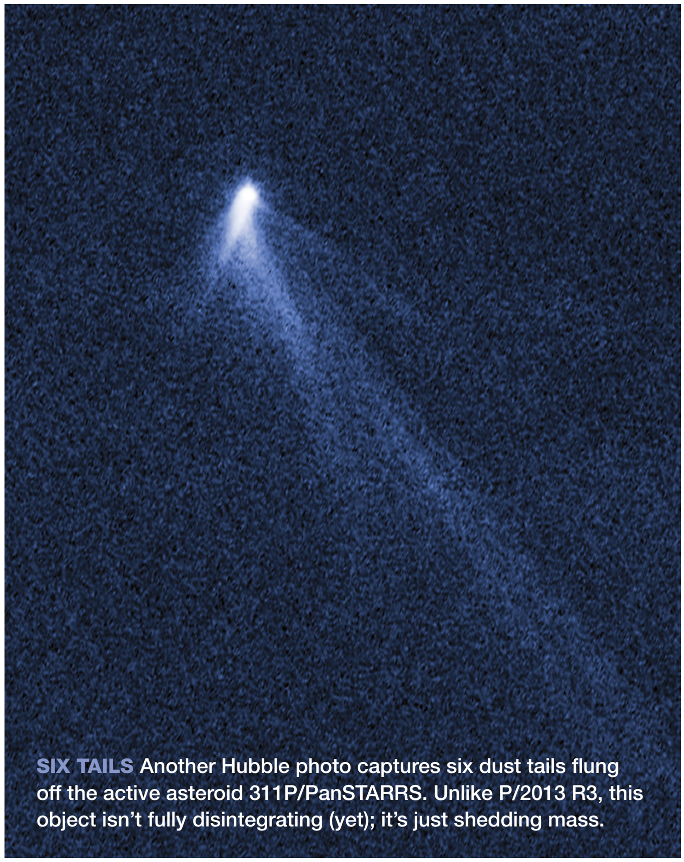
One current hypothesis is that Phaethon's activity could be produced when extreme heat chemically breaks apart minerals in its surface. The transformation could cause the surface to crack like sunbaked mud flats on Earth, releasing loose dust particles that are then swept away by centrifugal forces from Phaethon's fast rotation.

Interestingly, the near-Earth asteroid 101955 Bennu also actively ejects dust particles. The visiting OSIRIS-REX spacecraft discovered the outbursts in 2019 (*S&T:* May 2020, p. 20), even though extensive observations from the ground prior to the spacecraft encounter hadn't shown any hint of activity. Another sunbaking mechanism similar to thermal decomposition, called *thermal fracturing*, might help explain Bennu's activity; however, researchers haven't yet reached any definitive conclusions about any of the possible mechanisms, or about how frequently they might operate. There could be many of these "stealth" active asteroids that appear inactive when observed from Earth but active if viewed up close.

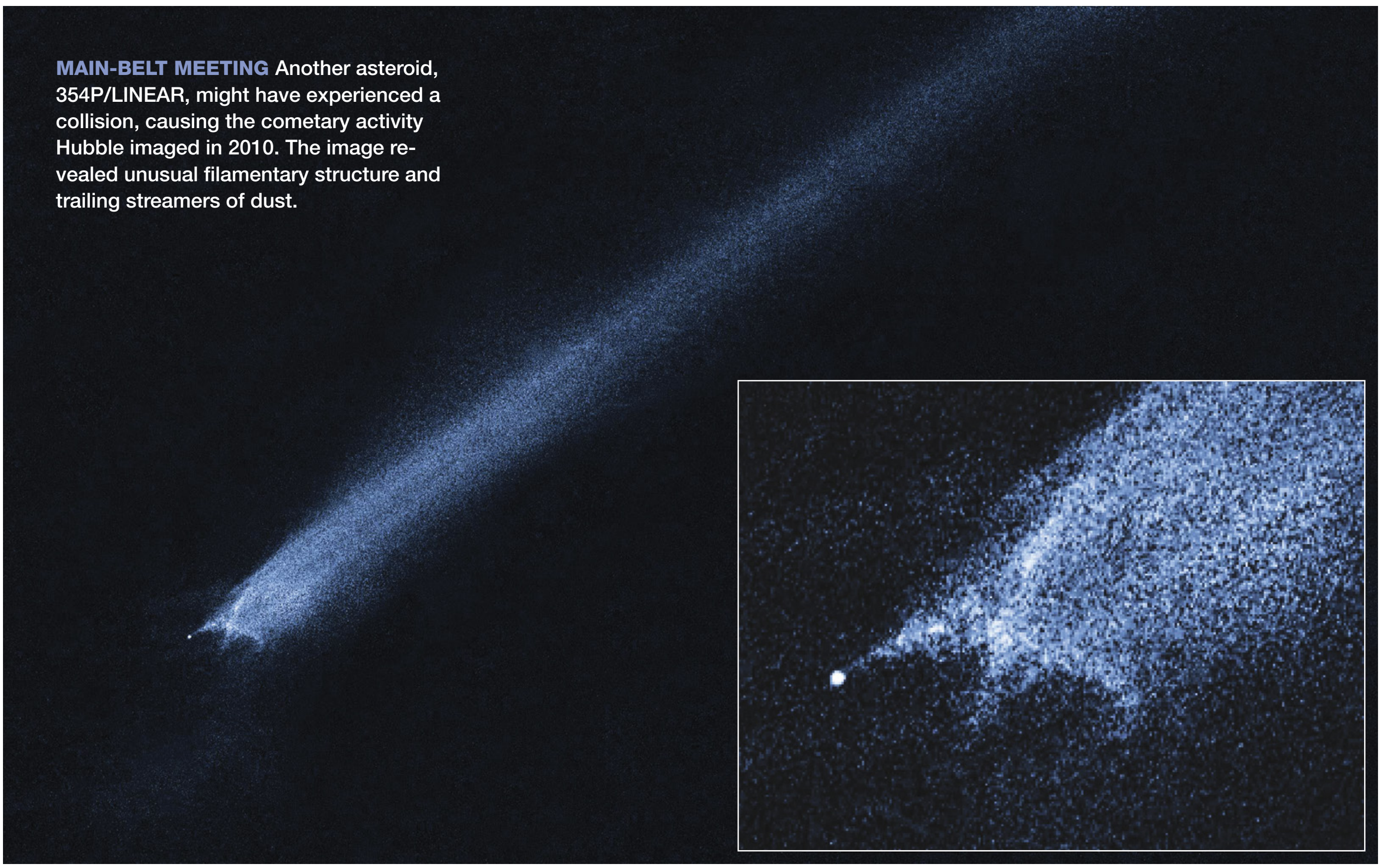
The Science of Active Asteroids

It's now clear that asteroids are far from being a boring collection of rocks quietly circling the Sun between the orbits of Mars and Jupiter. They are much more dynamic than astronomers realized even just 20 years ago. Moreover, these new discoveries are opening up opportunities for numerous new scientific investigations in a variety of areas.

For example, main-belt comets could play a key role in helping astronomers unravel the source of the water on Earth. Since Earth formed in the warm inner solar system, many have suggested that at least some of our present-day water — without which life on this planet could not exist — must have been delivered after Earth had already fully formed, perhaps by impacting asteroids, comets, or both



SIX TAILS Another Hubble photo captures six dust tails flung off the active asteroid 311P/PanSTARRS. Unlike P/2013 R3, this object isn't fully disintegrating (yet); it's just shedding mass.



MAIN-BELT MEETING Another asteroid, 354P/LINEAR, might have experienced a collision, causing the cometary activity Hubble imaged in 2010. The image revealed unusual filamentary structure and trailing streamers of dust.

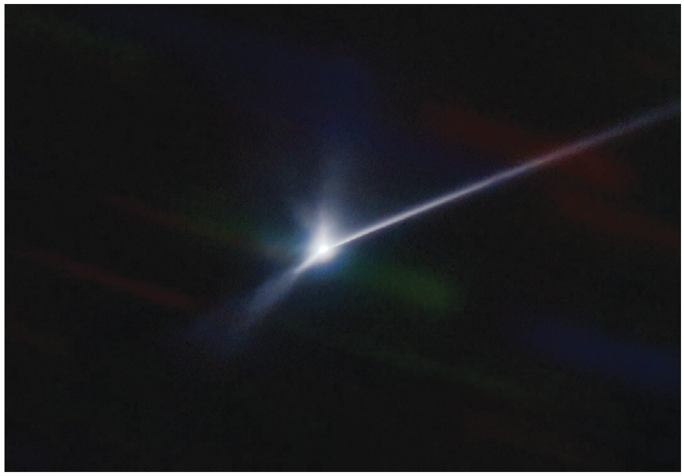
NASA / ESA / D. JEWITT (UCLA) (2)

(*S&T:* Mar. 2023, p. 34). Investigations of the detailed composition of main-belt comets, particularly of volatiles like water, could greatly advance our understanding of the origin of Earth's oceans and, by extension, life itself.

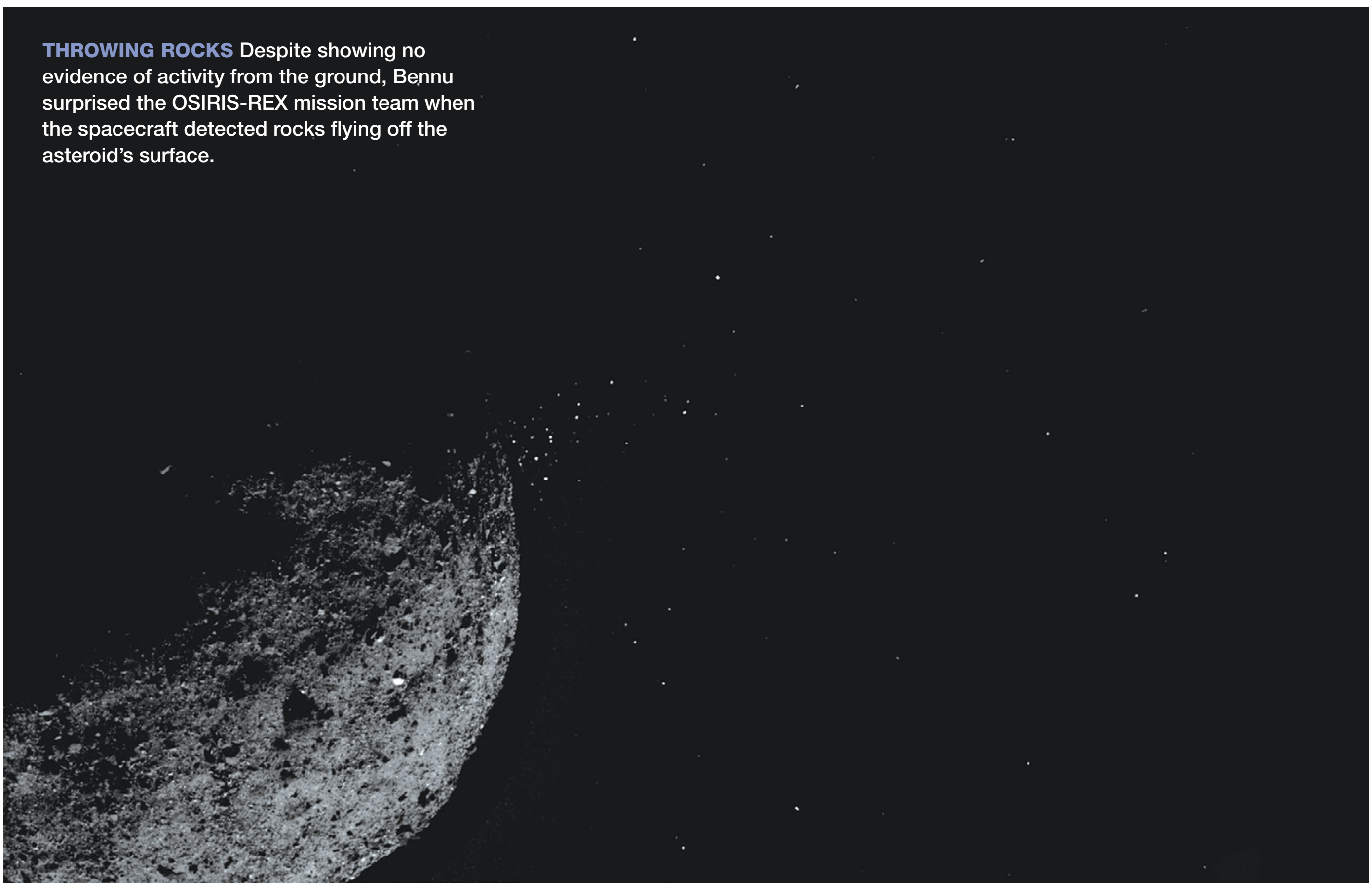
The existence of near-surface ice on main-belt comets also enables astronomers to refine computational models of these objects' heating history. Such models may eventually allow us to estimate the asteroid belt's current and primordial water content, with exciting implications for scientific efforts such as understanding the formative conditions of our solar system. This work is also exciting for its possible practical applications in areas like asteroid mining.

Meanwhile, real-time observational studies of disruption events have opened new windows on asteroids' material properties. The physics of impacts and of rotational-destabilization events both depend on a body's internal structure. Disrupted asteroids can thus teach us things about asteroid interiors that would be impossible for us to determine in any other way. Researchers can use computational analyses of these events, sometimes in combination with laboratory experiments, to ascertain the conditions of an impact event as well as the physical properties of both the impacting and impacted objects. Analogous analyses of spin-induced breakups can also help determine an asteroid's density, material strength, and other structural characteristics.

Earth-bound observers actually had a front-row seat to the artificial creation of an active asteroid on September 26, 2022, when NASA's Double Asteroid Redirection Test (DART) crashed into Dimorphos, the moon of the asteroid 65803 Didymos. The crash was an effort to test our asteroid-deflection capabilities in preparation for future impact threats to Earth, but it also had a bonus effect: The dust plume that the DART impact kicked up, clearly visible in images from



▲ **INTENTIONAL IMPACT** The collision of the DART spacecraft with the asteroid moon Dimorphos ejected vast, 10,000-km-long streams of dust and debris that became visible to ground-based telescopes.



THROWING ROCKS Despite showing no evidence of activity from the ground, Bennu surprised the OSIRIS-REX mission team when the spacecraft detected rocks flying off the asteroid's surface.

DART IMPACT DEBRIS: CTIO / NOIRLAB / SOAR / NSF / AURA / T. KARETA (LOWELL OBSERVATORY), M. KNIGHT (U.S. NAVAL ACADEMY); IMAGE PROCESSING: T. A. RECTOR (UNIVERSITY OF ALASKA, ANCHORAGE / NSF'S NOIRLAB), M. ZAMANI & D. DE MARTIN (NSF'S NOIRLAB); BENNU AND ROCKS: NASA / GODDARD / UNIVERSITY OF ARIZONA / LOCKHEED MARTIN ground-based telescopes, surprised perhaps even the most optimistic of observers. The ensuing social media frenzy showcased animations of the rapidly expanding and then dissipating dust cloud.

Detailed analyses of these ground-based observations are now being published. Given that many details of the impact are already known — because we caused it! — we are learning a lot about the asteroid's moon from the real-time observations of the impact and its aftermath.

These analyses will also help improve the tools astronomers use to analyze natural impacts, providing them an opportunity to "check their work" in a controlled situation with known parameters.

Looking Ahead

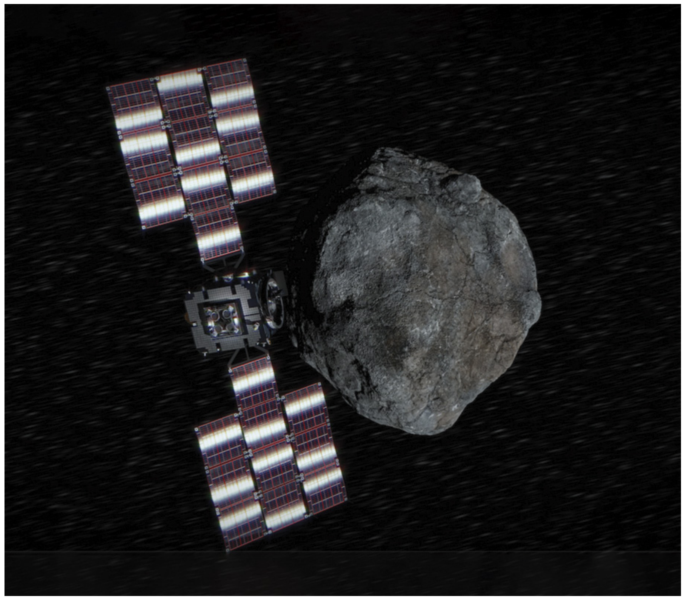
A key current limitation in active-asteroid science is the relatively small number of objects known: only 40. By discovering more main-belt comets, disrupted asteroids, and possibly other types of active asteroids we don't know about yet, we'll be able to better understand the range of properties that different kinds of events can have, and how those properties vary based on things like an asteroid's orbit, size, and composition.

Given the rarity of active asteroids and the unpredictability of their outbursts, the most productive method of discovering them is through the use of wide-field surveys. Such surveys repeatedly and systematically image the night sky in order to simultaneously serve a multitude of science cases. In order to find rare objects that are only active for short periods of time, we must observe as many objects as possible as frequently as possible, and this is the kind of data that such surveys provide.

While several wide-field surveys are currently operating, a single project known as Pan-STARRS, which began operating in 2010, has found the majority of currently known active asteroids. Pan-STARRS is expected to relinquish this crown soon, though, to the Vera C. Rubin Observatory's Legacy Survey of Space and Time when the latter begins operations in late 2024. Finding active objects with the Rubin Observatory will require automated software, because the massive amount of data the telescope will acquire on a nightly basis is far beyond what humans will be able to handle without assistance (*S&T:* Sept. 2016, p. 14).

NASA also plans to launch two space-based survey telescopes in the near future, the Near-Earth Object (NEO) Surveyor and the Nancy Grace Roman Space Telescope. Both spacecraft will observe at infrared wavelengths, making them sensitive to a different size range of dust particles than Rubin (which will observe at visible wavelengths). Combined, their efforts will cast a wider net in the search for active objects in the asteroid population.

Another key need is more detailed characterization of currently known active asteroids. The James Webb Space Telescope (JWST) should enable ground-breaking targeted studies of comet and asteroid compositions with its high-resolution cameras and sensitive spectroscopic instruments. In fact, JWST has already enabled astronomers for the first time to directly detect water vapor outgassing from a main-belt comet.



NAOYA OZAKI (JAXA)

▲ **DATE WITH DESTINY** The Japanese craft Destiny+ will rendezvous with Phaethon in 2028, as shown in this artist's illustration.

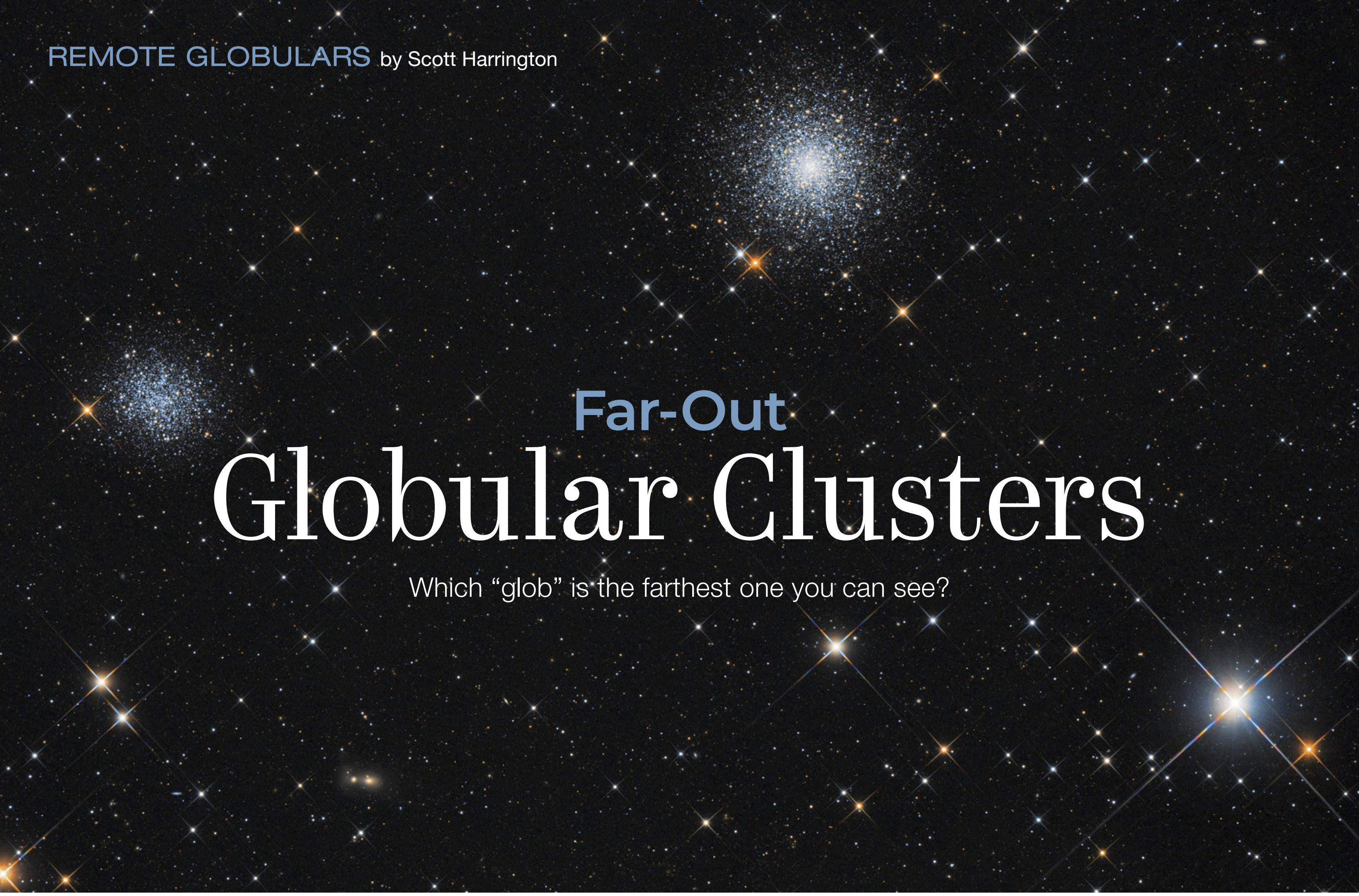
We can also look forward to Japan's Destiny+ mission, scheduled to fly by Phaethon in 2028, and China's Tianwen 2 mission, scheduled to visit 311P/PanSTARRS in the mid-2030s. Astronomers have proposed a number of mission concepts to NASA and the European Space Agency to visit main-belt comets. So far, none has been selected, but perhaps one will be in the near future. Missions are an important piece of the active-asteroid research landscape because of the data that only they are capable of acquiring, from details of the outgassed vapors' compositions to close-up monitoring of how mass loss unfolds in real time.

In the meantime, missions to "classical" comets such as ESA's Rosetta, which performed a detailed study of Comet 67P/Churyumov-Gerasimenko from 2014 to 2016, can provide important context for interpreting future spacecraft observations of active asteroids.

There is thus much we may learn in the next decades about all of the ways that small solar system bodies can come alive with activity. We should not assume that the picture we have built so far will remain unaltered. For if there is one lesson to take away from studies to date, it is that assumptions were made to be overturned.

■ **HENRY HSIEH** is a senior scientist at the Planetary Science Institute who studies active asteroids both in the wild and in theoretical models.

PARTICIPATE IN DISCOVERY Join Active Asteroids to help find asteroids with comet-like tails: **activeasteroids.net**



Far-Out

Globular Clusters

Which “glob” is the farthest one you can see?

▲ DOUBLE GLOBULAR M53 (right) and NGC 5053 (left) not only lie closer to each other in the sky than any other pair of globular clusters in the Northern Celestial Hemisphere, but they may actually constitute a true binary system. You’ll find them gracing the constellation Coma Berenices.

While our understanding of the origin of the Milky Way’s globular clusters is still shrouded in mystery, that’s not the case with their distances from Earth. In fact, thanks to the most recent data from the European Space Agency’s Gaia spacecraft (*S&T:* Feb. 2023, p. 34), we know how far away they are to within an accuracy of a few percent. The data reveal that roughly three-quarters of all known globulars in our galaxy are less than 50,000 light-years from us.

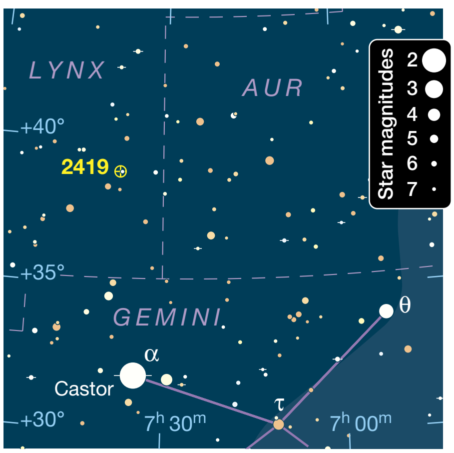
Last year, Contributing Editor Ted Forte took readers on an extensive tour of these “star cities” (*S&T:* July 2022, p. 20). He visited 22 globular clusters, with the most distant being about 50,000 light-years away. This month’s tour is going to be different since the *nearest* ones we’ll chase down all lie farther out! So grab your telescope — but don’t forget your binoculars as these dozen distant denizens are brighter than you think.

Up, Up, and Away!

Our first target, **NGC 2419** in Lynx, is an absolute must-see — even if it’s presently getting too low in the west for a proper look. By carefully star-hopping 7° due north of Castor, with averted vision it’s just visible in my 8×56 binoculars as a tiny, dim smudge immediately east of 7.2-magnitude HD 60771. The view doesn’t improve much even in my 15×70s.

In my 5.1-inch (130-mm) reflector at 72×, the cluster’s broad central glow and hints of a far-reaching outer halo resemble an elliptical galaxy. At 300× in my 16-inch f/4.5 Dobsonian, NGC 2419 has a smooth, uniform appearance, but with a slightly brighter core.

Harlow Shapley drew attention to this Lynx globular in 1922 after inspecting images taken with the 40-inch reflector at Lowell Observatory (among others). He not only established NGC 2419’s globular nature, but



◀ FIND YOUR WAY The finder charts peppered throughout the article will guide you to the globular clusters discussed here.

THOMAS LELU

he also determined it to be one of the most remote known at the time. Thirteen years later, Walter Baade studied the cluster further and — based on its great distance — noted that it was possibly "an independent intergalactic object."

Today, we know that it's nearly 290,000 light-years away — almost twice as far as the Large Magellanic Cloud (albeit lying in the opposite direction) — and is among the most luminous and massive globulars in the Milky Way. In fact, several recent studies have indicated that our "Intergalactic Wanderer" may indeed have an extragalactic origin!

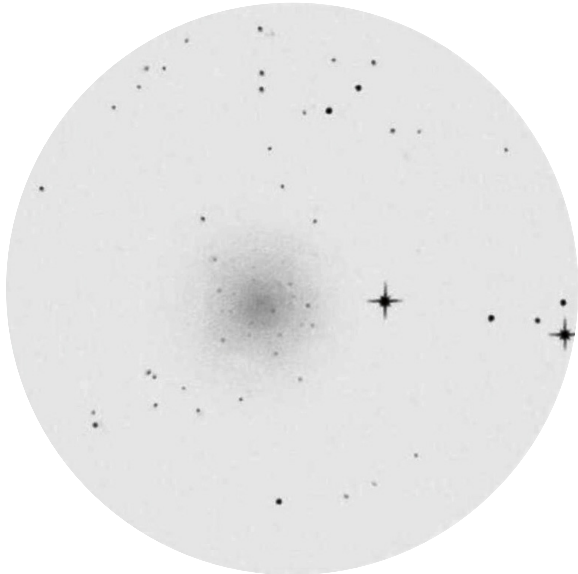
Knots in Her Majesty's Hair

The next three clusters in our tour seem out of place in the galaxy-rich constellation of Coma Berenices. The first and arguably most difficult to hunt down is **NGC 4147**, which you'll find 6.4° northeast of 2nd-magnitude Beta (β) Leonis, or 3.6° west of the 9th-magnitude galaxy M85. The cluster is just visible in my 7×35s as an extremely faint "star" 14′ west-southwest of 8.0-magnitude HD 105865 (not labeled in the chart below right but visible on the outer edge of the globular cluster symbol). With my 12×60s and even more so in my 15×70s, the cluster looks like a faint star with a soft, very faint halo around it.

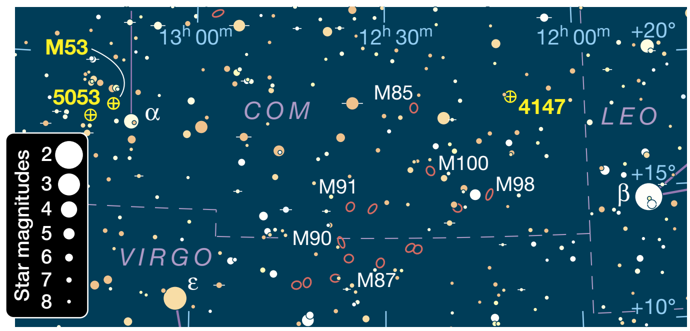
At 59× in my 5.1-inch, HD 105865 has a yellow hue, and NGC 4147 strongly resembles a small elliptical galaxy about 2′ across with a bright core. In my 10-inch Schmidt-Cassegrain telescope at 117×, I see a small but bright core in a larger, diffuse halo and a faint star almost due south in the outer halo. At 260×, the small, dense core sports an irregular appearance, and there's a star visible in the halo to the northwest. My favorite view came at 300× and above in my 16-inch when the globular broke apart into a good handful of foreground and member stars scattered around a small, chunky center.

Just shy of a degree northeast of 4.3-magnitude Alpha (α) Comae resides **M53**, the second-brightest deep-sky object in Coma Berenices. In his 1998 book *Deep-Sky Companions: The Messier Objects*, author and former *S&T* associate editor Stephen James O'Meara writes about M53: ". . . I could not positively identify it with the naked eye. I do believe someone with eyes younger than mine could." Well, after midnight on a crisp night in March of last year, I challenged myself and came *awfully* close to doing so as the zodiacal band stretched faintly from Virgo to Cancer.

In my 8×56s a pair of 9.3- and 9.9-magnitude stars twinkle off the south-southeastern edge of the cluster, while in my 12×60s it spans an impressive 8′ across. During moments of steady seeing, member stars emerge at the cluster's edges in my 10-inch at 94×. Switching to a similar magnification in my 16-inch, the view is stunning. The core of the cluster exhibits a square shape except for the northwestern side, which has stars exploding out of it. At 300×, it's hard to believe that this cluster is as far away as NGC 4147, considering its boxy core alone is as broad as the entirety of NGC 4147!



▲ **INTERGALACTIC WANDERER** Astronomers of the 1920s were the first to note that NGC 2419 lies at a great distance from Earth. Seventh-magnitude HD 60771 lies directly west of the globular, and an 8th-magnitude star lies just a tad beyond that.



▲ **BLINDING LIGHT** The orange-yellow, 8th-magnitude star HD 127119 makes what would be an easy-to-see globular in binoculars quite difficult. The 6th-magnitude star 104 Virginis is just outside the right-hand side of the frame, around 0.5° west-southwest of NGC 5634.

NGC 2419 SKETCH: DAVID GRAY; NGC 5634: KATHY WALKER

While there is a high probability that M53 was formed long ago in another galaxy, figuring out more than that has proven very difficult. Nonetheless, it does seem to have a traveling companion less than 1° away and closer than 5,000 light-years away from it in space. William Herschel swept up **NGC 5053** for the first time on March 14, 1784, immediately after observing M53 with his 20-foot (18.7-inch mirror) reflector. In my 8×56s, with care and patience I'm able to detect the cluster's very faint but noticeably nonstellar glow 6′ west-northwest of a 9.7-magnitude star.

Using an eyepiece yielding a 1.4° true field at 59× on my 5.1-inch, I'm able to just squeeze both globulars into the view. Placing NGC 5053 at the center, I note a subtle east-to-west elongation that's even more evident in my 10-inch at 94×, along with a scattering of faint stars across its surface. With almost no central brightening visible, though, it strongly resembles a low-surface-brightness dwarf galaxy! In my 16-inch at 150×, the cluster no longer looks out of round and instead is a fine mist with more than half a dozen similar-magnitude stars scattered across its face.

New Season on the Horizon

Every time I chase down **NGC 5634** in the eastern reaches of Virgo, I know a new observing season is fast approaching because Antares is twinkling away in the southeast. If you can see the two 4th-magnitude stars Iota (ι) and Mu (μ) Virginis naked-eye, then you can quickly find the globular by aiming your binoculars midway between them. In my 8×56s, I can just detect its ghostly presence immediately northwest of 8.0-magnitude HD 127119, while my 12×60s show, with averted vision, a soft, round glow jutting out from the star's glare.

The view is so tantalizing that it demands a look in a scope. Indeed, at 59× in my 5.1-inch the cluster appears 1.5′ wide with a bright, broad core and an 11.9-magnitude star sitting 1.7′ to its northwest. NGC 5634 displays no central brightening even at 260× in my 10-inch, but I do see flashes of a few stars scattered over its surface at 400×.

Only in the previous two decades have we gleaned that NGC 5634 is likely an orphan from another galaxy. Scientists attribute the cluster's origin to a dwarf galaxy dubbed Gaia-Enceladus, one of several remnants of a past galactic merger with the Milky Way, the earliest and most massive known to date.

Down and Out

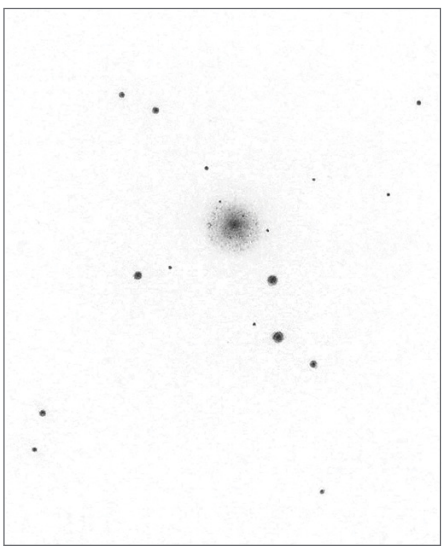
Lurking nearly 7.5° east of 3.3-magnitude Pi (π) Hydrae, near the tip of the Water Snake's tail, is **NGC 5694** — the third most distant globular on our tour. When the 3.5°-long, wavelike star chain formed by 4 Librae and 54, 55, 56, 57, and 58 Hydrae appears in the binocular field, I know to look just right of it to find the cluster.

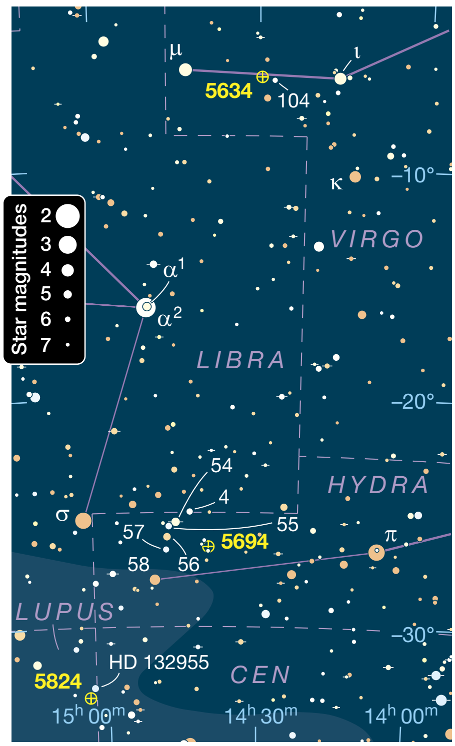
While doable in my 8×56s, NGC 5694 is easier to see in my 12×60s as a 10th-magnitude dot nearly 12′ north of 7.0-magnitude HD 128787. At 27× in my 5.1-inch, I see a very small glow with what looks like a faint star at its center. Only at 200× in my 16-inch does the cluster start to look grainy, and at 300× it grows gradually brighter, from halo to core to a faint stellar point.

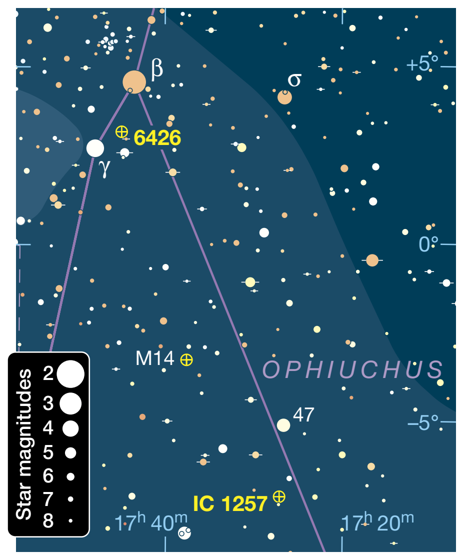
However, the view that absolutely took my breath away one crisp spring morning was when I swept it up in my 16-inch with a newly acquired 20-mm eyepiece boasting a 100° apparent field of view. Yielding a true field of 1.1° at 91×, NGC 5694 appeared as a dynamic glow just shy of 1′ across that seemed to float at the northern end of a chain of brighter stars.

If NGC 5694 is low in your sky, then get ready for this next one because it

▼ **MANY VIEWS** A variety of optics will provide delightful views of NGC 5694. Besides the arc of stars to its east, you can also orient yourself with 7th-magnitude HD 128787, which lies south of the cluster, immediately outside the frame of the sketch (it's the orange speck in the chart at right, just right of the label 56).







SCOTT HARRINGTON

barely rises higher than 20° from my location in northern Arkansas! I'm talking about **NGC 5824**, in northwestern Lupus, less than 20′ from the border with Centaurus. Scottish astronomer James Dunlop discovered it in 1826 while he was working in Australia. To find the globular, drop about 7.4° down from 3rd-magnitude Sigma (σ) Librae to 5th-magnitude HD 132955, and from there go another 0.5° south-southeast.

While not the brightest globular in Lupus, NGC 5824 does hold the distinction of being the farthest one I've seen in my 7×35s — it's at an incredible distance of 103,400 light-years. With scrutiny, the globular is vaguely nonstellar in my 12×60s, while 27× in my 5.1-inch reveals a faint star to its north. At 117× in my 10-inch, NGC 5824 spans just 1′ and displays a compact core set in a distinct halo, which reminds me of NGC 4147.

The 17th Hour

Our next two globulars lie on the eastern flank of the expansive constellation Ophiuchus and offer quite a visual contrast. The first one, **IC 1257**, at magnitude 13.8 is the faintest object on our tour and the only one *not* visible in my binoculars. It's just 2° south of the 4.5-magnitude star 47 Ophiuchi, and with my 5-inch at 59× I see an extremely faint, nonstellar smudge almost exactly midway between a 12′-wide pair of 11th-magnitude stars. While the cluster's entire glow spans less than 1′ in my 16-inch, at 150× I'm still able to make out a nearly stellar core surrounded by a very faint halo. Even with 664× in a 36-inch alt-az-driven Dobsonian at Whispering Pine Observatories (WPO) in northwestern Arkansas, I only noted a soft glow with a slightly brighter center and hints of irregular chunkiness all over.

IC 1257 is dimmed by more than two full magnitudes due to its location behind the galactic bulge on the far side of the Milky Way's disk. American astronomer Edward Emerson Barnard and Austrian astronomer Rudolf Spitaler, on either side of the Atlantic, spotted it one night apart in the summer of 1890, thanks to a faint comet passing nearby. However, its early (mis)classification as an open cluster wasn't fully questioned until the 1990s when the late Czernic Crute (Los Angeles Astronomical Society) brought the problematic nature of IC 1257 to the attention of Brian Skiff (Lowell Observatory) — ever a friend to amateur astronomers. Skiff, in turn, alerted his colleagues in amateur and professional circles, including William Harris, a renowned globular cluster researcher. Shortly thereafter, the 200-inch Hale reflector at Palomar Observatory captured images of it, confirming it to be a "moderately low-luminosity halo cluster."

NGC 6426 is easier to find — look for it about 1.5° south-southeast of 3rd-magnitude Beta Ophiuchi or 0.9° northwest of 4th-magnitude Gamma (γ) Ophiuchi. However, the smallest binoculars I have that show it are my 12×60s, which reveal the cluster as a very faint patch a few arcseconds across. At 94× in my 10-inch, it's a delicate glow gently elongated east to west, with even surface brightness throughout.

NGC 6426: RUDOLF RIEDL

▲ **EYEPIECE SURPRISE** While the author can't make out NGC 6426 in his 8×56s, he was surprised to find that he could just split the 21″-wide double star 61 Ophiuchi, which lies only 36′ south. Fourth-magnitude Gamma Ophiuchi is the bright star at left.

At 200× in the 10-inch, the globular reminds me of the open cluster M46 in Puppis in my 8×56s! Only in my 16-inch at 300× does the cluster's uniformity break down and I'm able to detect a small central brightening. I see no resolution or granularity, however, except for three stars equally spaced along the western edge. Can you spy any member stars?

The Forgotten Labor

While you might not even be aware that Hercules holds a third globular cluster (in addition to the well-known pair of M13 and M92), little **NGC 6229** is a worthy binocular challenge 4.8° east-northeast of 4th-magnitude Tau (τ) Herculis in the northern reaches of the constellation. Under dark skies, my 7×35s reveal it to be the faintest "star" in a near-equilateral triangle with two 8th-magnitude suns immediately west of it. The cluster has a peculiar softness to it in my 12×60s and looks like a bloated star in my 15×70s. If only Herschel (who discovered it) could have known that his class IV (of planetary nebulae) find was a tightly packed cluster of stars nearly 100,000 light-years distant!

Even in my 5.1-inch at 27×, it's hard for me not to pass right over it due to its compactness. A broad core of high

▲ **NORTHERLY BEACON** At magnitude 9.3, NGC 6229 is not only the 13th brightest globular cluster in the Northern Celestial Hemisphere, but it's also the second brightest north of M13. A pair of 8th-magnitude stars guard the globular on its right.

▼ **DAINTY IN THE DOLPHIN** To globular cluster aficionados, NGC 7006 is only the first of three globulars discovered in the celestial Dolphin. Seventh-magnitude HD 200393 (the reddish star in the image) points the way: Look for the globular a smidgen more than 20′ northwest of the star.

surface brightness with very little outer halo is all that my 10-inch at 200× reveals. It's so compressed that I can see why Herschel erred in his classification. At 400× the cluster's glow is 1.6′ across, and there's a slight mottling to the core and halo. Fascinatingly, NGC 6229 as well as IC 1257, NGC 5634, and NGC 4147 all seem to have their origin in Gaia-Enceladus.

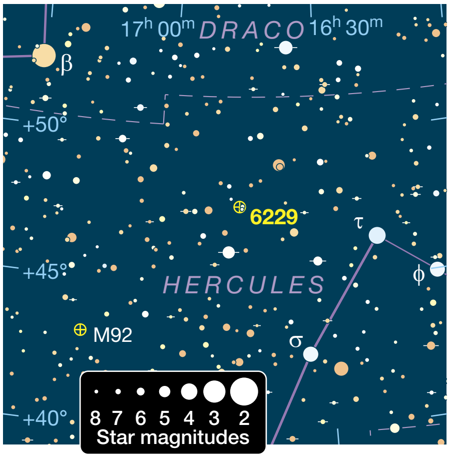
If you read Contributing Editor Steve Gottlieb's article on the Sagittarius Dwarf Spheroidal Galaxy (*S&T:* Oct. 2021, p. 26), then you know that **M54** is special in many ways. But one thing he didn't tell you is its potential to be the farthest object in our galaxy visible to the naked-eye — it's about 86,000 light-years away and yet shines at magnitude 7.5. In fact, it wouldn't be such a challenge if its light weren't subject to half a magnitude of interstellar dimming.

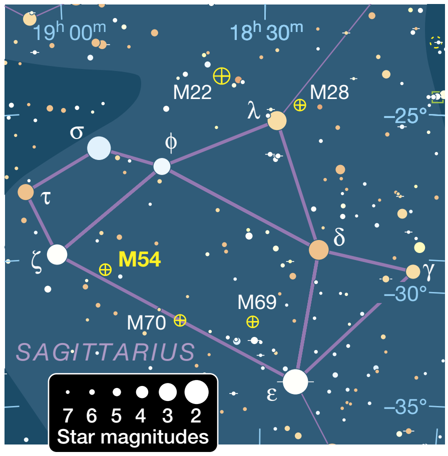
In my 8×56s, M54 looks like a soft, 8th-magnitude star, while in my 5.1-inch at 59× it has a stellar core. I can see a faint foreground star lodged in the southeastern part of its outer halo in my 10-inch at 200×. Only with 336× in the WPO's 36-inch Dob can I start to see resolution in the outer third of the cluster.

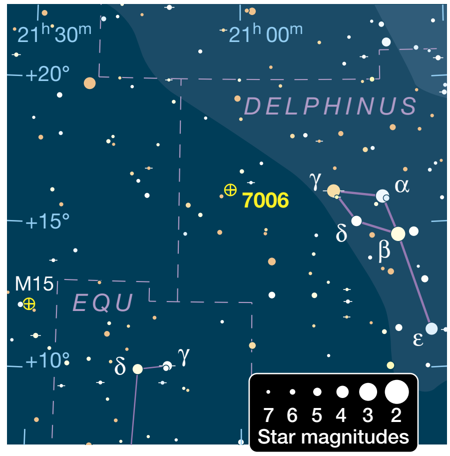
Summer's End

Our final target is an incredible sight considering its light is visible in my 8×56s and yet has been skimming along the southern side of the Milky Way's disk for about 130,000 years

NGC 6229: VITALI PELENJOW; NGC 7006: STEFAN BINNEWIES / FRANK SACKENHEIM / JOSEF PÖPSEL / CAPELLA OBSERVATORY







before reaching us. To find **NGC 7006**, start at 4th-magnitude Gamma Delphini — a tight pair of bright, golden suns at 27× in my 5.1-inch. The globular lies about 3.5° due east, but I've found it's easy to overshoot it and land on the Toadstool instead, a possible open cluster that amateur and author Phil Harrington discovered at Stellafane in 1993 and was so nicknamed by former *S&T* Contributing Editor Sue French.

Once acquired, NGC 7006 is a small but distinctly nonstellar glow whose size and tiny core are reminiscent of a little galaxy. At 105× in my 16-inch, its entirety spans just 1.5′ and reminds me of what NGC 6229 looked like at 59× in my 5.1-inch. Increasing to 300×, I see a broad core that brightens just a bit at the center, along with a distinct stellar pair just 1.5′ south and a couple of fainter stars northeast of the cluster.

By starting with NGC 2419 "above" (north of) the Milky Way's disk and finishing just "below" it with NGC 7006, we traveled more than 120° across the sky. In so doing, we took advantage of the fact that the majority of globulars beyond 50,000 light-years from the center of our galaxy all currently reside north of its disk. That, coupled with the possibility that many of the outer halo globular clusters were captured during mergers, makes me savor each view just that much more. I hope you will, too.

■ With nothing more than 8×56 binoculars, **SCOTT HARRINGTON** has seen about half of the Milky Way's globular clusters — and would love to help you do the same! You can reach him at **sn4ark@gmail.com**.

FURTHER READING: Check out Bill Tschumy's free app, *Our Galaxy 2.0*, which you can use to better explore the locations of each globular discussed (**otherwise.com**). Among other globular cluster resources, you'll find a database maintained by William Harris at **https://is.gd/harris_globulars**.

Distant Denizens

Object	Constellation	Mag(v)	B * Mag(v)	Distance (kl-y)	Size	RA	Dec.
NGC 2419	Lynx	10.6	17.3	288.6	4.6′	$07^h 38.1^m$	+38° 53′
NGC 4147	Coma Berenices	10.3	14.5	60.5	4.4′	$12^h 10.1^m$	+18° 33′
M53	Coma Berenices	7.7	13.8	60.3	13′	$13^h 12.9^m$	+18° 10′
NGC 5053	Coma Berenices	9.9	13.8	57.2	10′	$13^h 16.5^m$	+17° 42′
NGC 5634	Virgo	9.5	15.5	84.7	5.5′	$14^h 29.6^m$	−05° 59′
NGC 5694	Hydra	9.9	15.5	113.6	4.3′	$14^h 39.6^m$	−26° 32′
NGC 5824	Lupus	8.9	15.5	103.4	7.4′	$15^h 04.0^m$	−33° 04′
IC 1257	Ophiuchus	13.8	17.5	86.7	5.0′	$17^h 27.1^m$	−07° 06′
NGC 6426	Ophiuchus	11.1	15.2	67.5	4.2′	$17^h 44.9^m$	+03° 10′
NGC 6229	Hercules	9.3	15.5	98.2	4.5′	$16^h 47.0^m$	+47° 32′
M54	Sagittarius	7.6	15.2	85.7	12′	$18^h 55.1^m$	−30° 29′
NGC 7006	Delphinus	10.7	15.6	128.2	3.6′	$21^h 01.5^m$	+16° 11′

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. B * Mag(v) is the estimated brightness of the brightest stars — your telescope must reach this magnitude to partially resolve the cluster.

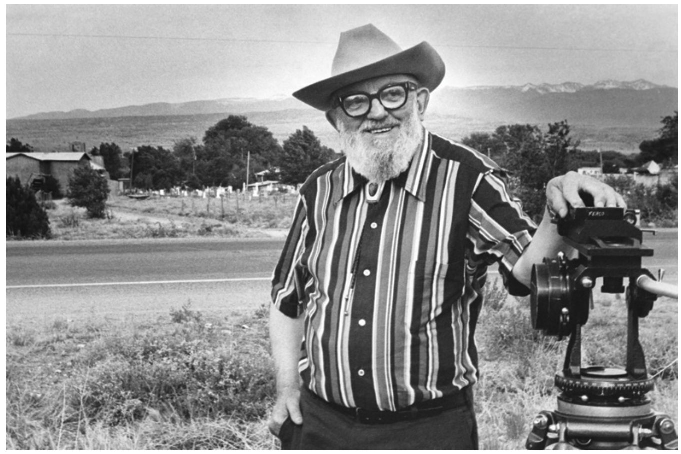
HIGH COUNTRY CRAGS AND MOON, SUNRISE, KINGS CANYON NATIONAL PARK, CALIFORNIA, 1936, PHOTOGRAPH BY ANSEL ADAMS / COLLECTION CANTOR ARTS CENTER, THE CAPITAL GROUP FOUNDATION PHOTOGRAPHY COLLECTION AT STANFORD UNIVERSITY, 2019.42.20,

Ansel Adams and Moons Over the High Sierra

Astronomical detective work uncovers the dates for a pair of photographs by a legendary artist.

Few photographers are as well known and respected as Ansel Adams (1902–1984). Many of his photographs — especially those depicting California's Yosemite National Park and other locations in the American West — can rightfully be called "iconic." Adams kept meticulous records of camera and darkroom data for his photographs, but he rarely recorded the dates for any images, even his most important works.

Mary Street Alinder, a former assistant to Adams, observed that "Ansel was notoriously bad at dating his own negatives . . . though he kept immaculate records of each negative's f/stop, lens, and exposure" (*Ansel Adams: A Biography*, Little, Brown and Company, 1996, p. 144). In the text of an exhibition catalog, Karen E. Haas and Rebecca A. Senf agreed that "Dating Adams' work is notoriously difficult . . . The artist often claimed to remember nearly every detail that went into taking a specific photograph but rarely to be able to recall a date . . ." (*Ansel Adams in the Lane Collection, Museum of Fine Arts*, Boston, 2005, p. 147).



▲ **MASTER LANDSCAPE PHOTOGRAPHER** This photo of Ansel Adams was captured during a return visit in June 1980 to the scene of one of his most famous photographs. The graveyard on the left side of this image appears dramatically illuminated by a low Sun in his iconic *Moonrise, Hernandez, New Mexico*.

Past Successes

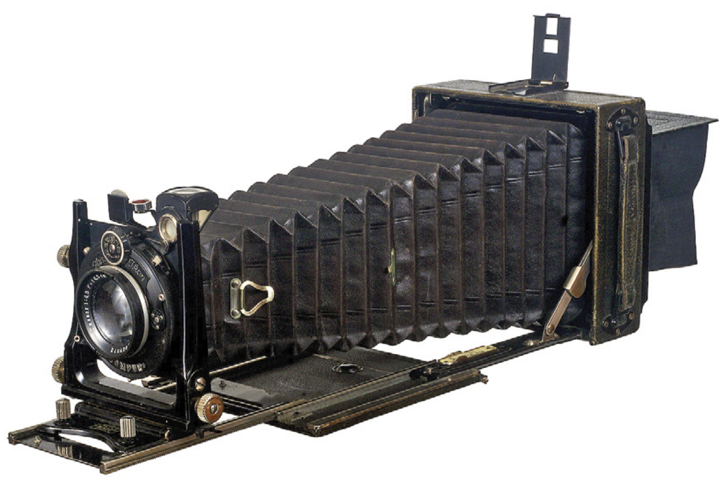
For his most famous composition, *Moonrise, Hernandez, New Mexico*, Adams was uncertain about when he captured the haunting scene and gave the year as 1940, 1941, 1942, 1943, and 1944 in different publications. The presence of the waxing gibbous Moon in the Hernandez image provided the key to establishing the correct date. *Sky & Telescope* Senior Contributing Editor Dennis di Cicco visited the New Mexico site to find the precise spot where Adams had placed his tripod. From that location, he took a star-field photograph and calculated the altitudes and azimuths of numerous visible stars. Matching the terrestrial features in his image to the horizon in *Moonrise*, di Cicco also determined the altitude and azimuth coordinates of the Moon in Adams's photo. Subsequent astronomical computing proved that Adams took the Hernandez photograph at 4:49:20 p.m. MST on November 1, 1941 (*S&T:* Nov. 1991, pp. 480 and 529–33).

Inspired by di Cicco's efforts, I, along with senior lecturer Russell Doescher and students from Texas State University, employed similar methods to determine precise locations and dates for five more photographs by Ansel Adams. On a research trip to Yosemite, we located a tripod spot in Ahwahnee Meadow and took star-trail photographs to show that Adams fired the shutter for *Moon and Half Dome* on December 28, 1960, at 4:14 p.m. Pacific Standard Time (*S&T:* Dec. 1994, pp. 82–86). We likewise determined that he made both the color and black-and-white versions of *Autumn Moon, the High Sierra from Glacier Point* in Yosemite on September 15, 1948, at 7:01 p.m. and 7:03 p.m. Pacific Daylight Time, respectively (*S&T:* Oct. 2005, pp. 40–45).

With assistance from the staff at Denali National Park in Alaska, we dated *Moon and Denali* to July 14, 1948, at 8:28 p.m. and *Denali and Wonder Lake* to the following morning, July 15, 1948, at 3:42 a.m., both Central Alaska Standard Time (Olson, *Further Adventures of the Celestial Sleuth*, Springer, 2018, pp. 136–46).

The opportunity to extend this type of analysis to the early days of the photographer's career arose during planning at the Cantor Arts Center at Stanford University (California) for the exhibition *Reality Makes Them Dream: American Photography, 1929–1941*. Kim Beil, an art historian at Stanford, wondered whether our Texas State University group could use astronomy to date one of the exhibition's images — another dramatic Ansel Adams photograph that features the Moon.

◀ **SIERRA MYSTERY PHOTO** *High Country Crags and Moon, Sunrise, Kings Canyon National Park*, photograph by Ansel Adams. The photographer was notorious for not keeping good records of the dates when he captured some of his most iconic images — and this one is no exception. Fortunately, the presence of a waning gibbous Moon makes dating the photo possible.



▶ **THE "EYE" OF THE BEHOLDER** Ansel Adams used many different cameras throughout his long photographic career. He shot *High Country Crags and Moon* with a Zeiss Ikon Universal Juwel camera of the type shown here.

ANSEL ADAMS: PHOTOGRAPH BY DAVID ROYBAL, COURTESY PALACE OF THE GOVERNORS PHOTO ARCHIVES, NEW MEXICO HISTORY MUSEUM, DEPARTMENT OF CULTURAL AFFAIRS, SANTA FE NEW MEXICAN COLLECTION, NEGATIVE NUMBER HP.2014.14.1774. USED WITH PERMISSION; CAMERA: KEVIN MURRAY

Into Kings Canyon

High Country Crags and Moon, Sunrise, Kings Canyon National Park depicts a waning gibbous Moon, approximately 85% lit. As Adams took this photo, early-morning sunlight illuminated both the distinctive rocks that form the local horizon and a granite ledge in the middle distance, while Adams's position at a lower elevation still remained in shadow.

As was his way, the photographer gave only an approximate date for *High Country Crags and Moon*. In the catalog for a major exhibition in 1979 at the Museum of Modern Art in New York, he listed the date as "c. 1935." This photograph was presented in 1979 in the portfolio called the "Museum Set." The website of the National Gallery of Art in Washington, DC, follows Adams by giving the date of this image as "c. 1935, printed 1979." The Los Angeles County Museum of Art offers a somewhat earlier year for the creation of the original negative on their website: "1932, printed 1979."

As a first step in the analysis of *High Country Crags and Moon*, Beil queried online message boards dedicated to outdoor activities in the Sierra Nevada to ask whether anyone could identify the location. The climber Daniel Jeffcoach recognized the triangular shape of Horn Peak and the ridge line extending to the right (north), near the place at the southern end of Deadman Canyon where a trail begins a steep climb to Elizabeth Pass.

To determine Adams's tripod spot, Beil and her husband Patrick Turner visited the canyon last September. They had to overcome challenges such as the remoteness of the location, high elevations, and, on the return hike, fresh mountain lion tracks on the trail!

Based on Beil's daytime and nighttime photographs, Texas State physics graduate Ava Pope's and my topographical analysis showed that Adams set up his tripod near the spot with GPS coordinates 36° 36′ 39.3″ north, 118° 34′ 6.2″ west and at an elevation of 2,990 meters (9,810 feet). Although the Moon in the Adams photograph appears relatively close to the local horizon, it's actually surprisingly high in the sky. Horn Peak, at elevation 3,600 m, towers over Adams's position, with the summit of Horn Peak rising to about 22° above an idealized, flat horizon.

In Beil's accurately timed star-field photographs, we could recognize portions of the constellations Ophiuchus and Hercules over the terrestrial scene. By calculating the positions of the stars, we were able to determine the altitude and azimuth coordinates for the Moon in Adams's photograph — a crucial piece of data.

We now could use computer planetarium programs to search for dates and times when an 85%-lit waning gibbous Moon passed through this part of the sky at the same time that the Sun was high enough to cast sunlight on the features seen in the photograph. The best matches fell in the summer months, which in turn suggested a possible connection to the Sierra Club outings known as "high trips."

These outings were an annual tradition that began in 1901. Club members hiked the trails and climbed the mountains in remote regions of the High Sierra for four weeks each summer. As many as 200 participants participated in high trips, with a pack train carrying supplies accompanying them. Adams first joined one of these Sierra Club outings in 1923, and by the 1930s he took on the duties of "camp master." In this role he planned the location of each camp and organized entertainment at the nightly campfires. World War II forced a temporary halt to the Sierra Club's outings program.

As mentioned above, Adams recalled capturing the scene "c. 1935" — certainly in the years before World War II. To be on the safe side, we decided to look at all the waning gibbous Moons from 1923 to 1941, with the option of extending the search to later years if we could not find a definitive solution

▲ **GRANITE, LIGHT, AND SHADOW** The rocks of *High Country Crags and Moon* can be recognized on the right side of this early-morning panorama from September 2022. Sunlight illuminates the triangular shape of Horn Peak, the ridge line extending to the right (north), and the granite ledge in the middle distance. Light from the rising Sun has not yet reached the lower elevations at the head of Deadman Canyon, where Patrick Turner stands in shadow near where Ansel Adams had set up his tripod.

KIM BEIL

in this range. Computer programs showed that the closest matches to *High Country Crags and Moon* occurred on four dates, all in the month of August and in the years 1923, 1929, 1933, and 1936.

Lunar Libration Clues

With assistance from *Sky & Telescope* Senior Contributing Editor Roger Sinnott, we were able to identify features on the Moon's surface in the Adams photograph. The visibility of certain lunar maria, craters, and mountain ranges is greatly affected by an apparent oscillation called *lunar libration*. Libration is the reason we can see more than 50% of the lunar surface even though the Moon always presents nearly the same face to us. Indeed, a patient telescope user willing to keep track of the Moon through many months will eventually be able to observe 59% of the Moon's surface thanks to libration effects.

The Moon undergoes two primary types of libration: libration in latitude, and libration in longitude. During *libration in latitude*, the Moon behaves like a person nodding up and down to indicate "Yes." This nodding allows us to see a bit more of the Moon's north and south polar regions. The Moon's aspect during *libration in longitude* is similar to a person shaking their head side to side, indicating "No." During libration in longitude, we alternately get to view features near the Moon's east and west limbs. The two kinds of libration cycles combine to present the Moon's face in many different ways over time.

In *High Country Crags and Moon*, the Moon's north polar region is tilted away from the Earth, with Mare Frigoris and the Northern Highlands relatively near the northern edge of the Moon. Astronomers refer to this as a *negative* libration in latitude. We calculated libration values for each of our four possible dates to see if we could find a good match.

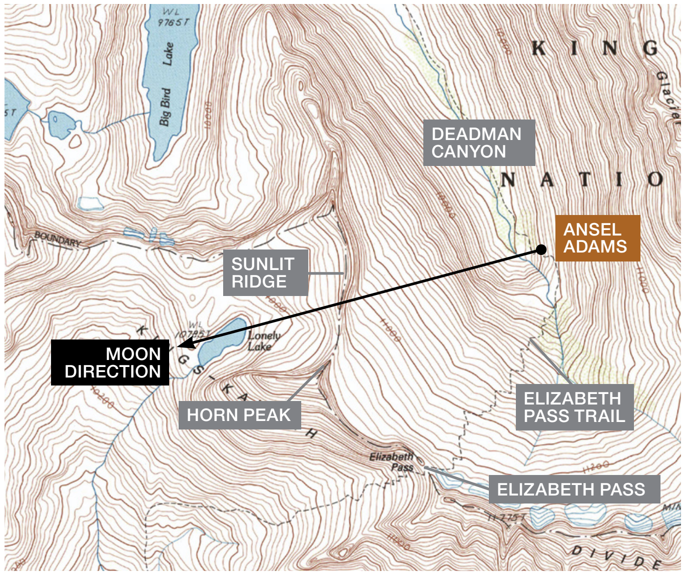
On August 30, 1923, the calculated libration in latitude was large but positive, with Mare Frigoris and the north polar region tilted earthward and appearing far from the northern edge of the Moon. The Moon's appearance on this date is definitely inconsistent with the Adams photograph and allowed us to conclusively rule it out.

A positive libration in latitude likewise rules out August 24, 1929. Moreover, biographical information also eliminates this date. The Ansel Adams collection at the Center for Creative Photography at the University of Arizona preserves his correspondence. Public Services Assistant Ashley Swinford found letters showing that in the second half of August 1929 Adams was making prints in his San Francisco darkroom for a proposed book project.

Biographical considerations also rule out August 9, 1933. The itinerary of the Sierra Club outing in the summer of 1933 ran from July 8th to August 4th, though Adams could have ventured to Deadman Canyon on his own after the conclusion of the high trip. However, his son Michael Adams was born in the Yosemite hospital on August 1st — Ansel left the high trip on the 3rd and hurried back to Yosemite Valley to see his newborn son. He subsequently continued to San Francisco to plan for the opening of his new gallery there. So, he was not in the High Country on August 9th to photograph the waning gibbous Moon.

A Perfect Match

The 1936 Sierra Club high trip ran from July 11th to August



▲ **CANYON SETTING** As shown on this map, Ansel Adams set up his tripod near the south end of Deadman Canyon to photograph the Moon above a granite ridge just north of Horn Peak. The rising Sun was high enough to illuminate those features, but Adams and his camera in Deadman Canyon remained in shadow.

▲ **SCENIC LOCATION** In September 2022, researcher Kim Beil camped at an elevation of 3,050 m (10,000 ft) in Deadman Canyon, Kings Canyon National Park, in order to photograph the scene depicted in *High Country Crags and Moon* both by day and by night.

MAP OF REGION: USGS; KIM BEIL IN DEADMAN CANYON: PATRICK TURNER

8th, with camps in Deadman Canyon on the evenings of August 4th and 5th. Louise Hewlett, who chronicled the trip, judged that this camp:

> *. . . in Deadman Canyon was the loveliest . . . It seemed the spot most poised between heaven and earth, the most magic at sunset, nearest the stars at night . . . we took our sad leave and turned up the canyon toward Elizabeth Pass.*
>
> (*Sierra Club Bulletin*, Feb. 1937, p. 67)

After breakfast on August 6th, the main group headed south in the canyon and then crossed over Elizabeth Pass. They camped that evening at Lone Pine Meadow, on the southern side of the pass.

As camp master, on any day involving a move Adams would have had to leave before the main group. From Deadman Canyon, he would have started out before sunrise and gone on ahead to locate and to lay out the next campsite. The schedule for the Sierra Club high trip of 1936 therefore has Adams passing through the correct location near the southern end of Deadman Canyon, on the appropriate date and at the appropriate time of day to create *High Country Crags and Moon*.

But does the Moon's phase and libration match what appears in the photo? For this date and time, the calculated lunar libration in latitude is large and negative (–6.4°), indicating that the Moon's north polar region was tilted away from Earth, just as in the Adams image. Both the calculated lunar illuminated fraction (85% lit) and the position of the waning gibbous Moon in the sky perfectly match the photograph.

When Adams tripped the shutter for *High Country Crags and Moon*, the Moon stood at an altitude of 26° and at an azimuth near 255°, that is, 15° south of due west. The Sun at that time would have risen high enough (altitude 19°) to illuminate Horn Peak, the ridge line to the north, and the granite ledge in the middle distance, while the tripod location down in Deadman Canyon would have still been in shadow. It's certain that Adams made the exposure on the morning of August 6, 1936, at 6:47 a.m. Pacific Standard Time (California did not adopt Daylight Saving Time during the 1920s or 1930s).

Expert help from Mary Street Alinder and John Sexton, both former assistants to Ansel Adams, helped us determine the camera and lens the photographer used on that date. The negative number 5-C-148A indicates a 3¼-inch × 4¼-inch film size. Adams used only Zeiss cameras and lenses on the 1936 high trip, and to create this exposure he would have employed a folding Zeiss Ikon Universal Juwel camera (sometimes known as the model 275/7) like the one shown on page 27, and a Zeiss Protar lens with a focal length of 290 mm, providing a field of view approximately 15° by 20°. The use of a moderate telephoto lens and a relatively narrow field of view is consistent with the angular size of the Moon as it appears in *High Country Crags and Moon*, *Sunrise, Kings Canyon National Park*.

SIERRA STAR TRAILS The distinctive triangular shape of Horn Peak appears near the left edge of this star-field photograph captured on September 14, 2022, with a view looking generally toward the southwest. Stars of Ophiuchus and Hercules sink toward the local horizon formed by the ridge line north of Horn Peak, as moonlight illuminates the terrestrial scene.

KIM BEIL

▲ **MORNING MOON** *Dawn, Mount Whitney*, photograph by Ansel Adams. A waning crescent Moon stands high in the sky above pinnacles near the summit of Mount Whitney. But when was this scene recorded?

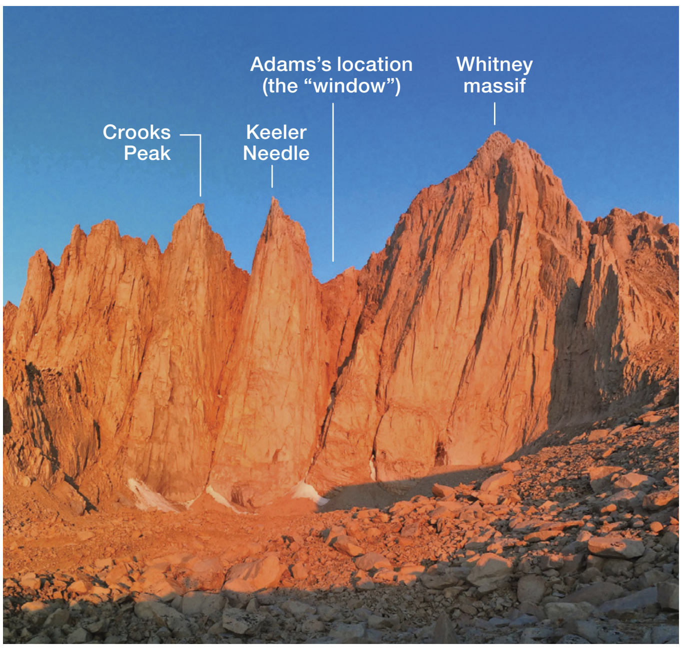
Another Moon, Another Mystery

During our research of the early years of Adams's career we identified another photograph as a candidate for astronomical dating. *Dawn, Mount Whitney* features a waning crescent Moon, approximately ¼ illuminated, high in the sky above the morning twilight glow.

Identifying the precise location where the photo was taken wasn't difficult because large numbers of hikers follow the trail to the Mount Whitney summit (4,421 m) and post their photographs online. The rock known as Keeler Needle dominates the Adams photograph. The sharp-pointed crag at the right edge of the image was known as Day Needle prior to 1990, when it was renamed Crooks Peak. An online image search yielded several modern views that happen to be close matches to the foreground of *Dawn, Mount Whitney*.

Especially helpful were three experienced Sierra hikers — Ashley Hill, Derek Loranger, and Rini Sugianto — who graciously shared their digital photographs with us. Analysis based on the image data showed that Adams set up his tripod near the GPS coordinates 36° 34′ 33.3″ north, 118° 17′ 38.5″ west and at an elevation of 4,300 m. The image data also included lens focal lengths, which (with sensor sizes) determined the field of view for the scene.

Kim Beil, with assistance from curator Christine Hult-Lewis of the Bancroft Library at the University of California, Berkeley, found that *Dawn, Mount Whitney* appears in an album that Adams compiled for the Sierra Club after the 1932 high trip. But did he capture the photo in 1932, or before that summer's trip?



▲ **SUNRISE SCENE** The view in this photograph looks toward the west and shows the steep east face of Mount Whitney just after sunrise. (Crooks Peak was previously known as Day Needle.) The "window" is where Ansel Adams set up his camera to aim east and capture his *Dawn, Mount Whitney* photograph.

RINI SUGIANTO

The negative number 4-S-18 assigned by Adams corresponds to a 4 × 5 (inch) film size. This suggests he shot the scene with the same Korona View camera he carried on the 1932 high trip to make his iconic photograph *Frozen Lake and Cliffs*, which is also included in the 1932 album. For *Dawn, Mount Whitney*, his Goerz Dagor lens, with a focal length of 120 mm, would have provided an image with a wide field of view (approximately 44° × 54°) consistent with both the scale indicated by the modern digital photographs and the relatively small apparent size of the Moon in the Adams image. The photograph shows the Moon at an altitude of about 47°.

The Sierra Club group reached base camp at a location called Crabtree Meadow on the evening of July 27, 1932. The Mount Whitney climb took place on the morning of the 28th, with Adams leading the adventurous souls who started very early with the incentive of witnessing the sunrise through natural "windows" near the summit. Hollis T. Gleason described how this hike began in darkness:

> *. . . we pressed on to our big objective – Mount Whitney . . . At last we reached the open timber of Crabtree Meadow . . . By sunset the many clouds departed . . . the white granite steeps of Whitney . . . invited us to climb . . . many of our jaded group who craved a new sensation insisted on a midnight party with a sunrise goal . . . there were rumors of some faltering in the darkness . . . Those aspirants who viewed the orient pearls of sunrise through the V-shaped apertures of the crest record a sublime experience . . .*
>
> (*Sierra Club Bulletin*, Feb. 1933, pp. 14-15)

According to Jules Eichorn, a close friend of the photographer, Ansel Adams knew "there was to be a partial moon in the skies, so he hustled us all to the top" and made the famous image (*Sierra Club Reminiscences III*, 1985, p. 23).

The waning crescent Moon on this date was 23% lit — in good agreement with the lunar phase in the photo. When the rising Moon reached an altitude of 47°, the Sun was 5° below the horizon. Indeed, dawn on July 28, 1932, at 4:33 a.m. Pacific Standard Time is a perfect match for *Dawn, Mount Whitney*.

With these two photographs, the reach of astronomical dating techniques for Ansel Adams photographs now extends back to the 1930s. Our analysis also determined the tripod spots in the High Sierra and the camera and lens combinations Adams used.

The results of these efforts help bring the modern reader closer to the moment of creation of these striking photographs and to the person who captured them. By solving mysteries in art with astronomy, we can potentially open the doors to a richer appreciation of nature and human culture.

■ **DON OLSON** is a regular *Sky & Telescope* contributor and professor emeritus of physics at Texas State University. His most recent book is *Investigating Art, History, and Literature with Astronomy* (2022).

▲ **IN THE MASTER'S FOOTSTEPS** The rising Sun appears in a natural window, framed by Mount Whitney on the left and Keeler Needle on the right, with the sharp point of Crooks Peak just visible at the extreme right. The mountains of the Inyo Range form the local horizon just below the Sun. From this viewpoint along the Whitney section of the John Muir Trail, Ansel Adams and participants of a Sierra Club high trip observed a waning crescent Moon rising into the sky above the glow of morning twilight.

MOUNT WHITNEY SUNRISE: RINI SUGIANTO; KEELER NEEDLE AND CROOKS PEAK PAN: DEREK LORANGER

▲ **HIGH-ALTITUDE PINNACLES** Silhouetted against the sky on the left are Keeler Needle and Crooks Peak, both part of a ridge that extends to the south and parallels the Whitney section of the John Muir Trail.

 by Benjamin Skuse

Despite more than a decade of exploration, cosmologists have yet to strike it rich in their search for primordial gravitational waves. Will the next generation of projects succeed?

It's been more than a century since Albert Einstein predicted the existence of gravitational waves, half a century since Joseph Weber first attempted to detect them, and just seven years since they were finally spied by Italian postdoc Marco Drago in data from the Laser Interferometer Gravitational-Wave Observatory (LIGO). Since that first seminal detection, LIGO and its ilk have sensed about 100 gravitational-wave events. Each one was a burst of ripples in the fabric of spacetime, created by the merger of pairs of black holes and/or neutron stars (*S&T:* June 2022, p. 12). In fact, we're at the stage where gravitational waves produced by colliding cosmic objects are now just another tool in the astronomer's utility belt.

But some cosmologists are on the hunt for a more elusive type of gravitational wave, hypothesized to be far too weak for detectors to catch directly.

These ***primordial gravitational waves*** would be something else entirely — the smoking gun that tells physicists their

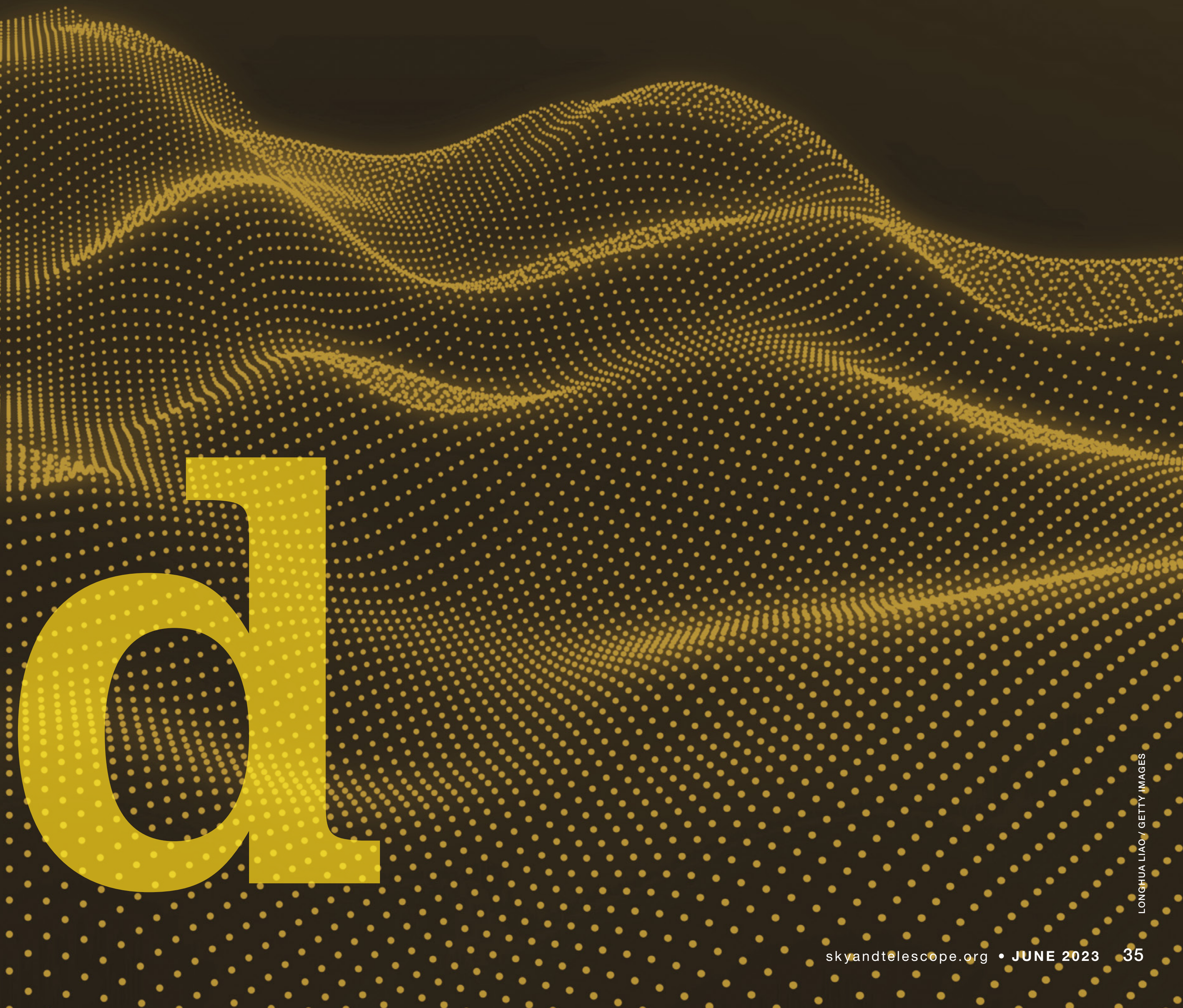
Panning for Gol

ideas are right for how the first moments of the universe unfolded and evolved into what we see today. They would provide a window into a new understanding of fundamental physics. There's just one problem: Finding signatures of primordial gravitational waves is like panning for gold in a river — laborious, time-consuming work with no guarantee of sifting out a precious glowing nugget from the sediment.

CMB and Inflation

To understand the challenges that prospectors for primordial gravitational waves face, we need to rewind the clock as far back as we can go. If we were to run today's cosmic expansion backward in time using the known laws of physics, we would eventually arrive at two key moments in the life of the cosmos that are central to the argument for these waves' existence.

The first of these moments we would encounter would be the birth of the cosmic microwave background (CMB), a form of radiation pervading the universe that was first picked up by Bell Labs' Arno Penzias and Robert Wilson almost 60 years ago. The CMB was released about 380,000 years after the Big Bang, when the opaque primordial plasma that made up the universe became diffuse enough that matter and radiation could go their separate ways, leaving a transparent cosmos. It is therefore the universe's first light — anything preceding the CMB's release can never be directly observed (except perhaps neutrinos, which is a whole subfield in its own right, see *S&T:* May 2023, p. 14).



LONGHUA LIAO / GETTY IMAGES

The other key moment happened further back in time, right at the beginning of the universe, roughly 10 nano-nano-nano-nanoseconds (10^{-35} second) after the Big Bang. It's an extremely brief period known as the *inflationary epoch*, or just *inflation*, when instead of spacetime expanding relatively slowly as it has throughout the rest of its history, it ballooned exponentially at faster-than-light speeds. Inflation lasted an infinitesimally small fraction of a second before petering out, but in this near-instant it managed to expand the universe by an unfathomable amount.

This stupendous growth spurt was the brainchild of Alan Guth (MIT), who in 1979 scribbled down what he called a "spectacular realization": The sudden, extreme ballooning of the universe could account for inconsistencies between Big Bang theory and what the universe looks like now.

One of these inconsistencies has to do with the CMB's remarkably uniform temperature profile. The universe is so vast that well-separated regions shouldn't have had time to exchange heat. The CMB sky should therefore be dotted with regions substantially hotter and colder than average. But we don't see that. Inflation essentially locks in uniformity. Regions that would have been well-separated in the standard Big Bang picture were instead a lot closer before rapid expansion. This uniformity explains the rather bland and consistent CMB temperature, which varies by just one part in 100,000 wherever you look.

Ironing out such inconsistencies made inflation compelling, but it didn't constitute hard evidence. Theorists needed a unique feature of inflation that couldn't be produced by other means. They discovered a candidate not long after Guth's spectacular realization: Inflation should have stretched quantum fluctuations in gravity itself, sending tremors through the nascent universe — primordial gravitational waves. However, researchers thought these waves would be impossible to view because of the barrier that the CMB represents.

Then, in 1997, two teams found a loophole.

The theorists focused on the photons of the CMB. These photons scattered off free electrons before the latter were snatched by protons to make the first atoms. Scattering generally polarizes light, confining the light waves' oscillations to a specific orientation, which is detectable. But because light was flying off in all directions at the time, it shouldn't have left an observable mark.

Inflation should have stretched quantum fluctuations in gravity itself, sending tremors through the nascent universe.

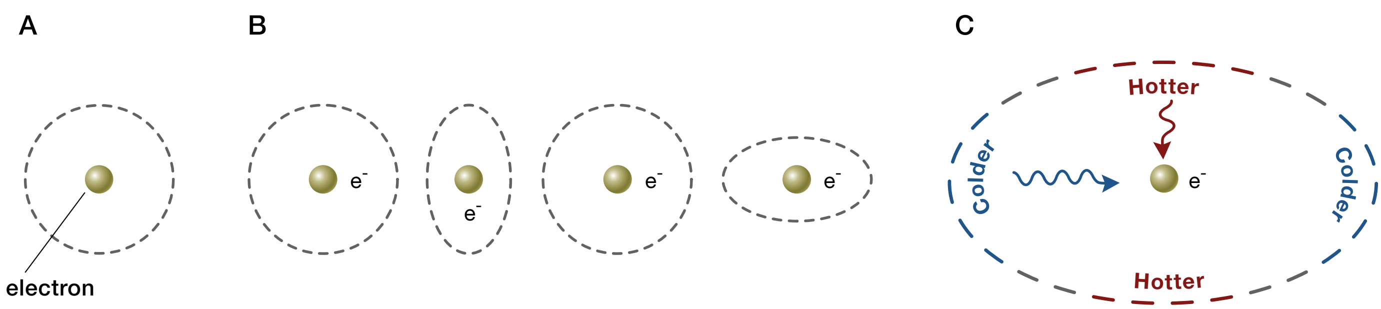
However, the two teams argued, if a primordial gravitational wave happened to be passing by, it would have stretched and squeezed spacetime in a way that made electrons in its path scatter photons in a preferred direction. This would have left two different types of polarization patterns: E-modes and B-modes. E-modes look like fireworks or rings; B-modes look like swirls.

The only other way the CMB would innately have significant detectable polarization patterns is through density fluctuations of the primordial soup, but these patterns could only be E-modes. By this reasoning, the authors of the two 1997 papers concluded that any B-mode pattern seen in the CMB could only come from primordial gravitational waves. Finally, astronomers had a fingerprint of inflation they could go after. "It's so mind-blowing what they did, with figuring out that there could be this special signature that's not that hard to look for in the CMB polarization pattern," says Suzanne Staggs (Princeton University).

False Alarm

Soon, the primordial B-mode gold rush began by land, space, and air, via advanced ground-based observatories, the European Space Agency's Planck space telescope, and balloon-borne experiments. At first, the searches came back empty.

▼ HOW PRIMORDIAL GRAVITATIONAL WAVES POLARIZE THE CMB Gravitational waves in the early universe stretched and squeezed space — and therefore the plasma soup of photons and particles — as the waves passed.



A: Before a wave hits it from behind, a cross-section of space with an electron in the middle looks normal.

B: But when the wave hits, the cross-section stretches and squeezes one way, then another, in an oscillating pattern.

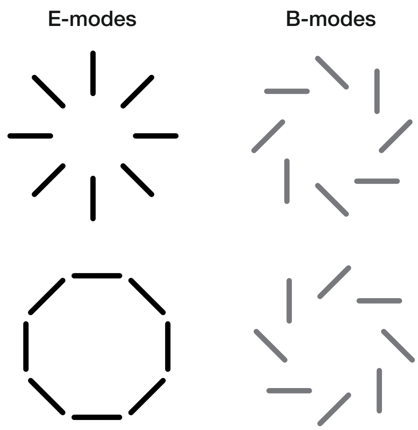
C: Instead of a uniform soup, the electron "sees" around it a universe a bit hotter in the squeezed direction and a bit colder in the stretched direction.

LEAH TISCIONE / S&T

But then, on March 17, 2014, astrophysicists from the Background Imaging of Cosmic Extragalactic Polarization (BICEP) collaboration held a press conference. There, they announced that they had detected “B-mode polarization . . . that matches very closely the predicted pattern” using the BICEP2 observatory in Antarctica. Alongside the announcement, they released a preprint detailing their discovery, writing that “a new era of B-mode cosmology has begun.” Many experts heralded the news as potentially being one of the greatest cosmological discoveries of all time.

Sadly, the announcement was premature. Other researchers soon raised concerns, and the following year, a joint analysis by the BICEP and Planck teams revealed a much more mundane explanation for the signal: dust in our own galaxy (*S&T:* May 2015, p. 12).

When interstellar dust grains interact with the Milky Way’s magnetic field, they can emit polarized microwaves that look just like primordial B-modes. At certain frequencies, the dust emission is so strong that it would overwhelm any primordial signal. The BICEP team knew this and tried to account for it. “We worked really hard to convince ourselves that the signal we were seeing was real, wasn’t systematic, or an error that somehow the analysis produced,” recalls Jamie Bock (Caltech), who has been involved in the BICEP collaboration since its inception. But BICEP2 could only measure polarization at 150 GHz, which gave them limited information about where and how dust could be contaminating the signal. Combining Planck’s seven polarization bands showed the dust’s emission far more clearly.



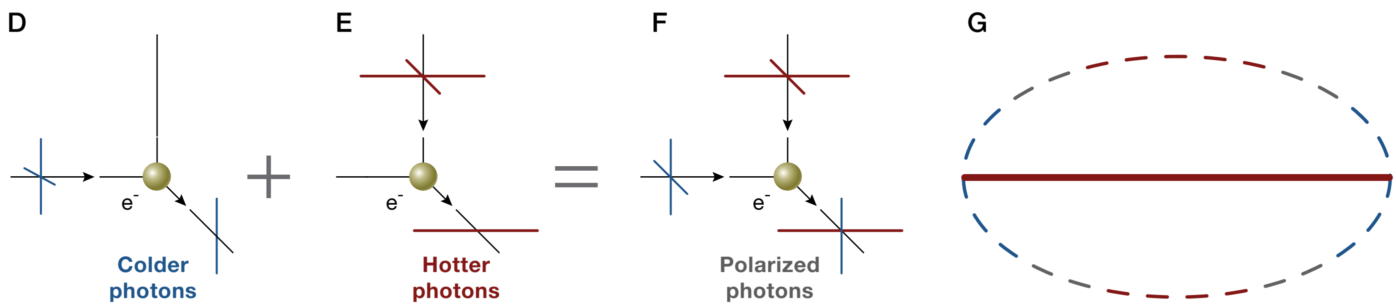
◀ **E-MODES AND B-MODES** E-mode polarization patterns have no “handedness” — if you draw a line down the pattern’s center and reflect the pattern, nothing changes. B-modes look like spirals and don’t reflect. Although gravitational waves can create both types in the CMB, E-modes can also arise by other means. So cosmologists focus on looking for B-modes.

B-mode Prospectors

Undaunted by this setback, astronomers have since redoubled their efforts. The team upgraded BICEP2 first to become the Keck Array and then BICEP3; it will soon be observing the CMB as the latest iteration, BICEP Array — all operating from the Amundsen–Scott South Pole Station. Meanwhile, rival team POLARBEAR (Polarization of Background Radiation), observing from the Atacama Desert in northern Chile, is similarly in the process of upgrading and expanding their experiment to become the Simons Observatory. Among other aims, these upgrades are intended to detect B-modes in the CMB.

Both BICEP Array and Simons Observatory will sit in prime locations for B-mode prospecting. The dry, high-altitude air in both locations minimizes the confounding effects of water vapor in the atmosphere. The projects are also taking a similar approach in their observatory setups, with each utilizing a handful of modest telescopes loaded with detectors. “CMB detectors are limited by photon noise, not detector noise,” explains Bock. “So obtaining more sensitive measurements means you need more detectors — CMB experiments pack as many detectors into their telescope focal planes as will fit!”

BICEP Array will consist of four, 55-cm (22-inch) microwave refractor telescopes, with a total of more than 30,000 detectors looking for CMB polarization. Each telescope will observe a different frequency (or pair of frequencies): 30/40 GHz, 95 GHz, 150 GHz, and 220/270 GHz. Meanwhile, Simons Observatory combines three, 42-cm telescopes



Originally, a photon’s wave wiggles in all planes perpendicular to the photon’s motion (D and E, incoming crosses). When photons scatter off the electron, they become polarized, wiggling in only one plane (outgoing lines). The resulting pattern (F) is a sum of the cold and hot photons’ polarizations.

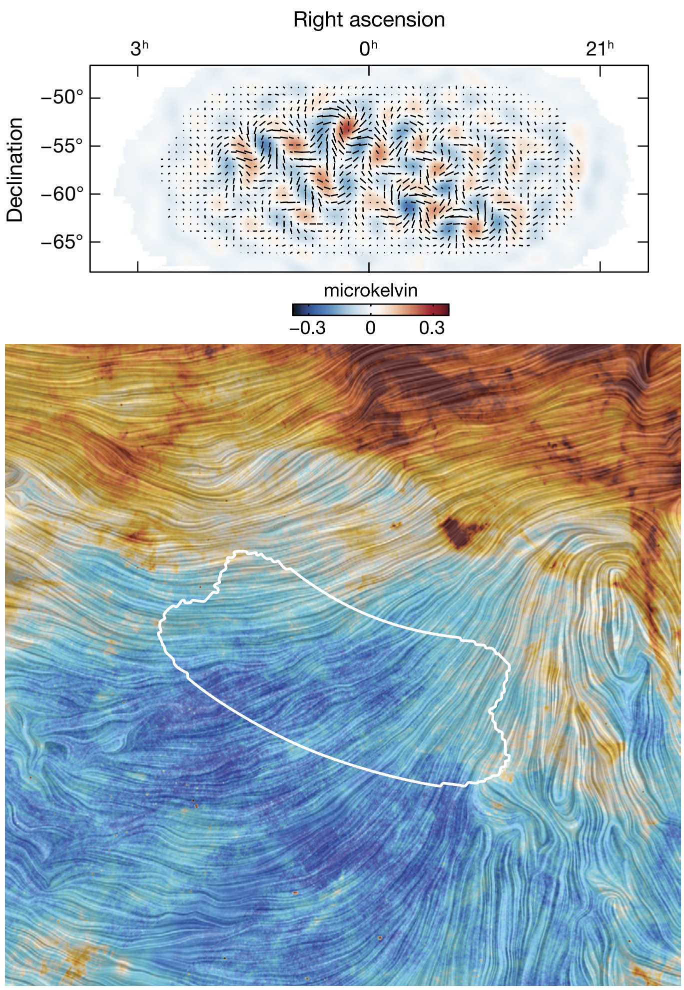
But because photons from hotter regions have more energy, their pattern “wins out,” meaning the overall polarization is parallel to the hot regions.

LEAH TISCIONE / *S&T*

observing at 27/39 GHz, 93/145 GHz, and 225/280 GHz, and boasting over 30,000 detectors.

Both teams chose modest B-mode hunting telescopes intentionally. They may be low resolution, but they require simple optics, and researchers find it much easier to control systematic errors in the signal. "They have sufficient resolution to reconstruct the inflation signal," explains BICEP team member Zeeshan Ahmed (SLAC National Accelerator Laboratory). "And by making BICEP compact, you can also rotate the telescopes about their axes so that you're able to average out certain kinds of instrumental effects."

The major drawback with small telescopes is that the lack of resolution means "confusion signals" easily obscure a potential B-mode signature. Some of these come from our galaxy. Dust is still a problem, for example. Similarly, synchrotron radiation — produced by high-energy electrons flying around in the galaxy's magnetic fields — camouflages the CMB signals.



▲ **DUST INTERFERENCE** BICEP2 detected swirling polarization patterns in the CMB that looked like primordial B-modes (*top*). But Planck found polarized dust emission in the same region of sky (*outlined region in bottom image; redder colors are stronger dust emission, pattern is the galaxy's magnetic field*). Combining the data, researchers realized that the detected B-modes were likely from the dust, not a primordial imprint.

To get around this, astronomers observe the CMB at a few different frequencies to isolate the dust and synchrotron components, which change with frequency in unique ways. They can then separate the different contributions to peel away the foreground obscurations, leaving a clearer view of the CMB.

But perhaps the most pernicious signal frustrating primordial B-mode prospectors is a type of fool's gold from the CMB itself: primordial E-modes masquerading as B-modes. Since their release, CMB photons have travelled through space for eons, navigating a web of matter to finally reach Earth. Every time a given CMB photon passes near a large gravitational mass, its path can be distorted, in turn blurring our map of the CMB's temperature distribution. This weak lensing effect can also change the light's polarization pattern, flipping photons from E-modes to B-modes.

Former E-modes that have been twisted into *lensed B-modes* are a nuisance for primordial B-mode prospectors, and neither BICEP Array nor Simons Observatory can remove them with just their small telescopes. This is why both teams also need a big telescope: BICEP Array uses the 10-meter South Pole Telescope (16,000 detectors) and Simons Observatory has the 6-meter Large Aperture Telescope (LAT; 30,000 detectors). These big telescopes take measurements of the CMB with a finer angular scale to map the E-mode pattern and lensing structures in the foreground of the telescope's view of the CMB. "We then do this mathematical magic to predict what the lensed B-mode pattern looks like," explains Bock. With this information, researchers can subtract the lensed B-modes from the signal to reveal the real primordial B-modes, if they exist.

Race to be Ready

Which team has the better chance of detecting primordial B-modes is unclear. Neither has much of an advantage when it comes to how quickly they can start collecting data. The BICEP Array team installed the first 30/40 GHz receiver in late 2019, and shipped the first 150 GHz telescope in late 2022 to the South Pole, with the plan to add further cameras each year. Meanwhile, Simons Observatory's mounting platforms have already been constructed, with LAT's structure being packed into containers ready for shipping at the time of writing. "We're at this late, very exciting moment when we're about to have a ton of stuff in the field," explains Simons Observatory founding member Staggs. "We're expecting first light in 2023, and the construction part of the project is meant to be completed by April 2024."

Once up and running, each observatory will have some factors in its favor. BICEP Array boasts bigger and more telescopes, but Simons Observatory will run 24/7. BICEP Array will zone in on a single patch of the sky and follow it for months to produce a very low-noise map. Simons Observatory, in contrast, will cover an order-of-magnitude larger portion of sky but at the expense of greater noise. What's more, the two observatories will be monitoring different parts of the sky with different foreground contamination and will use different strategies for removing lensed B-modes. Overall, these differences average out so that the two observatories end up with broadly similar sensitivities. (There are also other ground-based and balloon-borne projects, but they are less sensitive than these two.)

Of course, there is a very real prospect that neither observatory will detect primordial B-modes. But if they draw a blank, both teams already know their next move: Plans are in motion to join forces in CMB-S4 — "the ultimate CMB experiment you can build on the ground," according to Ahmed, who is involved with all three projects.

With first light expected around 2030, the antennas of CMB-S4 will be distributed between Chile and Antarctica. The observatory will survey the southern sky for seven years with 21 telescopes (three large and 18 small) and more than 500,000 detectors covering the frequency range 20–280 GHz. This scale-up is necessary for one simple reason: noise, mostly from the atmosphere. Apart from building an observatory in space, the only way to combat this noise is by observing over long periods or by incorporating a huge number of detectors. CMB-S4 will do both.

Others are taking the space-based route. Of the many mission concepts explored since Planck was retired and sent into a graveyard orbit in 2013, only one has made it off the drawing board so far: the Japan Aerospace Exploration Agency (JAXA) mission LiteBIRD. Scheduled for launch in the late 2020s, LiteBIRD will consist of three millimeter-wave, polarization-sensitive telescopes with approximately 4,500 detectors observing across 15 frequency bands. Offering unprecedented precision, LiteBIRD will scan the entire CMB sky for three years in search of primordial B-modes.

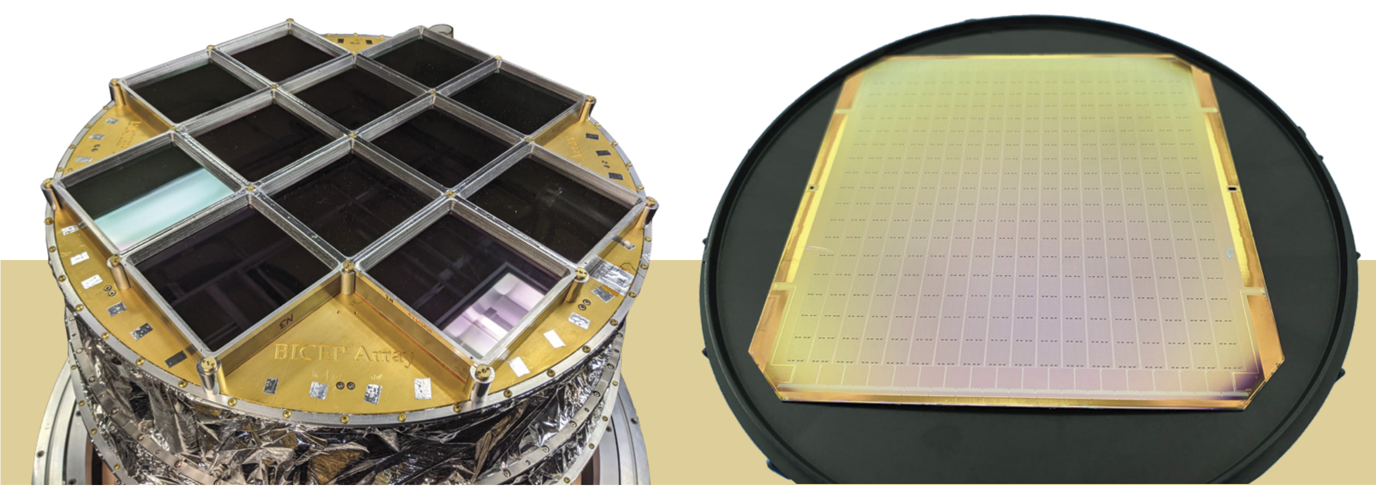
Back to the Drawing Board?

Running parallel to this intense observational activity is an equally intense effort to build theoretical models of inflation that would explain the primordial B-modes we might detect. The options are fewer than they once were. In 2021, a team — analyzing all the data from BICEP through 2018 and correlating the results with those from Planck and its NASA predecessor, the Wilkinson Microwave Anisotropy Probe — constrained the strength of B-mode polarization by a factor of about two. This effectively ruled out a broad class of "simple inflation" models that had looked promising in describing the earliest moments of the universe.

For instance, the *$m^2\varphi^2$ model* (pronounced "em-squared phi-squared") was popular for being one of the most straightforward and elegant. The favored driver of inflation is a

▲ **BICEP DETECTORS** Team members stand with the BICEP Array's 150 GHz focal plane. The focal plane is curved to improve optical performance at this higher frequency; the 30/40 GHz focal plane is flat.

▼ **BICEP BEEFS UP** Each BICEP focal plane *(left, 30/40 GHz receiver)* contains 12 array wafers *(right)*, which detect CMB photons with highly sensitive devices called bolometers, chilled to 0.3 kelvin. The wafer shown operates at 150 GHz, or a wavelength of 2 mm.



BICEP ARRAY COLLABORATION (3)

hypothetical field named the *inflaton*, which would have permeated the nascent tiny cosmos. An unknown spark then released the inflaton's exorbitant pent-up energy, exerting a repulsive force that led to exponential expansion. The $m^2\varphi^2$ model only required the mass of the inflaton field (calculable from observations of the CMB) to predict all the properties observed in the universe. But it also predicted strong B-mode signatures that BICEP or others would have observed by now. Various alternative models that seemed promising, because they invoked particles and theories occurring elsewhere in particle physics, have also fallen by the wayside for the same reason. Bock says this leaves researchers "looking at models that were not in your basic textbooks."

Far from leaving B-mode prospectors downhearted, though, this shrinking of the inflation model pool is generating excitement. A positive detection would steer theorists towards a truer description of the universe's birth, and a deeper understanding beyond the standard model of particle physics. "If we detect an inflation signal at the current level of sensitivity of these telescopes, it means quantum gravity will have some effect or relationship with the inflaton field," explains Ahmed, referring to the long-sought unification of gravity and quantum mechanics. "This would be a first foray into experimentally learning something about quantum gravity, which has been quite challenging from an experimental perspective."

Equally, null results from BICEP Array and Simons Observatory (and later CMB-S4) would be fascinating from a theoretical standpoint. "CMB-S4 is set up to be able to do the best that we can do to actually rule out primordial B-modes or not," says Staggs. "But if we were faced with the fact that there's a really great measurement of zero B-modes that sets as low a limit as we can, I think that there'll be a lot of intellectual activity to see if theorists can come up with a natural way to have primordial gravitational waves be smaller than that limit."

"Inflation occurs at high energies, beyond the standard model of particle physics," adds Bock. "So it's kind of a theorist's playground for all the phenomena that can happen." All cosmologists can do is keep on B-mode prospecting in evermore ingenious ways, holding on to the hope of striking gold.

■ **BENJAMIN SKUSE** is a science writer based in Somerset, United Kingdom.

▲ **BICEP ARRAY** Researchers are currently upgrading the BICEP experiment, shown here in 2020. The four telescopes and their mount sit in a temperature-controlled space; the tubes sticking out are baffles that shield the apertures from stray millimeter-wave radiation. The large forebaffle is 1.3 meters wide and belongs to the lowest-frequency telescope, while the other three smallest telescopes are from the previous-generation Keck Array.

SIMONS OBSERVATORY The three Small-Aperture Telescopes (seen here in December 2022) will scan the microwave sky looking for B-modes.

BICEP DEPLOYED IN ANTARCTICA: BICEP ARRAY COLLABORATION; SIMONS OBSERVATORY UNDER CONSTRUCTION: BRIAN KEATING

OBSERVING
June 2023

1 DUSK: Look toward the west-northwest to see Venus in Gemini forming a tidy line with Castor and Pollux. Watch as the lights brighten in the deepening gloaming.

2 EVENING: In the west, Mars hovers above the Beehive Cluster (M44) in Cancer. You'll need binoculars to tease out the cluster stars. Turn to page 46 for further details on this event and others listed here.

3 DUSK: Face southeast to see the full Moon trail Antares by about 3° as both clear the horizon.

10 MORNING: Night owls can see the last-quarter Moon follow Saturn as they climb above the southeastern horizon. Some 6½° separates the pair.

13 EVENING: It's Venus's turn to visit the Beehive Cluster. While you're admiring this sight, you'll also see Mars around 6° to the upper left. Face west-northwest to take in this view.

14 MORNING: The waning crescent Moon and Jupiter rise in tandem above the eastern horizon with about 2° between them. Catch this sight before sunrise washes it away.

16 DAWN: The very thin lunar crescent rises in the east-northeast, trailing the Pleiades and preceding Mercury.

19 DUSK: The Moon, two days past new, forms a triangle with Castor and Pollux low on the west-northwestern horizon.

21 THE LONGEST DAY OF THE YEAR in the Northern Hemisphere. Summer begins at the solstice, at 10:58 a.m. EDT.

21 DUSK: Look toward the west to see the waxing crescent Moon, Venus, and Mars in a tight triangle. You can follow the trio as they sink toward the west-northwestern horizon.

22 EVENING: The Moon visits Leo where it poses about 5½° right of Regulus, the Lion's brightest star. Mars and Venus complete a neat line that extends from the lunar crescent to the lower right.

27 DUSK: Look toward the south-southwest to see the Moon, one day past first quarter, gleaming in Virgo, less than 3° upper left of Spica.

28 EVENING: Mars and Venus are within 3½° of each other. Face west to see the pair.

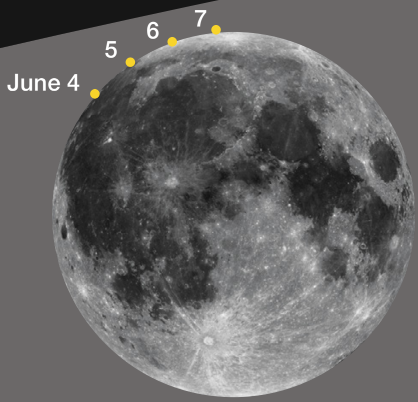
30 EVENING: The waxing gibbous Moon hangs in the south, roughly 2½° right of Antares, the Scorpion's heart.
— DIANA HANNIKAINEN

▲ June is the month of the summer solstice in the Northern Hemisphere. The photo shows the Sun setting over Lake Halsua in Ostrobothnia, Finland, in late June.
MARKUS HOTAKAINEN

JUNE 2023 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	

FULL MOON
June 4
03:42 UT

LAST QUARTER
June 10
19:31 UT

NEW MOON
June 18
04:37 UT

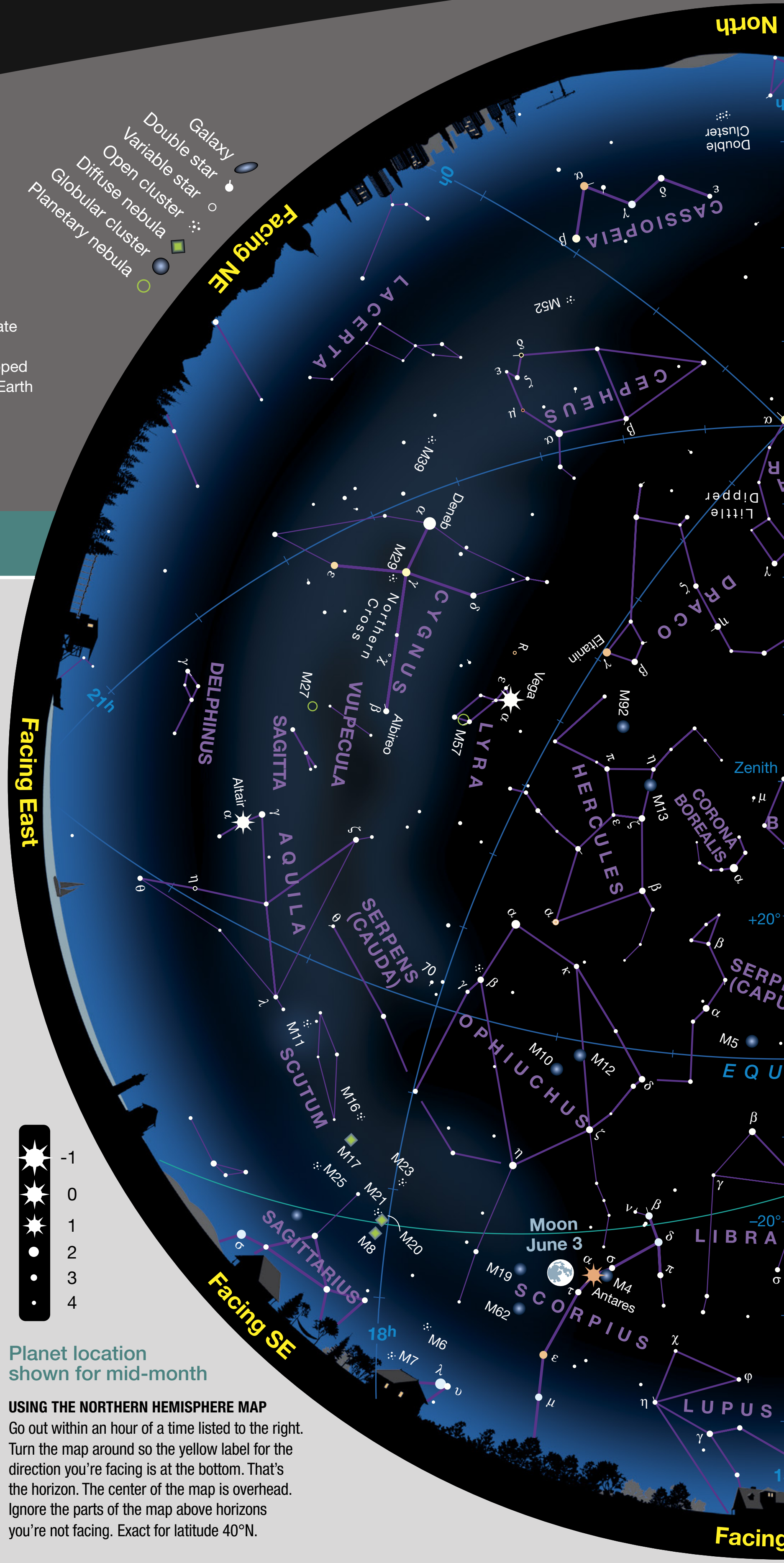
FIRST QUARTER
June 26
07:50 UT

DISTANCES

Perigee	June 6, 23^h UT
364,863 km	Diameter 32′ 45″
Apogee	June 22, 19^h UT
405,385 km	Diameter 29′ 29″

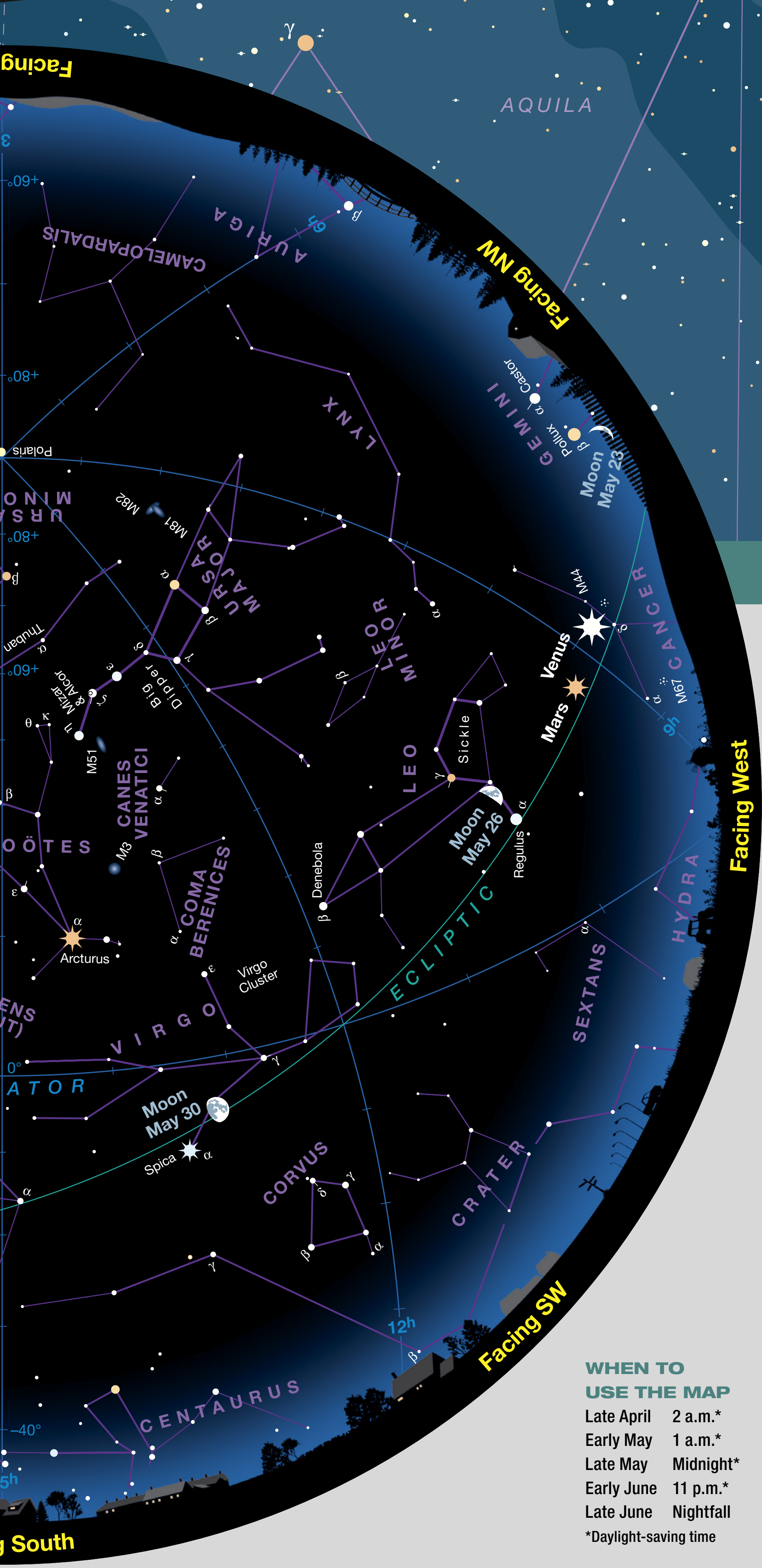
FAVORABLE LIBRATIONS

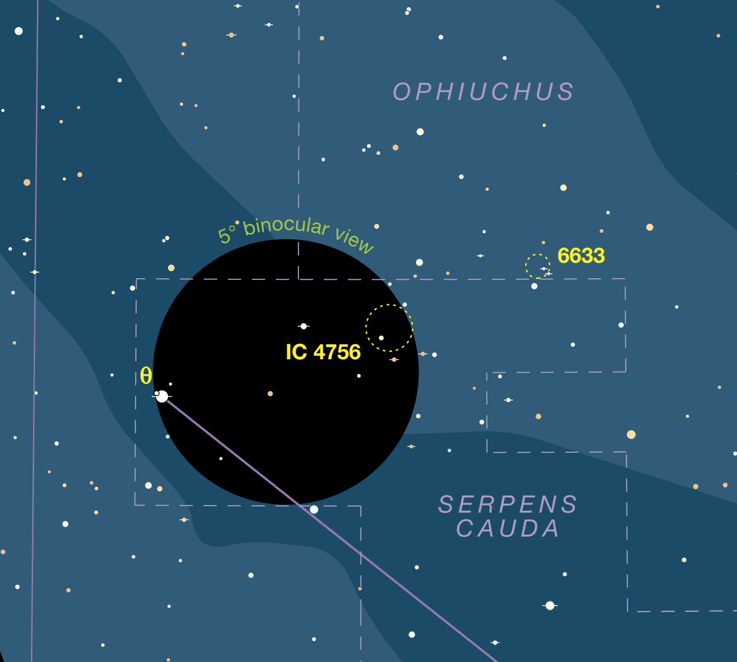
• Von Braun Crater	June 4
• Xenophanes Crater	June 5
• Pascal Crater	June 6
• Gioja Crater	June 7



Planet location shown for mid-month

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





WHEN TO USE THE MAP

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

*Daylight-saving time

Binocular Highlight by Mathew Wedel

Snaking Along the Milky Way

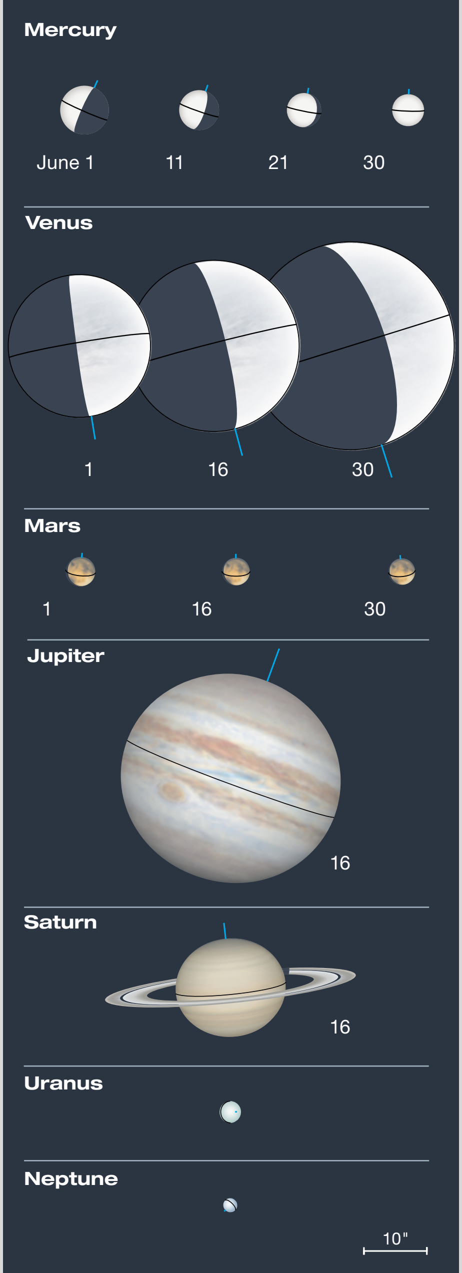
This month we travel to Serpens Cauda, the tail of the cosmic snake, to take in the open cluster **IC 4756**. To find it, scan about 4½° west-northwest of Alya, or **Theta (θ) Serpentis**. Alya itself is a splendid double star for small telescopes, but it's definitely a challenge object for binoculars — you'll likely need mounted 15×70 or 20×80 binos to split the 4.6- and 4.9-magnitude pair. In contrast, the cluster is a delight at any magnification, or none at all. At magnitude 4.6, IC 4756 is an easy catch even in 7×50 binoculars, and it's visible to the naked eye under good conditions. In 15×70s the cluster takes on real character, with its brightest stars forming twisting chains radiating from its center. In my mind's eye it's some marvelous creature shimmering in a tidepool, an octopus or a starfish, a wonder among wonders.

IC 4756 is often mentioned together with its similarly bright neighbor, **NGC 6633**, 3° to the west-northwest. I covered NGC 6633 way back in my very first column in June 2016, so perhaps it's fitting to return to this part of the sky seven years later. The two clusters do make a nice comparison — IC 4756 is larger, more ragged, and less dense than NGC 6633, with margins that are more likely to blend into the rich Milky Way background.

This whole stretch of sky, from Vulpecula, the Little Fox, down to Ophiuchus, the Serpent Bearer, is rife with star clouds, double stars, and asterisms. In particular, sweep along the cascade of progressively brighter stars west from IC 4756 to Gamma (γ) and Beta (β) Ophiuchi. It's the perfect stretch for a leisurely binocular cruise on an early summer evening.

■ **MATT WEDEL** suspects that exploring the Milky Way is going to be on his to-do list forever. And he's okay with that.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dawn from the 3rd to the 16th • **Venus** visible at dusk all month • **Mars** visible at dusk and sets after midnight • **Jupiter** visible at dawn all month • **Saturn** rises shortly after midnight and visible to sunrise.



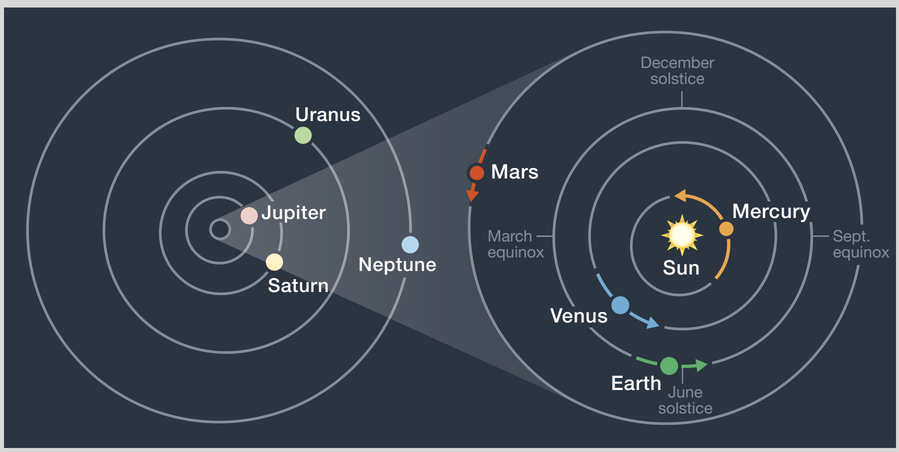
June Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$4^h\ 33.3^m$	+21° 56′	—	–26.8	31′ 33″	—	1.014
	30	$6^h\ 33.4^m$	+23° 13′	—	–26.8	31′ 28″	—	1.017
Mercury	1	$2^h\ 56.2^m$	+13° 14′	25° Mo	+0.2	7.7″	44%	0.868
	11	$3^h\ 49.1^m$	+17° 47′	21° Mo	–0.4	6.4″	64%	1.057
	21	$5^h\ 03.9^m$	+22° 25′	12° Mo	–1.2	5.4″	88%	1.236
	30	$6^h\ 27.1^m$	+24° 24′	2° Mo	–2.3	5.1″	100%	1.323
Venus	1	$7^h\ 50.9^m$	+23° 42′	45° Ev	–4.4	22.6″	52%	0.738
	11	$8^h\ 30.6^m$	+21° 16′	45° Ev	–4.5	25.4″	46%	0.657
	21	$9^h\ 04.7^m$	+18° 19′	44° Ev	–4.6	28.9″	39%	0.576
	30	$9^h\ 29.6^m$	+15° 25′	42° Ev	–4.7	32.9″	33%	0.506
Mars	1	$8^h\ 35.9^m$	+20° 09′	56° Ev	+1.6	4.7″	93%	2.000
	16	$9^h\ 11.5^m$	+17° 37′	51° Ev	+1.7	4.4″	94%	2.111
	30	$9^h\ 44.3^m$	+14° 53′	46° Ev	+1.7	4.2″	95%	2.204
Jupiter	1	$2^h\ 05.0^m$	+11° 31′	37° Mo	–2.1	34.4″	100%	5.729
	30	$2^h\ 27.1^m$	+13° 21′	59° Mo	–2.2	36.5″	99%	5.407
Saturn	1	$22^h\ 35.9^m$	–10° 29′	93° Mo	+1.0	17.2″	100%	9.686
	30	$22^h\ 36.4^m$	–10° 32′	121° Mo	+0.8	18.0″	100%	9.228
Uranus	16	$3^h\ 13.3^m$	+17° 37′	34° Mo	+5.8	3.4″	100%	20.482
Neptune	16	$23^h\ 52.0^m$	–2° 11′	87° Mo	+7.9	2.3″	100%	29.945

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

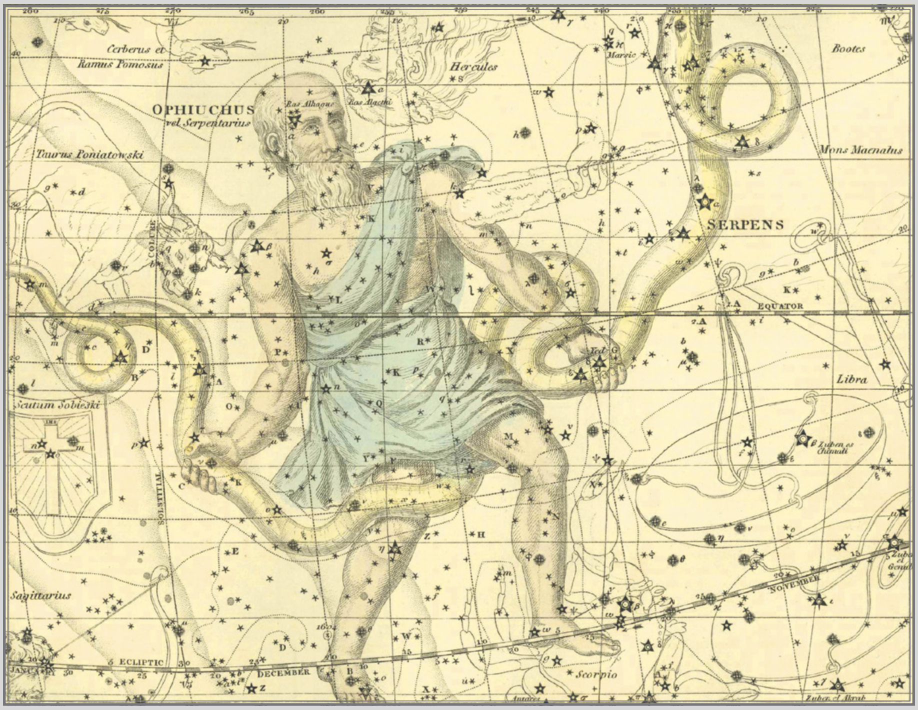
▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

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



Visiting Ophiuchus

The Serpent Bearer has a fine collection of celestial treats.



▲ **GETTING A GRIP** Ophiuchus is depicted in this chart from Alexander Jamieson's 1822 *Celestial Atlas* head-to-head with Hercules. Although vast, Ophiuchus mainly consists of faint stars — the most conspicuous is 2nd-magnitude Alpha (α) Ophiuchi, also known as Rasalhague.

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

You're at a party and someone overhears that you're interested in the stars. They ask, "So, what's your sign?" We've all been there — confusing *astrology* with *astronomy* is common. If I'm in the mood to provoke conversation, I'll answer "Ophiuchus." This always starts an interesting discussion.

Perhaps Ophiuchus should be regarded as the 13th constellation of the zodiac. After all, the Sun spends more time within its borders than it does in neighboring Scorpius ("Scorpio" to those astrologically inclined). Ophiuchus is also impressively large. Indeed, if we use the official boundaries adopted by the International Astronomical Union, only 10 of the 88 constellations occupy a larger swath of sky. But for stargazers, it's not the Sun's presence or the constellation's size that matters most; rather, it's the many nighttime wonders that can be enjoyed in Ophiuchus on June evenings.

Ophiuchus is the Serpent Bearer, who is holding the middle section of Serpens, the Serpent. The snaky constellation is the only one that is split in two by another. The part that extends from the western side of Ophiuchus is Serpens Caput (the Serpent's Head) while the other half, which extends east from Ophiuchus, is Serpens Cauda (the Serpent's Tail).

The head of the Serpent Bearer is marked by 2nd-magnitude Alpha (α) Ophiuchi, better known as Rasalhague. Appropriately, the name is Arabic for "the head of the snake-man." However, it's not the only Alpha star in the area. Just a bit more than 5° west-northwest of Rasalhague is Alpha Herculis, better known as Rasalgethi, Arabic for "the kneeler's head." Note that in another Semitic language, the word for head is similar — Rosh Hashanah is the Jewish holiday whose meaning is "head of the year." And on old star charts, in fact, Ophiuchus and Hercules are depicted as head-to-head in the sky.

Shifting our attention southeast from Alpha we come to Beta (β) Ophiuchi, also known as Cebalrai. This 2.8-magnitude star marks the Serpent Bearer's eastern shoulder and shines a full magnitude brighter than Gamma (γ) Ophiuchi, which lies to the southeast. Just a few degrees northeast of Beta is the sparse but large open star cluster cataloged as IC 4665. Although this 1°-wide cluster is best appreciated in binoculars, at magnitude 4.2 it's bright enough to be glimpsed without optics under a good, dark sky.

Several degrees east of Beta and Gamma you'll find a fascinating, tiny triangle of dim stars. The easternmost member of the triangle is 4th-magnitude 70 Ophiuchi, which is notable for being only 16.6 light-years from Earth — almost identical to the distance of Altair, one of the brilliant Summer Triangle stars. Nearby is another 4th-magnitude star, 67 Ophiuchi, located in the tiny triangle just west-northwest of 70. Given that 67 Ophiuchi is at a distance of about 2,400 light-years, the fact that it shines as bright as 70 Ophiuchi demonstrates that it must be very luminous indeed! Completing the triangle of 4th-magnitude sparks is 68 Ophiuchi, lying just south of the other two.

Let's wrap up our brief Ophiuchus visit by looking at the mythology associated with this big constellation. While the ancient Greeks saw Ophiuchus as the god Apollo wrestling with the monstrous snake guarding the Oracle at Delphi, to the Romans the figure represented Aesculapius, the god of medicine and healing. His staff is depicted with a snake wrapped around it — the "caduceus." If that sounds vaguely familiar to you, it's because even today the caduceus serves as a symbol for the medical profession.

■ **FRED SCHAAF** enjoys the tale of how Aesculapius/Ophiuchus raised Orion from the dead after one of the Hunter's two (!) deaths.

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

Venus and Mars Dazzle at Dusk

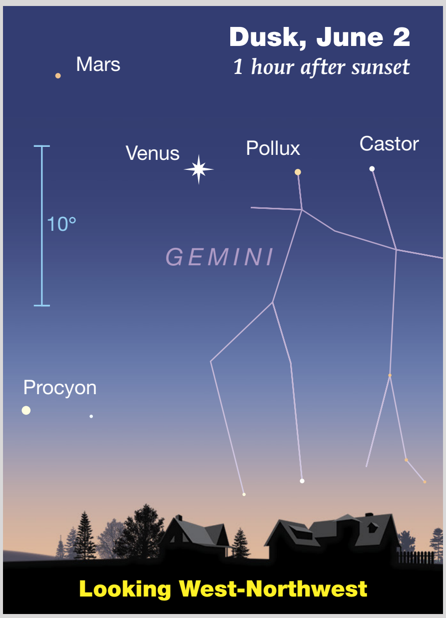
Two evening planets provide some eye-catching sights.

FRIDAY, JUNE 2

Mars is continuing its eastward trek along the ecliptic and participates in a few more conjunctions before its (seemingly never-ending) current apparition finally wraps up. For the most part, the Red Planet ceased being an interesting telescopic target back in February, but it's still a naked-eye gem shining at magnitude 1.6 — good enough to be one of June's 10 brightest evening-sky lights.

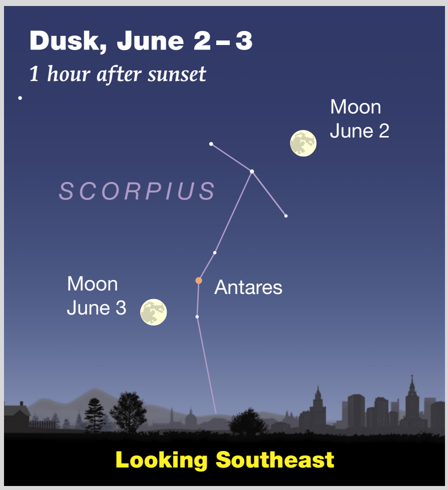
Tonight, Mars makes a shallow, naked-eye triangle with Delta (δ) and Gamma (γ) Cancri, which shine at magnitude 3.9 and 4.7, respectively. But the view in binoculars is more interesting because the planet is nestled among the stars of **M44**, the Beehive Cluster in Cancer. The Beehive is one of a small handful of bright open clusters found along the ecliptic — another being the Pleiades, in Taurus, which Mars approached back in January. However, this evening's encounter with M44 is much more intimate. Thanks to the planet's rapid motion (roughly ½° per day), it crosses the cluster's 1½° expanse in just two nights by taking a shortcut across its northern half. You can also catch Mars at the western edge of the Beehive on the evening of the 1st and on its eastern extremity on the 3rd. (Turn to page 49 for additional conjunction details.)

▼▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west).



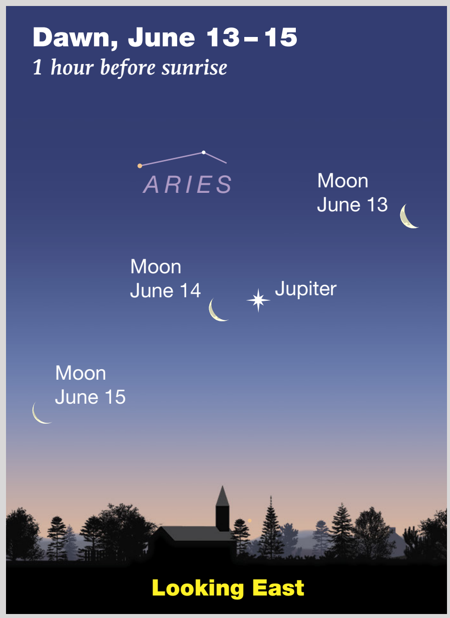
SATURDAY, JUNE 3

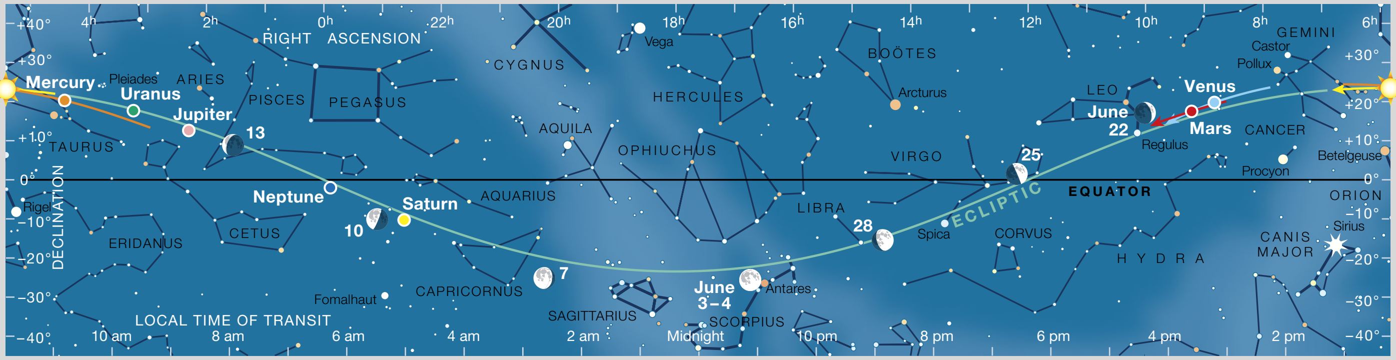
This evening, look to the southeast as twilight begins to fade and watch the full **Moon** rise with **Antares** less than 3° to its upper right, both in Scorpius. There aren't many stars that can stand up to the overpowering luminosity of the full Moon, but at magnitude +0.9, Antares is one of them. Indeed, it's one of the brightest ecliptic stars. Some sources give a tiny edge in brightness to Aldebaran and Spica, but in fact all three stars are slightly variable, and each can be regarded as a 1st-magnitude sun. Aldebaran is out of sight this month, but save the date: You can catch the Moon near **Spica** on the evening of the 27th. That's when the Moon (just past first-quarter phase) sits about 3° above left of the star. And three nights later (on the evening of the 30th), Antares gets a second June visit from ol' Luna, when it will be around 3° lower left of the Moon.



MONDAY, JUNE 12

Venus has been a conspicuous presence this spring and will continue to gleam at dusk all the way into August. On June 4th it reached its greatest elongation from the Sun, and on this evening and the next it, too, passes just north of **M44**. If you thought Mars badly outclassed the Beehive Cluster's stars on the 2nd, you ain't seen nothin' yet!





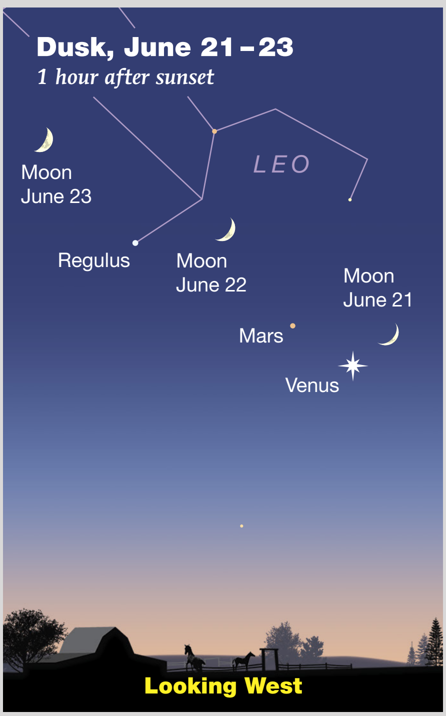
▲ The Sun and planets are positioned for mid-June; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

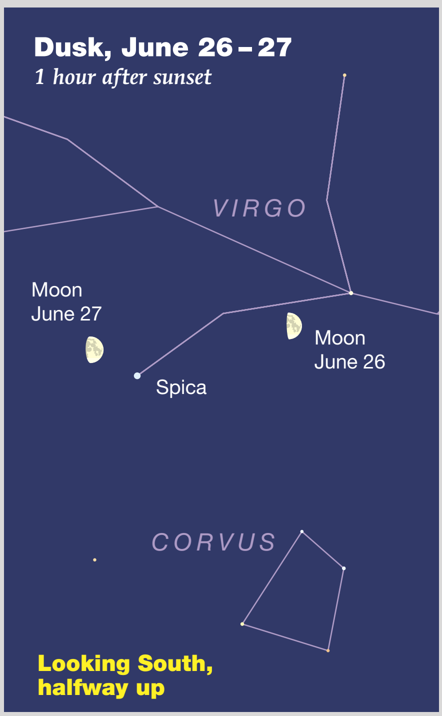
At its current magnitude of –4.5, Venus outshines the brightest bee in the hive by nearly 20,000 times! Binoculars are going to be an essential accessory to see the cluster and Venus together, though a telescope is even better. As a naked-eye sight, however, Venus's visit to the Beehive is a bit of a nonevent given the vast brightness difference between the planet and cluster stars.

WEDNESDAY, JUNE 14

Most of the planetary action so far this month has been concentrated in the evening sky, but it's not as if early risers have nothing to see — especially with **Jupiter** gaining altitude with each passing week. This morning it's visited by the waning crescent **Moon**. Moderately high in the east as the first blush of morning twilight lights the sky, the pair are some 2½° apart. And the Moon will be sporting a healthy amount of earthshine on its "unlit" side as well.

This conjunction will be a pretty naked-eye sight, but given how close the objects are to each other, I'd certainly have a look with binoculars, too. With the boost binos provide, you should also be able to glimpse one or two of Jupiter's four brightest Moons. **Callisto** shines at magnitude 6.6 and is nicely positioned to the planet's east and far from the glare of the Jovian disk. And since you're up early anyway, turn your gaze toward the east-northeastern horizon to see if you can spot **Mercury** rising. The little planet shines gamely at magnitude –0.6 but precedes the Sun by just one hour.





WEDNESDAY, JUNE 21

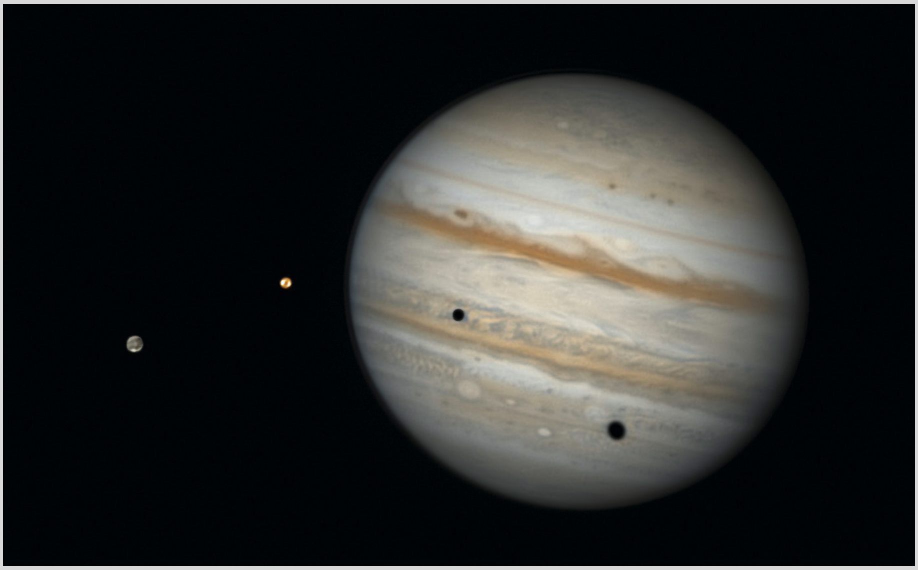
Here's a wonderful way to celebrate the solstice and the start of Northern Hemisphere summer. Exactly one week after it sat next to Jupiter at dawn, the **Moon** pops up in the evening sky and forms a tidy right triangle with **Venus** and **Mars**. The lunar crescent is slightly less than 3° above right of Venus, while Mars is about 4½° above left of the brilliant planet.

You can try a fun experiment by starting your viewing session just before sunset. At that time, you'll easily be able to spot the Moon, but how much later will Venus first appear? You might be surprised to find you can see the Evening Star even when the Sun is still up. Certainly, binoculars will make easy sport of it. What about Mars? Given that the Red Planet is so much fainter than Venus, you'll need substantially darker conditions before the celestial triangle is complete. In fact, several stars will emerge before then — including 1.4-magnitude Regulus, positioned some 11° upper right of Mars, in Leo.

■ Consulting Editor **GARY SERONIK** always appreciates a good display of celestial geometry.

Shadow Games at Jupiter

Watch Galilean satellite shadows transiting the Jovian disk this month.



◀ Ganymede (left) and Io simultaneously cast shadows on Jupiter's South Equatorial Belt and South Temperate Belt, respectively, during a double-shadow transit on August 9, 2022. Ganymede's greater distance from Jupiter, paired with its slightly steeper orbital inclination, displaces its shadow farther to the south compared to Io.

DAMIAN PEACH

Jupiter's double-shadow transit season is underway as the gas giant ascends in the morning sky. Five shadow pairings speckle the planet this month, and then poof! No more until autumn. So, June is the best month to get your scope out and enjoy the show.

A shadow transit occurs when one (or more) of the four bright Galilean moons passes in front of the planet and casts an inky black dot onto Jupiter's pale cloudtops. Prior to Jupiter's opposition date, the shadow precedes its moon; after opposition, the moon precedes its shadow.

Occasionally, two satellites will cast shadows simultaneously in a *double shadow transit*. A dozen occurred in May, but nearly all were unviewable from the Americas because they took place in daylight or when dawn's glare obscured the planet. Fortunately, eight remain — five in June, one in October, and two in December.

Often, both the satellite and its shadow transit together, though the moons themselves tend to blend into the background of bright Jovian clouds. However, thanks to limb darkening, you can see a transiting satellite shortly after a transit begins, or just before it ends.

As our table on page 51 indicates, single shadow transits are frequent, occurring on 29 different occasions this month alone. More than half involve the innermost moon Io, which circles the planet once every 1.8 days with an orbital inclination of only 0.04° relative to the planet's equator. This knife-edge tilt ensures that both satellite and shadow regularly pass squarely over Jupiter's equatorial region.

Callisto, the outermost Galilean moon, presents the opposite extreme, orbiting once every 16.7 days at the comparatively steep inclination of 0.19°. It's far enough from Jupiter that when we view the planet from above its equatorial plane (as we do at present), both moon and shadow miss Jupiter's disk altogether. In fact, Callisto never "touches" Jupiter in 2023. Instead, we'll see it pass slightly north and south of the planet — a curious sight indeed!

Here's a sampling of Callisto's upcoming near-misses visible for observers in the Americas: May 31st at 12:37 UT (West Coast); June 17th at 9:02 UT (Eastern and Central regions); July 4th at 5:00 UT (Eastern only, though Jupiter will be below the horizon when the alignment is best); and July 29th at 8:43 UT (widely visible). The moon passes south of Jupiter on the first three events and north on the last. Attractive alignments endure for about three hours, centered on the times listed.

Ganymede's orbit is inclined by 0.18°, but being closer to Jupiter than Callisto is, the extremes of its tilt lie within the north-south expanse of Jupiter's disk. Ganymede's shadow might fall near the polar regions, but it never misses the planet entirely. It takes Ganymede four times longer to orbit the planet, diminishing the number of transits to four this month.

Europa's orbital inclination is the greatest of the Galilean satellites at 0.47°. But because it's relatively close to Jupiter, the moon's shadow transits are quite frequent, with eight occurring in June.

The inclinations of Jupiter's four largest satellites combined with the interplay of the planet's orbital tilt (1.3°) are why the moons and their shadows don't march across the Jovian disk in a neat line across its equator. The situation is further complicated by the 1:2:4 orbital resonance of the innermost three Galilean moons. That resonance means every time Ganymede circles Jupiter once, Europa goes around twice, and Io four times. As a result, double-shadow transits of Io and Europa are the most frequent, while triple transits are rare. All five double-shadow transits visible this month involve just these two moons and occur on June 4th (5:09 – 6:47 UT); June 7th (18:28 – 19:44 UT); June 11th (7:47 – 8:40 UT); June 14th (21:06 – 21:37 UT); and June 18th (10:25 – 10:34 UT).

The June 11th and 18th events are visible from the Western Hemisphere though, practically speaking, only eastern regions will see the 11th transits during morning twilight, while farther west Jupiter won't rise in time. On June 18th, the Sun will be up on the East Coast and Jupiter too low from the West Coast, but observers across the Midwest and mountain states will get to see two shadows dotting opposite limbs on the planet at dawn for roughly nine minutes.

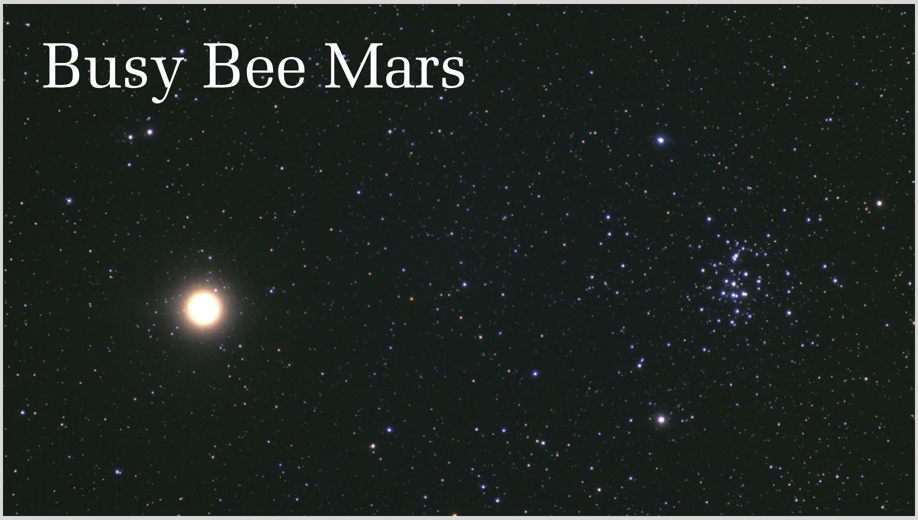
Triple-shadow transits always involve Io and Callisto, combined with either Ganymede or Europa. The most recent triple-shadow event occurred on January 24, 2015, when the shadows of Io, Europa, and Callisto as well as the disks of Io and Callisto formed a string of shadows and pale dots across Jupiter's Equatorial Zone. The next triple event won't happen until March 20, 2032, when the shadows of Io, Ganymede, and Callisto occupy Jupiter's disk for 20 minutes in a striking north-south line. I hope we're all around for that one.

Can we ever see four shadows at once? Unfortunately, no. The orbital resonance described earlier means that either Europa or Ganymede take turns sitting on the sidelines when Io and Europa align.

You don't need a large telescope to observe shadow transits. A 3- or 4-inch (75- to 100-mm) instrument magnifying around 100× will show these black dots under good conditions. After you've seen a few transits, you'll be able to recognize each moon by the size of its shadow. At mid-month, Europa measures 0.8″ across, Io 0.9″, and Ganymede 1.3″ — the size of each shadow closely matching the apparent diameter of each moon.

When you view a shadow transit in your telescope, imagine how the event might appear when seen from the window of a spacecraft in Jovian orbit. How amazing it would be to watch Ganymede eclipse a tiny, distant Sun as you pass into the gloom of the moon's shadow!

Busy Bee Mars



ALAN DYER

▲ Mars is a regular visitor to the Beehive Cluster, M44 in Cancer. Shown above is the planet's 1995 encounter with the open cluster. This month Mars passes directly across the Beehive, north of its center.

AS NOTED ON PAGE 46, Mars will cross the Beehive Cluster (M44) in Cancer on the evening of June 2nd. The constellation is low in the western sky at the time, so it's best to view in late dusk, before the end of astronomical twilight. Binoculars or a small telescope will clearly show Mars in the company of several dozen cluster stars.

While the planet isn't the spectacle it was earlier this year, at magnitude 1.6 it still outshines the Beehive's brightest star by nearly 76 times. Mars is far enough past opposition that its apparent size is only marginally larger than Uranus — 4.6″ versus 3.4″. Chances are you won't see anything more than a ruddy blip in your scope.

But thanks to the swarm of stellar bees nearby, you'll easily be able to detect Mars's orbital motion as it drifts across the cluster. The planet chugs along the ecliptic at about 35′ per day, or 1.5′ per hour. Begin observing as early as possible and pick out a couple of cluster stars to create a line with Mars. You can then test your visual acuity by noting how long it takes to break that line. Is half an hour long enough? It might be — try this experiment and see for yourself.

Interestingly, Mars isn't the only planetary body "in" the Beehive. In 2012, then graduate student Sam Quinn (Georgia State University) used Harvard's 1.5-meter (60-inch) Tillinghast Telescope in southern Arizona to survey 53 stars in the cluster and discovered a pair of exoplanets cataloged as Pr 0201 b and Pr 0211 b. Each closely orbits Sun-like stars of 10th and 12th magnitude, respectively. Another gas-giant planet, Pr 0211 c, was discovered in the Pr 0211 system in 2016. So, your telescope's field of view will not only corral Mars but at least three exoplanets, too.

BOB KING

Noctilucent Clouds Arrive with the Solstice

▲ Luminous blue and wispy noctilucent clouds reflect in Eagle Lake north of Duluth, Minnesota, late in evening twilight on June 27, 2021. Look for the clouds starting an hour after sunset low in the northern sky. They're typically brightest in the direction of sunrise or sunset.

ON JUNE 21ST at 10:58 a.m. EDT, the Sun will reach the summit of its yearly hike around the ecliptic, better known as the *summer solstice*. Although in the Northern Hemisphere things may warm up on the ground, the upper atmosphere reaches extremely low temperatures around this time. In particular, the *mesosphere*, a scant layer of air some 80 km (50 mi) high, drops from its usual –90°C (–130°F) to around –128°C (–198°F). That extra chill coaxes what little water vapor that's present at that altitude to condense around the dust of vaporized meteoroids and form noctilucent clouds (NLCs). Because of their composition and position near the edge of space, I like to think of NLCs as having dual citizenship — part Earth, part celestial.

Most common at latitudes higher than 50° north and south, the fragile strands and wavelets of NLCs have been sighted at lower latitudes in recent years, perhaps as a consequence of climate change. NLCs appear low in the northern sky (between about 5° and 20° altitude) about 60 to 90 minutes past sunset or before sunrise — long after more familiar clouds have gone gray. From my location in Duluth, Minnesota, I see NLCs about half a dozen times each year from late May through July.

The clouds coalesce at an altitude of around 85 km and shine well into deep twilight, when the first stars appear. An unobstructed northern horizon is essential for success. If you can spot Capella, located below Polaris this time of year, you're good to go. The clouds' bluish tint comes from the ozone layer located from 15 to 30 km high. Ozone filters out red light, allowing the cooler blue to reach our eyes. I'm sure you'll agree that the fragile forms and color of NLCs are absolutely entrancing.

Action at Jupiter

AS JUNE BEGINS, Jupiter rises in the predawn less than two hours before the Sun. By month's end the situation improves, and the planet is up nearly 3½ hours before sunrise, at which time it hangs some 38° above the east-southeastern horizon — high enough for some fine telescopic views. It won't be until mid-August, however, that Jupiter climbs to the meridian before sunrise. Even so, it's likely you'll get your first good views of Jupiter during June. How will its various cloud features have changed since you last saw it? Will the Great Red Spot still be reasonably prominent? These are the kinds of questions that make one's first glimpse of this dynamic planet so exciting.

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.

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.)

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

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

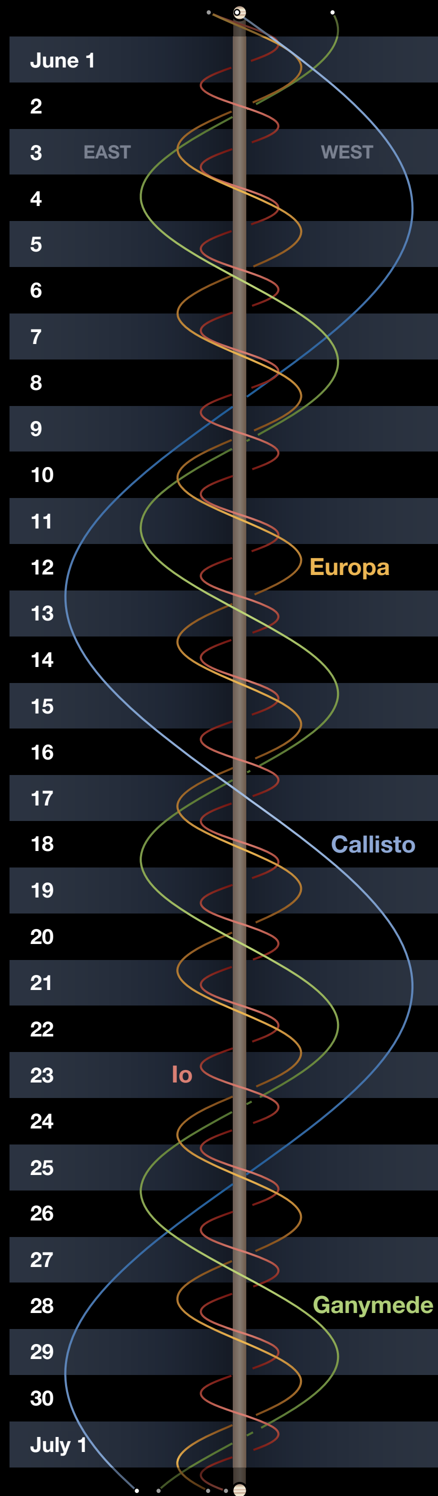
These times assume that the spot will be centered at System II longitude 40° on June 1st. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 40° and $1\frac{2}{3}$ minutes later for each degree more than 40°.

Phenomena of Jupiter's Moons, June 2023

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

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.

Relatable Lunar Distances

These terrestrial analogs can help you bring the Moon closer to home.

◀ The arc of the Ohio River seen in the radar-topography map at far left compares in scale to the rim of Copernicus crater shown at near left.

From Earth, we see the Moon as a thumb-sized, ½°-diameter disk in the sky. Even with a small telescope, myriad craters and dark plains are visible, but it can be hard to grasp the true sizes of these features. Now, with humans about to return to the Moon with the ultimate goal of a permanent presence, you may want to relate sizes of the lunar features you see in your scope with terrestrial landforms.

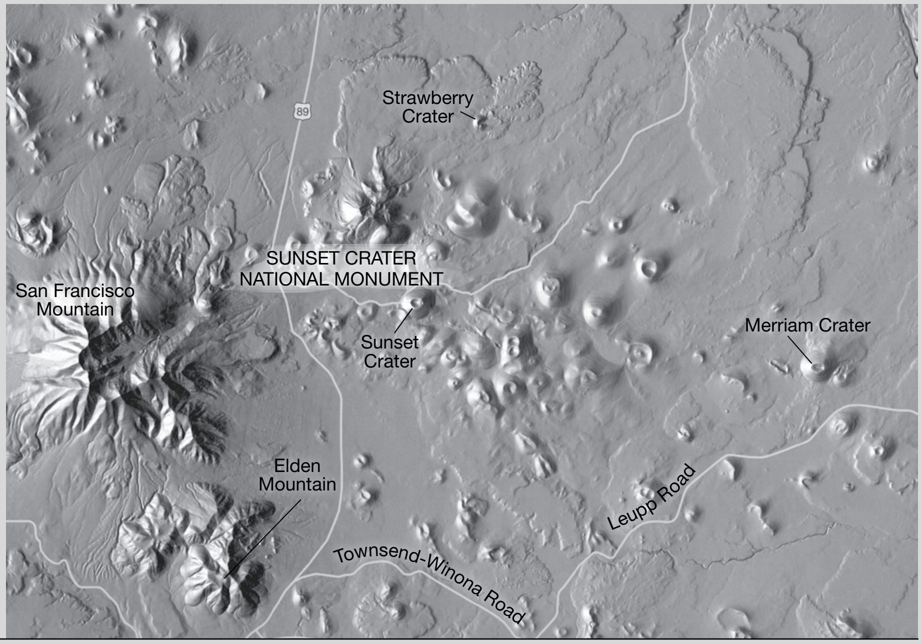
For example, how does the 93-kilometer-wide (58-mile-wide) crater **Copernicus** compare with familiar features on Earth? I live in Wheeling, West Virginia, a small town along the Ohio River, some 95 km from the metropolis of Pittsburgh, Pennsylvania. The distance between these places is easy for me to compare to the diameter of Copernicus. You can fire up Google Maps and find a similar commute distance from your own home.

When I drive to Pittsburgh, I often think about what I would see if traversing Copernicus from rim to rim. Of course, my terrestrial scenery isn't nearly so dramatic. I don't descend a steep, 3.2-km terraced rim to reach the crater's mostly flat floor, and halfway to Pittsburgh there are no kilometer-high peaks to detour around. I cross mostly hills carved by flowing water that are about the same hundred-meter height as small hills of impact melt on Copernicus' floor, but I do get a personal feel for the actual extent of a major lunar crater.

The Ohio River makes a huge, irregular bend between where it passes Wheeling and reaches Pittsburgh. The river is a sinuous erosional channel carved by water, and similar features on the Moon called sinuous rilles were carved by lava flows. The Ohio is about 1,600 km long, with a width of 0.8 km or so in places. The most famous lunar analog is **Hadley Rille**, visited by Apollo 15 astronauts in 1971. That rille is 145 km long and about 1.2 km wide. Most lunar rilles are much shorter, while the longest have sinuous paths extending about 480 km. Rilles are made by thermal erosion of rapidly flowing fluid lava across underlying solid lavas. Unlike terrestrial rivers, rilles usually only carry fluid once in their multi-billion-year lifetimes.

The largest lunar landforms are the wide plains of lava spanning hundreds of kilometers that make up the dark patches (or *maria*) visible to the naked eye. Most of these plains erupted between 3.5 to 3 billion years ago, with smaller expanses forming as recently as

LEFT: NASA / JPL-CALTECH / NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY; RIGHT: NASA / GSFC / ARIZONA STATE UNIVERSITY



▲▶ The San Francisco Volcanic Field in Northern Arizona (a 50-km span of the eastern field is seen at right) is similar to the much larger mass of cinder cones that make up the Marius Hills on the Moon seen above (image width 400 km).

MARIUS HILLS ON THE MOON: NASA / GSFC / ARIZONA STATE UNIVERSITY / MAURICE COLLINS; SAN FRANCISCO VOLCANIC FIELD: NASA / JPL-CALTECH / NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY

1 billion years ago. Maria tend to have few large craters because they formed after the most intense period of cratering, which occurred during the Moon's first 500 million years. As a result, the few craters we do find on maria are mostly smaller.

Lava plains are also found on Earth. In eastern Washington State, the 15-million-year-old, 480-km-wide Columbia River Basalts consist of many layers of basaltic lavas. Driving along these surfaces must be somewhat like rovering across a lunar maria. If you don't live out West, there are many relatively flat, sedimentary plains to be found across the U.S., so you can imagine crossing a mare floor. For example, the distance from Cleveland, Ohio to Indianapolis, Indiana is a flat 420 km, the same distance as the diameter of **Mare Crisium**, which lacks the distractions of cities, farmland, and highways.

The **Marius Hills** in western **Oceanus Procellarum** comprise the largest concentration of volcanoes on the Moon. About 265 km wide, this vast region contains roughly 300 ash cones created by explosive eruptions as well as low domes formed by lava flowing from central vents. A few sinuous rilles also cross the area.

You can visit a close terrestrial analog to the lunar Marius Hills north of Flagstaff, in northern Arizona. The San Francisco Volcanic Field is 80 km wide, with nearly 600 volcanic cones similar to what those in the Marius Hills may have looked like 3 billion years ago when they erupted. The younger Arizona cinder cones, like 938-year-old Sunset Crater, have deep pits at their summits, but as they age these craters and their rims erode, so they look more like the cone stumps in the Marius Hills. The diameters, heights, and surrounding lava flows in northern Arizona give a feel for rovering around that unique lunar region.

The largest mountains on the Moon are the curved basin rims best represented by the great range of **Montes Apenninus** that arc around the southeast margin of **Mare Imbrium**, and the scarp of **Rupes Altai** that marks the southwest rim of the Nectaris impact basin. These partial basin rims span 650 and 400 km, respectively, and rise 3 to 5 km high. In the United States, the 475-km-long curve of mountains called the Mogollon Rim that marks the southern edge of the Colorado Plateau in Arizona rises about 0.5 to 1.5 km above the interior desert terrain. The processes that formed the lunar mountain chains and the Mogollon Rim are completely different, and the Arizona example lacks the steepness of the lunar scarp, but you can probably imagine the curved ranges and mountainy terrain as a plausible substitute.

While talking of lunar-like features in Arizona, one can't overlook Meteor Crater near Winslow. This 1-km-wide, 180-meter-deep terrestrial impact feature is very similar to **North Ray Crater** at the Apollo 16 landing site. North Ray is the same diameter as Meteor Crater and 60 meters shallower. North Ray Crater may be too small to directly observe in most amateur scopes, but it's surrounded by a bright nimbus of ejecta that is visible. North Ray is 50 million years old, while the Arizona crater is 1,000 times younger, forming 50,000 years ago. Visiting Meteor Crater must mimic the visceral feeling of standing on the rim of North Ray.

I encourage you to identify local features that match the scales of lunar landforms mentioned above. What counties, national parks, cities, or trips you've taken share dimensions with well-known lunar features? And when driving near rivers, just imagine your fate if you were actually racing along an active lunar sinuous rille some 3.5 billion years ago.

■ Sadly, driving to Pittsburgh, Pennsylvania is the closest Contributing Editor **CHUCK WOOD** will get to the Moon.

Capturing the Summer Milky Way

A dark sky is the secret to dramatic photos of our home galaxy.

The mild months of summer are a great time to photograph the Milky Way. That's when our galaxy's bright core, in Sagittarius, is perfectly positioned for dramatic compositions. If you're a city dweller, you owe it to yourself to plan a getaway to a remote dark-sky location where you can take in the full majesty of the Milky Way. But photographing it can be both rewarding *and* challenging. Here are a few tips to save you time and frustration while ensuring that you come away with some stunning images.

Where and When

Beyond the crucial absence of light pollution, an ideal destination will also offer a compelling landscape to add interest to your Milky Way images. Lakes, rivers, and mountains are classic subjects to help anchor a composition. National parks and dark-sky preserves are often good bets, as are the locations of numerous summer star parties across the country.

Once you've selected a promising location, flip to this magazine's center spread and review the Lunar Almanac section, which lists dates for the various phases of the Moon. Each month offers a window of several days centered around the time of new Moon, when light from Earth's celestial neighbor doesn't interfere with our photographic goals. Even a thin lunar crescent can

◀ **LIGHT BEAM** The author used a Canon 6D DSLR camera (set to ISO 1600) on a fixed tripod and a Canon 15-mm fisheye lens at f/2.8 for this 30-second-exposure self-portrait. The photo was captured near the Amphitrite Point Lighthouse on the remote west coast of Vancouver Island, British Columbia.

▲ **WIDER THAN WIDE** Sometimes even a fisheye lens isn't wide enough to capture everything you'd like. This horizon-to-horizon panorama consists of three individual frames stitched together. The author captured each 30-second exposure with a Canon 15-mm fisheye lens wide-open at f/2.8 and a Canon EOS 6D camera set to ISO 3200.

add enough light to wash out at least some of the sky.

If you're venturing to a location for the first time, plan to arrive well before sunset. This will give you ample opportunity to scout for the perfect photographic spot and set up your gear before it gets dark. Some mobile phone apps (such as *SkySafari* and *PhotoPills*) have an augmented-reality feature that lets you overlay a graphical representation of the night sky onto a live video image of the daytime landscape. This feature is helpful when composing your photographs because the apps allow you to see how the Milky Way will be positioned with respect to the foreground at any time of night.

What equipment should you bring for a successful outing? At a minimum, you'll need a camera, a wide-angle lens, a sturdy tripod, and a remote shutter release (or a built-in intervalometer, if your camera has that feature).

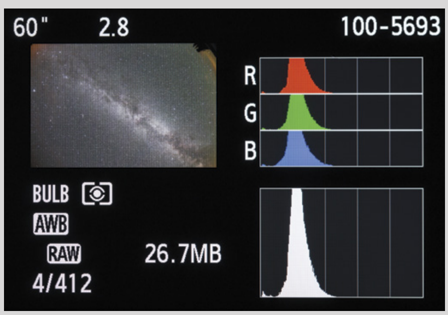
Getting Set

You can save yourself a lot of frustration by making all your camera settings during daylight hours so you're not fumbling with buttons and dials in the dark. You can even pre-focus your lens during the daytime by aiming at a distant object and then manually tweak the focus after dark using Live View (if your camera has that feature).

To prepare for a night of Milky Way photography, set your camera to Manual mode and crank up the ISO to the highest value that produces pleasing results without too much digital noise. This is one area that requires experimentation because the optimum setting will be specific to your camera's sensor. Newer, full-frame cameras tend to produce less noise and therefore allow higher ISO settings.

As a starting point, try ISO 3200 and see if you like the results. If the picture is too noisy, throttle the ISO down to 1600 and try again. Conversely, if the image looks fine at 3200, bump up the ISO and see what you get. You just might be surprised at how good it looks.

When it comes to your lens, start with the widest aperture offered (the lowest numerical f/stop value). It's critical to deliver as much light as possible to the camera's sensor if you want high-quality photos. Here again, a couple of test shots will reveal if you need to stop your lens down to produce reasonably round star images at the edges of the frame. Most lenses work best at least one stop down from fully open.



▲ **PIXEL PLACEMENT** Check your camera's instruction manual to see how to activate the histogram display. For Milky Way photography, your exposures should be just long enough that the histogram "hump" fully separates from the left side of the graph but doesn't extend beyond the halfway point.

If you're shooting with your camera mounted on a fixed tripod, the maximum exposure time will be limited by the focal length of your lens. Over time, Earth's rotation causes stars to trail across your images — an effect that's more pronounced with increasing lens focal lengths. A 50-mm lens (on a full-frame camera) will show trails in just 10 seconds. The same camera with a 16-mm lens will allow 30-second exposures without serious trailing. Ultra-wide-angle lenses accommodate the longest exposures and also have the advantage of including more of the scene you're trying to capture. (For more on this topic, turn to page 54 of the February issue.)

You can side-step these exposure limitations if you mount your camera on a motorized equatorial mount or a battery-powered portable star tracker.

▲ **SKY LIGHT** Even at a dark-sky location, moonlight can affect an image. A waxing lunar crescent is about to set, but its light is bright enough to partially wash out this 30-second exposure made with a tracking mount and a Canon EOS RP camera working at ISO 1600.

Camera trackers permit longer exposure times without the risk of star trails and let you take advantage of slower lenses and those with longer focal lengths. You can also utilize lower ISO settings to improve image quality. The main limitation is that foreground objects, such as trees or mountains, will start to blur as your camera tracks the stars. This is why many trackers offer a special, half-speed (0.5×) setting that lets you split the difference between pinpoint stars and a sharp landscape.

When evaluating your shots, don't rely solely on your camera's rear screen. Although "chimping" (as the activity is humorously known) gives you an overall sense of the image quality and composition, the camera's bright display can trick your dark-adapted eyes into believing an underexposed image looks fine. Instead, trust the histogram. This graphic shows the brightness range of the recorded pixels. (Check your camera's instruction manual to find out how to enable this valuable feature).

The histogram of a well-exposed image will have a hump fully separated from the left side of the screen while not extending much past the halfway point of the graph. You should also avoid over-exposing your images because this will wash out the vivid colors in the stars you're trying to capture.

Finally, shoot in RAW (not JPEG) mode. This will let you adjust the image's white balance after the fact and recover more highlight and shadow detail during post-processing.

Compelling Compositions

While it's tempting to point your camera straight up to capture as much of the Milky Way's expanse as possible, you'll get more appealing images if you include the horizon. The silhouette of a distant mountain range, or some nearby trees framing your subject, will make your photos more compelling. On calm evenings, nearby lakes and rivers can act like mirrors to reflect the sky, thereby adding impact to your composition.

Try shooting images in both horizontal and vertical orientations. A horizontal image emphasizes features in the landscape and works well when the Milky Way is rising or setting. A vertical orientation is a better choice when you have a tall tree in the shot, or when the Milky Way is arching high overhead.

Once you've got the framing and exposure settings sorted out, consider taking a sequence of shots, one right after the other. You'll want to minimize the delay between each individual exposure, so set your camera to high-speed continuous mode and turn off features such as image review or long-exposure noise reduction — these significantly increase the shot-to-shot time.

An image sequence opens up several important post-processing options. After you've downloaded the individual frames onto your computer, you can stack them together with software such as *Adobe Photoshop*, *Affinity Photo*, *DeepSkyStacker*, or *Sequator*. By averaging the pixel values across a large number of sequential shots, random digital background noise is smoothed out, producing a cleaner photo that allows for more extensive post-processing. Stacking is particularly helpful for removing airplane and satellite trails. (Turn to page 54 of the April 2022 issue for more about image stacking.)

Alternatively, you can combine a sequence into a stunning time-lapse movie. The *Photos* app in Windows allows you to add a set of images to a timeline and then export them as a video. On a Mac, you can do the same thing using *iMovie* or *QuickTime*. Time-lapse sequences shot from a fixed tripod will show the apparent motion of the stars drifting across the sky from east to west. Conversely, those captured on a sky-tracking platform or equatorial mount will reveal the somewhat surreal sight of the Earth's western horizon tilting up to cover the stars, which remain fixed in the frame.

Finally, I always recommend bringing along binoculars or a small, wide-field telescope so you can enjoy views of the sky while your camera busily clicks away in the background. After all, if you've made the effort to travel to a dark-sky location, you have the perfect opportunity to soak in the amazing sight of our home galaxy in real time.

■ **TONY PUERZER** is a retired professional photographer and avid amateur astrophotographer with a constant longing for clear, dark skies. He calls Vancouver Island, British Columbia, home.

The Many Delights of Messier 7

Explore this exquisite open cluster and its marvelous surroundings.

◀ **THE OPEN CLUSTER AND FRIENDS** My rendering captures M7 as I saw it through an 8-inch f/3.3 Dobsonian — specifically, the view through a 25-mm eyepiece, producing a 2.5° field of view and a magnification of 38×. I supplemented details in the drawing with views at higher magnifications. I noted the star colors best with my 30-inch and its silver-coated primary mirror at 95×. This sketch was built up at the eyepiece over six nights during the summer of 2022 while M7 was between 14° and 7° above the southern horizon. Sky Quality Meter readings were between 21.67 and 21.76 during this time. North is up.

It's a lovely summer evening, and as the sky transforms from blue to black, the central portion of the Milky Way becomes visible. Ah, so nice! Look about midway between the stinger stars of Scorpius and the spout of the Sagittarius Teapot and you'll see an obvious naked-eye clump in the Milky Way, which for the last 259 years we've known as the open cluster **M7**.

There are other naked-eye open clusters in the sky — heck, M6 is just a few degrees to the northwest — but that's not what makes M7 special. It's all the extra goodies that do that. M7 is located in a wonderfully rich Milky Way field intertwined with dark nebulae, as well as three other open clusters that overlap or touch its boundaries. There are even three challenging planetary nebulae one can see through the cluster. Perhaps most fascinating of all, there's an NGC globular on M7's western boundary. You can spend an entire evening observing just this one field of view.

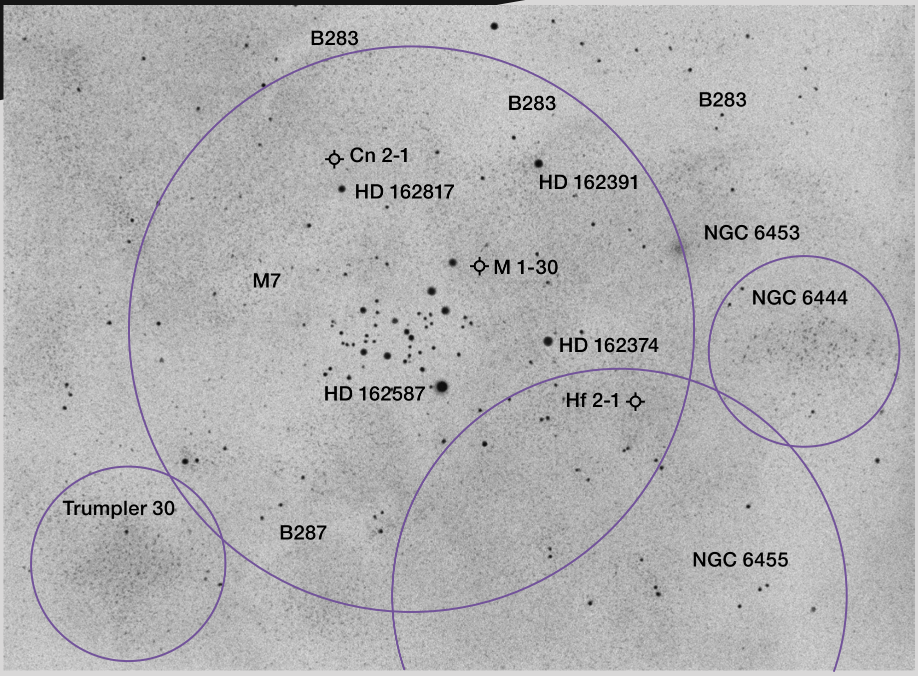
At –34.8°, M7 has the most southerly declination of all the Messier objects. This puts it agonizingly close to the southern horizon during summer in the Northern Hemisphere, where it's in the sky for only a few hours each night. Not surprisingly, objects this low on the horizon almost always suffer from poor to terrible seeing, not to mention *atmospheric dimming*, which happens because we're looking at objects through a thicker air mass. I can only imagine M7's splendor when seen high in a dark sky. The other side of this coin is the rather substantial advantage of not needing to tilt your head back to observe it naked-eye or with binoculars.

Given its eye-level location just above the southern horizon and a visual magnitude of 3.3, M7 is also one of Messier's easiest-to-locate objects. In the second century AD the Alexandrian astronomer Ptolemy described the cluster as a nebula, but humans have certainly known about it ever since they looked up into the night sky. The first astronomer to observe it with a telescope was Giovanni Battista Hodierna sometime before 1654, when he counted 30 stars in the cluster.

Since then, we've learned that M7 is about 910 light-years away and has a diameter of approximately 20 light-years. Its *tidal radius* — beyond which the gravitational forces of the Milky Way have more pull on the cluster's stars than the cluster itself — is

▶ **BY THE SCORPION'S STINGER** You should easily find M7 between the stars of the Scorpion's tail and the Teapot in Sagittarius in the summer Milky Way.

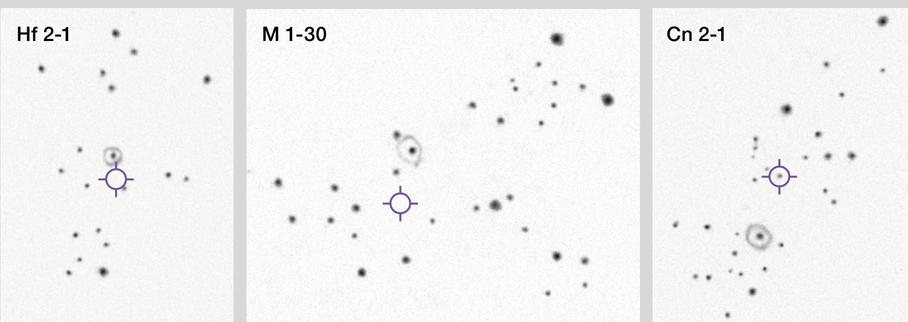
ALL DRAWINGS BY HOWARD BANICH; M7: GARY SERONIK



◀ **MARVELS OF M7** I've labeled the many delights of M7 in this negative version of my sketch. The view spans about 1.5° by 2°, showing the central portion of the 2.5° field of view produced by my 8-inch f/3.3 Dob. North is up.

46 light-years. M7 clocks in at 186 million years old and has a total mass of a little more than 1,000 times that of our Sun. It's a halo-type cluster, in which the most massive stars are concentrated toward the center and are surrounded by their low-density stellar siblings (not to be confused with being located in the Milky Way's halo).

Although early astronomers recorded the numbers of stars they could detect in M7, how many you see at the eyepiece is only one component of this or any other open cluster. For M7, where do you stop counting in such a rich field? To me, the visual character of an open cluster is much more about the brightness and arrangement of its stars. M7's most conspicuous members are mainly arrayed east-west in two somewhat ragged, curving lines of stars. There are many other suns scattered around and within this pattern, but to me these two arcs form the visual backbone of the cluster. The most distinctive member is at the southwestern end of the southerly of the two lines of stars — **HD 162587** is a noticeably yellow *K*3 giant star shining at magnitude 5.6. There are several other yellow stars in the cluster — can you spot them? I found it challenging to discern star colors using my 8-inch f/3.3 Dobsonian, but they stood out nicely in my 30-inch f/2.7 Newtonian.



▲ **PLANETARIES THAT WEREN'T** *Left:* Close but no cigar — the circled star is what I thought was Hf 2-1, with the correct position indicated by the standard planetary nebula symbol. Although I saw Hf 2-1 in 1999 with my 20-inch at 261×, the seeing in 2022 wasn't good enough for me to glimpse this tiny object in my 30-inch at 183×. *Middle:* I didn't see M 1-30 at all, but the circled star responded strongly to the O III filter. *Right:* I had spotted Cn 2-1 during my observing session, but the circled star responded more strongly to the O III filter! Note that the star images at the time of these observations were larger than shown here, not to mention impossible to bring into focus. South is up in all three eyepiece sketches made using the 30-inch at 183×.

Dark Nebulae and Overlapping Clusters

The brightest stars of M7 seem to float in the foreground of the Milky Way. The center of the cluster looks darker than much of the surrounding area, which I first thought was a contrast effect of the bright stars making the background sky appear darker than it really is. That's probably true, but there's also a diffuse dark nebula running through the heart of the cluster.

The best-defined dark nebula superimposed within M7's boundary is **B287**, about ½° south of the backbone cluster stars. The much larger **B283** is just northwest of M7 and is somewhat less defined than B287. There are subtle and more amorphous streams of dark nebulosity all around the cluster, though, and following them can take you in all directions.

Near the western edge of M7 is the open cluster **NGC 6444** — a ragged expanse of stars just bright enough to stand out from the rich Milky Way background. With my 30-inch scope, I see it as faint group elongated east-west that extends right to the edge of M7. It really jumped out with unintentional averted vision while I was observing the nearby globular cluster, NGC 6453, which we'll get to soon.

Overlapping both NGC 6444 and M7 is **NGC 6455**, which is more of a star cloud than a cluster, but it's a beautiful billow of Milky Way stardust.

On the southeastern edge of M7 is **Trumpler 30**, which looks much like NGC 6444 only it's more compact. Situated just east of B287, the outer tendrils of the dark nebula nearly reach it.

Lessons Learned

Three planetary nebulae are found within the boundaries of M7. The 14.0-magnitude planetary nebula **Hf 2-1** is large enough to detect as more than a starlike object if the seeing is steady enough to discern its 9″ disk. The other two planetaries are **M 1-30** and **Cn 2-1**, which are respectively magnitude 14.7 and 12.2 with apparent sizes of 5″ and 2″. All three planetaries lie far in the background of M7, and so — if you spot them — you're peering at them through the cluster.

Interestingly, these three objects are arrayed in a nearly straight line through M7: Cn 2-1 is located about 10′ north of the 6th-magnitude star **HD 162817**, and the other two are lined up to the southwest, spaced about 25′ apart. Their locations are all easy star-hops, but care is needed to identify them. I used my 30-inch one night in August 2022 during poor seeing — star images were huge, shimmering blobs. I blinked the fields of each planetary by holding an O III filter in front of the eyepiece and moving it in and out of view to see which "star" stayed bright. Real stars usually get dimmer with the O III filter, while tiny planetary nebulae will suddenly stand out. Usually. I made careful sketches of all three fields and, considering the strong O III response I got in the right spots, I was certain that I'd seen them all and didn't double-check until I got home.

Oops! I went 0 for 3. Dang. It turns out there's a star near each planetary that responds well to an O III filter, so beware. And now, as I write this article, it's too late in the season to try again.

Globular Cluster

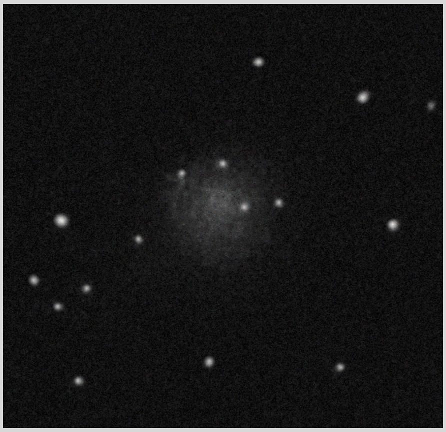
NGC 6453 appears on M7's western border but has no relation to the open cluster other than being in the same line of sight. Recent data place the globular at a distance of approximately 33,000 light-years on the opposite side of the galactic center from the Sun. And NGC 6453, like most galactic globular clusters, is in the halo and lies about 2,700 light-years below the galactic plane, putting it outside the Milky Way's disk. Somehow, in spite of the intervening gas and dust, it still manages to muster a visual magnitude of 9.2, making it accessible to most amateur telescopes. Even if you have little interest in M7, this improbably observable globular cluster is a must-see.

With the 8-inch, NGC 6453 was a small, fuzzy glow without any resolution into individual stars. Even the 30-inch could resolve only a few stars in the cluster, and for all I know they may even be in the foreground.

Depending on the source consulted, the apparent diameter of NGC 6453 is anywhere from 21.5′ to 7.6′ across, and based on my observations, I favor the smaller diameter. If you have trouble finding the globular, you can pinpoint its position by using the 5.9-magnitude stars **HD 162374** and **HD 162391**. NGC 6453 is about 17′ due west of a line connecting these two prominent stars; the cluster serves as the third point of an equilateral triangle.

Which Scope Is Best?

My 30-inch provided easier access to the faintest parts of the cluster — like the three "planetaries" and NGC 6453 — while still being able to comfortably fit M7 into its 1° field. However, the views through the 8-inch were the most breathtaking. Beholding M7 suspended within this magnificent part of the Milky Way through a rich-field 8-inch scope was just wow!



▲ **BALL OF STARS** This drawing shows the globular cluster NGC 6453 as I saw it through the 30-inch at 183×. Do any of the four stars arrayed over the glow of NGC 6453 belong to the cluster? North is up.

■ Contributing Editor **HOWARD BANICH** loves this stuff, even the oops. You can reach him at **hbanich@gmail.com**.

M7's Delights

Object	Type	Mag(v)	Size	RA	Dec.
M7	Open cluster	3.3	75′	17^h 53.8^m	–34° 47′
HD 162587	Star	5.6	—	17^h 53.4^m	–34° 54′
B287	Dark nebula	—	25′ × 15′	17^h 54.4^m	–35° 12′
B283	Dark nebula	—	90′ × 60′	17^h 51.3^m	–33° 52′
NGC 6444	Open cluster	—	12′	17^h 49.6^m	–34° 49′
NGC 6455	Star cloud	—	58′	17^h 51.8^m	–35° 10′
Trumpler 30	Open cluster	8.8	20′	17^h 56.4^m	–35° 19′
Hf 2-1	Planetary nebula	14.0	9″	17^h 51.2^m	–34° 55′
M 1-30	Planetary nebula	14.7	5″	17^h 53.0^m	–34° 38′
Cn 2-1	Planetary nebula	12.2	2″	17^h 54.5^m	–34° 22′
HD 162817	Star	6.1	—	17^h 54.5^m	–34° 28′
NGC 6453	Globular cluster	9.2	7.6′	17^h 50.9^m	–34° 36′
HD 162374	Star	5.9	—	17^h 52.2^m	–34° 48′
HD 162391	Star	5.9	—	17^h 52.3^m	–34° 25′

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.

Priming for PixInsight

Master the basics of the most popular astronomical image-processing software.

Deep-sky astrophotography is a hobby that requires mastering several skillsets. The mechanical know-how needed to record good deep-sky data doesn't necessarily overlap with the skills required to turn all those data into beautiful images. In fact, these days, you don't even need to acquire your own image data — you can buy time on a finely tuned telescope located under dark skies. You can even work with images acquired by NASA observatories like the James Webb Space Telescope. But regardless of where and how our photons are gathered, it takes powerful image-processing software — and an understanding of how to use it — to turn those ones and zeroes into dazzling portraits of nebulae, star clusters, galaxies, and the occasional bright comet.

I have some good news and some bad news. The bad news is there is no "Astronomy Picture of the Day" button in any software I've seen — you really have to work the image data carefully to produce a nice result. The good news is that it doesn't take many steps to get there. And while there is a host of software you can use, among the most popular for amateurs today is *PixInsight*, or *PI* (**pixinsight.com**). This program operates on any platform and is written by astrophotographers *for* astrophotographers. It uses a modular, open-architecture system that encourages users to develop their own add-ons and scripts, which in turn fosters the growth of a large online community to share these improvements. *PI* can cover most any task you'll likely encounter in astronomical image processing. And while it was developed with a focus on deep-sky imaging, it has many tools to improve lunar, solar, and planetary images. Here are

▲ ***PI* CAN DO IT ALL** *PixInsight* is a versatile astronomical image-processing workhorse suitable for deep-sky imagery as well as nightscapes and even planetary photography. While it has hundreds of processes and scripts, only a handful were needed to produce this deep, colorful photo of M31 in Andromeda.

ALL IMAGES COURTESY OF AUTHOR

some basic processing steps that I use that will illustrate the program's utility.

The Main Controls

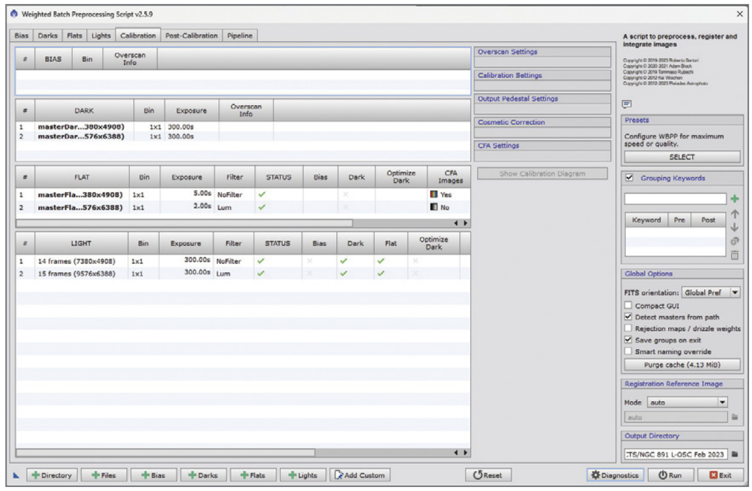
Knowing your way around the *PI* workspace is essential to getting the most from the software, so it's worth spending some time learning its user interface before you start working on your pictures in earnest. There's a free, 5-part video series to help show you the ropes at **https://is.gd/PIprimer**.

However, if you just want to get straight to using the program's tools, you'll find them grouped in subfolders within the ***PROCESS*** pulldown menu located at the top of the screen. You can also display an alphabetical list of all the processes by selecting ***PROCESS > All Processes***. Users can combine several of these into another type of command called *scripts* that are listed within the ***SCRIPT*** menu, which is also subdivided into several groups. A script executes a sequence of tasks, automates complex operations, or otherwise extends *PI*'s capabilities.

You'll also find some useful tabs along the left side of the workspace. The ***Process Console*** reports the progress of any actions being executed and lists warnings or errors if encountered. The ***History Explorer*** stores and displays everything done to an image and allows you to quickly go back to a previous state if needed. Double-clicking a process name in the History Explorer opens that process with the settings that were used.

Data Reduction

The first step in converting a set of raw data into a finished photo — an exercise known as *data reduction* — uses the ***WeightedBatchPreprocessing*** (WBPP) script. WBPP is a little like the conductor in an orchestra made up of various *PI* processes, telling each one what to do and when to do it. For example, the script creates one master image per color filter from all the individual sub-exposures and calibration frames.

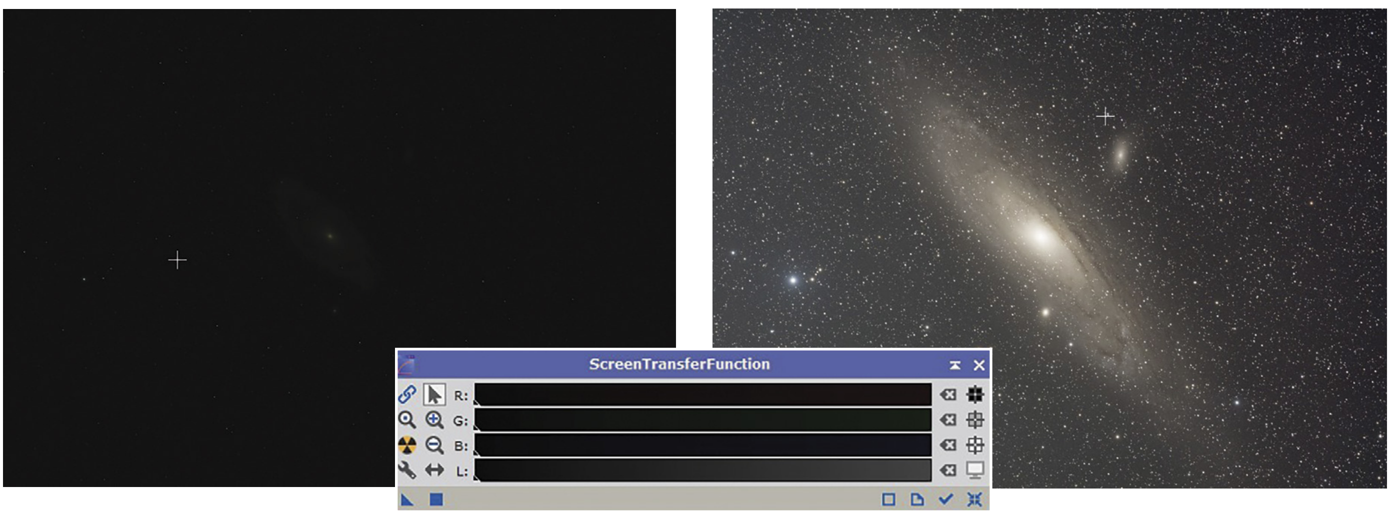


▲ **CONVENIENT CALIBRATION** The ***WeightedBatchPreprocessing*** script is the first step in producing an image from raw and calibration frames, orchestrating every aspect of data reduction. It includes the essentials of calibration, alignment, stacking, and other advanced features.

It then completes all the data-reduction steps for your light exposures, including calibration and alignment before stacking them into a single image ready to be worked up into a pretty picture. The WBPP script examines each image and ranks it by quality to use the most data from the best subframes, with less contribution coming from the lower-quality images included in the stack. The subframe image quality is evaluated by measuring each image's signal-to-noise ratio as well as the full-width, half-maximum (FWHM) parameter that examines the size and shape of stars.

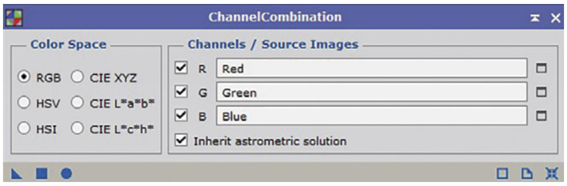
To use the WBPP script, launch it and then load all your calibration and light frames using the ***+File*** or ***+Directory*** buttons at the bottom of the script window. The program will automatically put the files in the proper locations in the script window using the information recorded in each file's FITS header. (You can inspect the FITS header of an

▼ **DETAIL IN THE DARKNESS** Straight out of the camera, images look almost entirely black, but there is detail hiding in the shadows. The ***ScreenTransferFunction*** process performs a screen stretch on linear images to display the detail in the dark areas without altering the underlying data.



open image using ***FILE > FITS Header***). If your acquisition software doesn't write this information into the FITS header, load the files using the ***Add Custom*** button at the bottom of the script window and input the details manually. You'll need to verify the settings on each tab and specify an output folder. When ready, run the script; it'll warn you of any potential issues before running.

PALETTE ASSEMBLY The ***ChannelCombination*** process (below) was used to make the color photo of M31 at far right from images taken with a monochrome camera and blue, green, and red filters (seen left to right, respectively).



Once the master frames are all generated, you're ready for the next step. Note that color images may come from using a color camera or can be made by combining red-, green-, and blue-filtered monochrome images. In the latter case, you'll need to combine the filtered shots into a color image using the ***ChannelCombination*** process, where you'll assign each filtered master file to its proper channel.

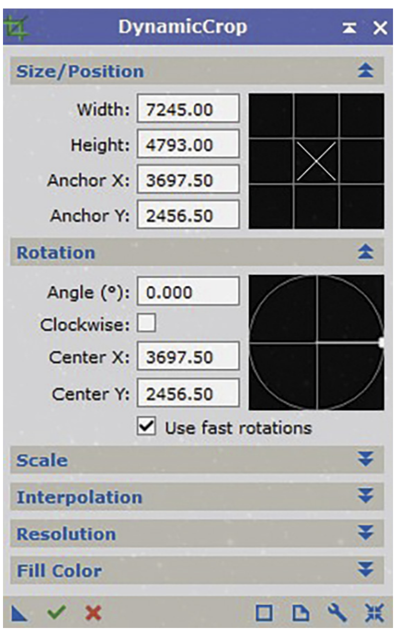
While your camera's files will most likely be in the FIT format (or RAW files from DSLR cameras like CR2 or NEF), *PixInsight* saves images as Extensible Image Serialization Format (XISF) files by default. This format saves more information about the processes applied to the file than other types. Still, the software can open and save files as FIT, TIF, PNG, BMP, JPG, and more.

As with most any unprocessed deep-sky image, the raw frames or reduced masters generated by WBPP appear virtually all black, with a smattering of bright pixels marking the location of the brightest stars. This is normal — the images aren't actually black, they're just very, very dark because your monitor can't display the full range of brightness present in the images. This is simply a result of the data being in a *linear* state, meaning that the brightness of each pixel is proportional to the number of photons that fell on it.

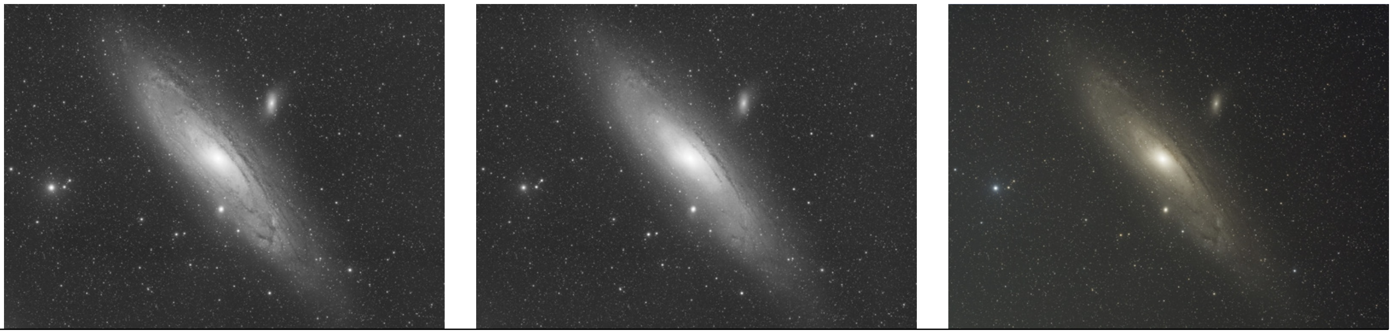
Visualizing Raw Data

Many of the early steps in deep-sky image-processing are applied to linear files. To make an image that shows the wealth of detail you desire, you'll need to selectively brighten the image while preventing the brightest pixels from becoming saturated and keeping the background dark. This *stretching* process results in a non-linear image that displays subtle differences in brightness and hue. Most of the final finishing in image processing is done on images after stretching.

NO CRUST, PLEASE It's important to crop out non-overlapping areas along the edge that result from aligning and stacking images. You use the ***DynamicCrop*** process for this. This step also allows you to adjust the framing of the composition.



However, linear images don't display very well, making processing decisions tricky. Enter one of *PixInsight*'s most helpful features, the ***ScreenTransferFunction*** (STF) found at ***PROCESS > IntensityTransformation > ScreenTransferFunction***. STF brightens and applies contrast and color balance to the displayed image without changing the underlying data. You can apply STF by pressing Ctrl + A (or Cmd + A on a Mac), but you'll need the process window open to finesse its settings or to reset it. It's important to reapply the STF tool each time you make a change to the image for it to display correctly. (When using the tool on color images, be sure to uncheck the chain-link icon at upper left of the process window until after you've balanced the color as described later.) It's well worth reading the tool's accompanying documentation, avail-



able by clicking the document icon at the bottom right of the process window.

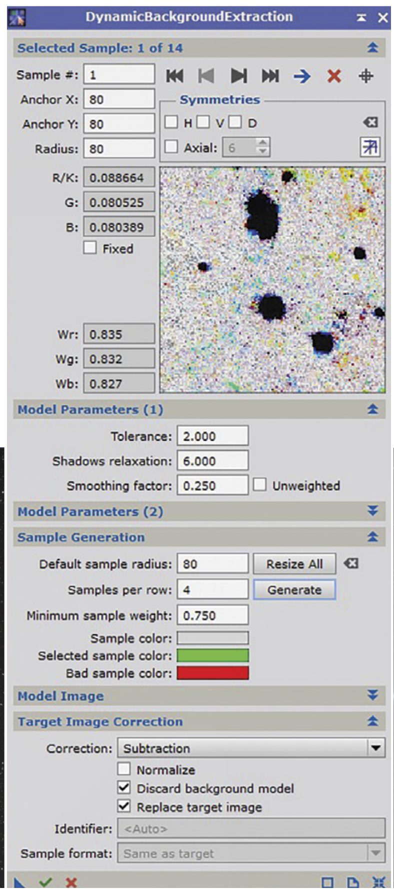
The next steps in my basic linear workflow involve removing unwanted signal from my images. I start with a ***DynamicCrop*** process to eliminate any edge artifacts that could negatively affect the picure, such as non-overlapping areas due to dithering or other pointing differences when shooting my target over multiple nights. This is accomplished using ***PROCESS*** > ***Geometry*** > ***DynamicCrop***. In the process window enter the size you want to crop to in the Size/Position section, and the angle of the crop in the Rotation section. You can also make these adjustments by manipulating the preview of the crop with the mouse. When ready, click on the Execute (green checkmark) button at the bottom left of the process window.

With a nicely framed image in hand, I then perform another STF stretch to check the image for *gradients* — uneven field illumination, often due to moonlight or light pollution. Imperfect flat-field calibration can also add gradients to your image. Fortunately, there are two powerful processes in *PI* to tackle this problem. ***AutomaticBackgroundExtractor*** (ABE) works reasonably well, with little or no adjustments. When activated, you'll need to specify the type of correction to make and whether the ABE should replace the current image or generate a new image.

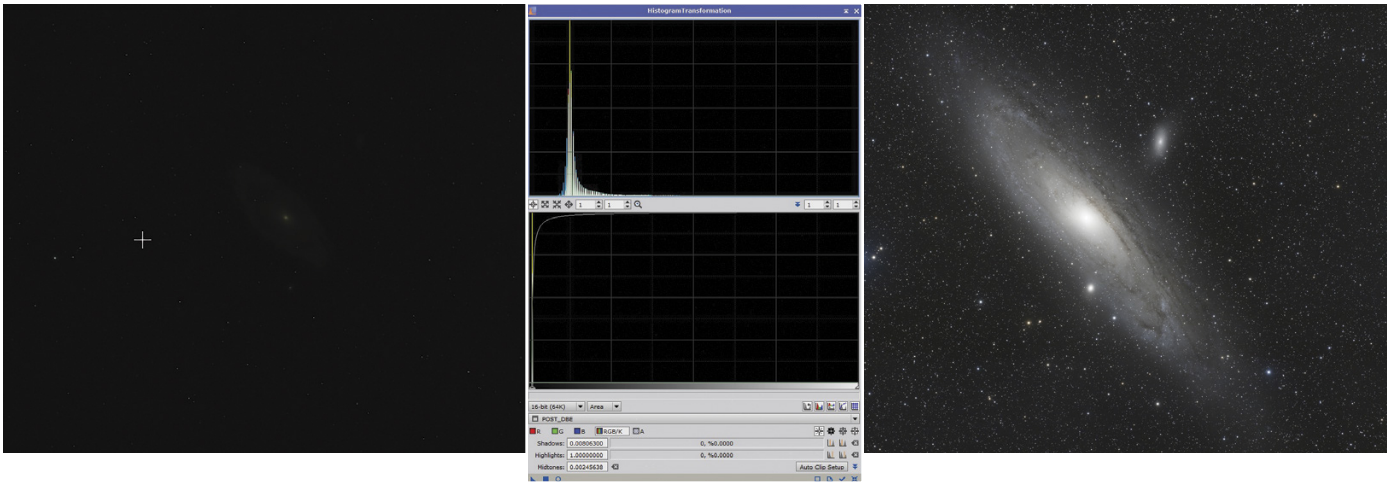
The more complex ***DynamicBackgroundExtraction*** (DBE) tool produces superior results compared to ABE. I highly recommend investing the time needed to master DBE, since most deep-sky images will have some gradients, and DBE can remove them effectively. DBE requires you to place points (called samples) in the background regions of your image. It then builds and applies a background model. Since gradients are large-scale, just a few sample points will do. In this window, I typically increase the Tolerance to 2.0 and the Shadows Relaxation setting to 6.0 in the ***Model Parameters (1)*** section. Then I move down to the ***Sample Generation*** area and change the Default sample radius to between 50 and 100 pixels and the Samples per row to 3 or 4 in order to get a good estimate of the background. This typically produces a dozen or more sample points, which results in a good representation of the gradient I want to correct.

With gradients addressed, I then move on to establishing the image's color balance. *PixInsight*'s ***ColorCalibration*** process works very well on RGB or natural-color

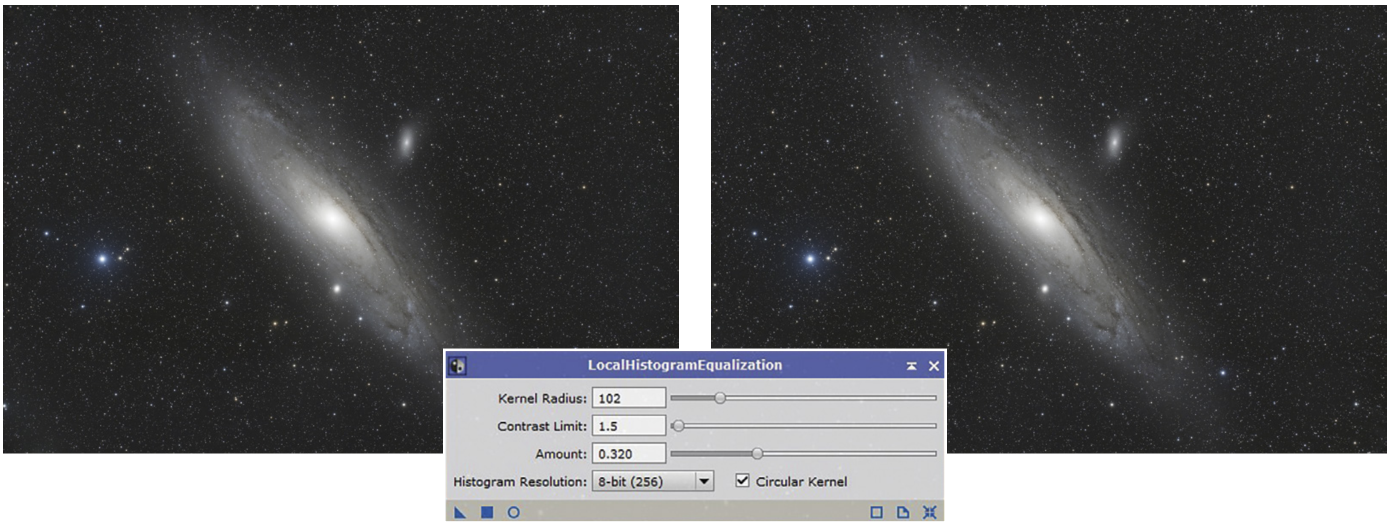
▼▶ **GRADIENT SUPPRESSION** Using the ***DynamicBackgroundExtraction*** process removes uneven field illumination that results in brightness gradients like the greenish brightening in the left side of the image below and corrected in the result at right.



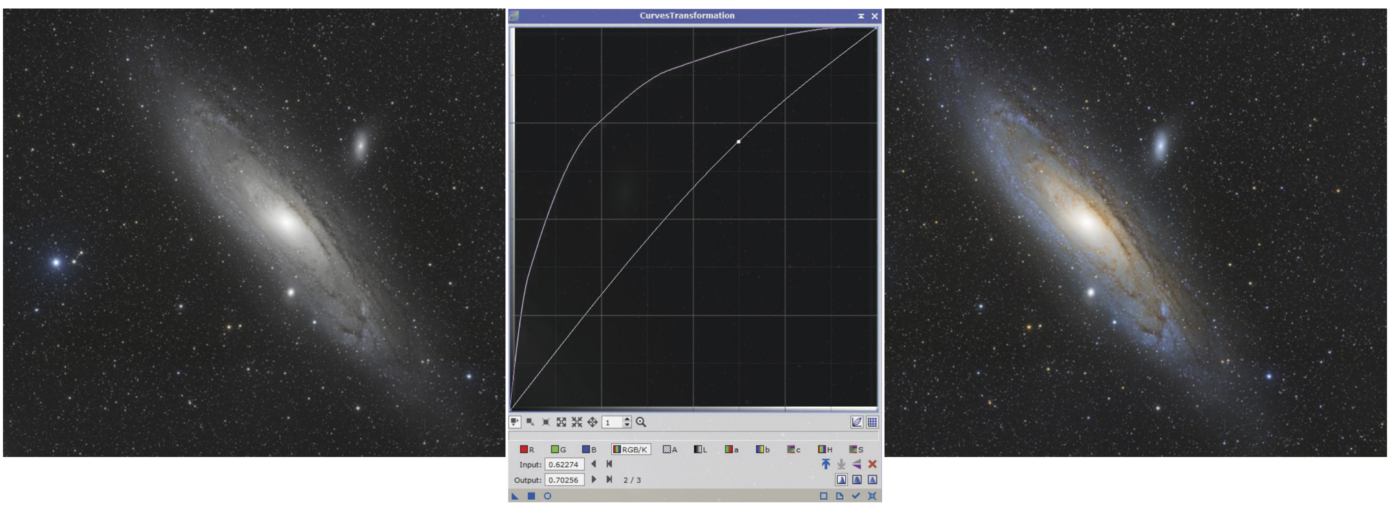
▼ **BIG STRETCH** The ***HistogramTransformation*** process is where you'll permanently stretch the image. The ***ScreenTransferFunction*** settings can be conveniently transferred to this process with the click of a mouse and then adjusted, if necessary, before being applied to your photo.



▼ **MORE CONTRAST** After you've stretched your picture (left), you can apply ***LocalHistogramEqualization*** to boost low-contrast regions in your image (right). It can be used in multiple passes to enhance both small- and large-scale features.



▼ **FINAL TWEAKS** The ***CurvesTransformation*** tool allows you to adjust any individual color channel's brightness and saturation. All the picture at left needed was a saturation boost and a little increase in overall brightness (center) before it was suitable for displaying on the web (right).



images. To use this process, I specify the location of a background region, which is used to color-balance the darkest pixels in the image. It then discerns the location of stars in the image and uses them as the ***White Reference***. Here I'll click Alt + N (Option + N on a Mac) to enter New Preview mode and define a small preview containing just background sky. I then set this preview as the Reference image in the ***Background Reference*** section and click the square at the bottom left to apply the process.

After balancing the color, be sure to invoke a STF with the chain-link icon at the left of the process window activated in order to link the color channels. Narrowband images also require adjustment to obtain a pleasing color palette. However, color balance with representational color is fairly subjective and can be approached differently (*S&T:* June 2022, p. 36).

The last step before non-linear stretching is to address any unsightly noise in the image. All deep-sky images contain some noise, and it tends to be most visible in the darkest regions of the picture. *PixInsight* includes several noise-reduction tools that are fairly complex to operate, so I prefer Russ Croman's ***NoiseXTerminator*** (NoiseXT) available at **https://is.gd/NoiseXT** ($59.95). This plug-in works better than any other method and is extremely easy to use. Once installed, you'll find it under ***PROCESS*** > ***NoiseReduction***.

Non-linear Processing

With the linear processing steps now complete, I can apply a permanent stretch to make the image non-linear. This is done using the ***HistogramTransformation*** (HT) process in conjunction with the STF process. First open STF, click on your image, and then click Ctrl + A. Next, copy the settings by clicking and dragging the New Instance triangle at the bottom left over to the bottom bar of the HT window. You can then adjust the shadow and midtone sliders to suit your taste, and then apply to the image by clicking the square button at the bottom left of the process window.

If you'd rather perform this task manually, the adjustments are made in the HT window using the sliders in the lower graph, while the predicted result of the stretch will be displayed in the top histogram. I begin by moving the midtone slider to the left until I start to see the histogram peak move away from the left side of the graph. Then, using the scroll wheel on my mouse, I'll zoom in on the bottom graph and adjust the shadow slider. I move it to the right, where the histogram begins to rise steeply. At this point ensure the STF is turned off by hitting the Reset button at the bottom-right corner of the STF window. Next, open a Real-Time Preview by clicking the open-circle icon in the bottom left of the HT window. While looking at the preview image and the histogram, I'll adjust the midtone slider again to achieve the look I want. I then click the square Apply button at the bottom left, and in moments the result is displayed.

After stretching, there are many additional enhancement options in *PixInsight*. Most astrophotographers make further adjustments to the brightness, contrast, hue, saturation, and sharpness. These steps can turn a good image into a *great* one. Boosting contrast is particularly important and is performed with the ***LocalHistogramEqualization*** (LHE) process. This tool is very powerful, so it requires a light touch. The Amount slider adjusts how much contrast boost is applied. Be aware that, particularly when using a small kernel radius, LHE can generate artifacts that appear as dark rings around stars, which require masks and other more advanced techniques to prevent.

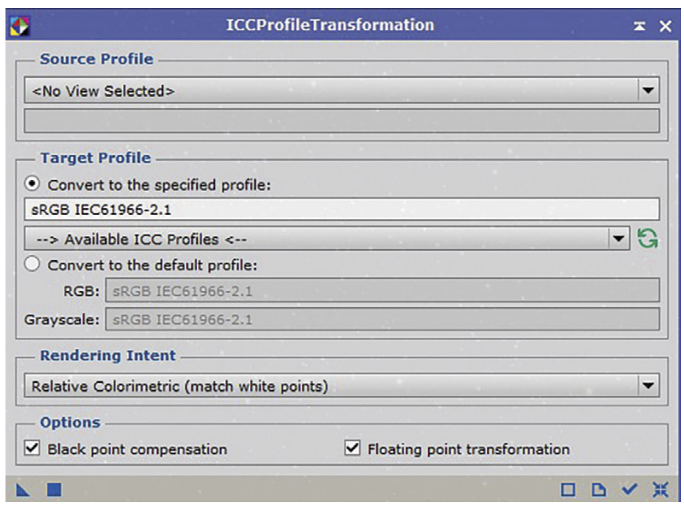
I often finish up with the ***CurvesTransformation*** process, adjusting the RGB/K (which controls brightness and contrast) and Saturation (S) curves.

Finally, when I'm ready to share my image with friends, it's helpful to embed a color profile in the JPG file. This tells web browsers and devices like printers and monitors how the colors in the image should be displayed. I use the ***ICCProfileTransformation*** process to ensure that my shared JPG images contain the sRGB color profile that is widely used by default.

In Closing

PixInsight is one of the most popular software packages for processing just about any kind of astronomical image. It's extremely versatile, though it takes some time to familiarize yourself with its collection of hundreds of processes and scripts — not to mention all the additional scripts and processes developed by other users. Beginners can get good results by setting the simple goal of mastering the user interface and the tools described above. As your skills improve, you can add other processing steps, but the ones I've highlighted will likely always be at the center of your workflow.

■ Contributing Editor **RON BRECHER** hosts *PixInsight* image-processing workshops at **mastersofpixinsight.com**.



▲ **DO YOU SEE WHAT I SEE?** Before saving your image as a JPEG to share or print, make sure other devices know how it should be displayed. Use the ***ICCProfileTransformation*** process to embed the sRGB color profile in your image that provides printers and display devices the correct color information.

The Vespera Digital Telescope

This little refractor makes astrophotography easier than ever. Is it worth the price?

Vaonis VE50 Vespera Exploration Station Digital Telescope

U.S. Price: $2,499
vaonis.com

What We Like

Ease of setup and use

User-friendly mobile app

Useful mosaicking feature

What We Don't Like

Limited battery life

Poor focus on Moon and Sun

SMART TELESCOPES, observing stations, or whatever you want to call the growing crop of cyborg scopes that meld digital imaging technology with semi-autonomous optics are finding their way into the amateur community. It's not uncommon to see one of these devices on the observing field at your local astronomy club, or particularly at a public outreach event.

These instruments are different than most — for one thing, they don't have a conventional eyepiece at all. Instead, the objective illuminates a tiny camera that sends its images wirelessly to a paired smartphone or tablet, where an image of the targeted nebula, galaxy, or star cluster slowly builds up on the device's screen. The "views" they produce are in most cases far better than you could see in an eyepiece on a much larger scope, and are in color.

Vaonis, the French company that released the first "smart telescope," the Stellina (*S&T:* Mar. 2020, p. 68), follows up on its success with the smaller, lighter, and less costly Vespera Exploration Station. This little device improves upon many of the original model's features while shrinking the package to a truly portable size.

I was loaned a Vespera along with several of its accessories at the end of 2022 to see how well it performs.

▲ Vespera is a 50-mm refractor with everything necessary to capture images of the night sky entirely contained within its pill-shaped body.

▶ Vespera's four-element, 50-mm objective is surrounded by a removable filter ring (top) that also covers the mounting position of the optional moisture sensor (seen at right).

Telescopic Jelly Bean

The Vespera is a 50-mm f/4 quadruplet apochromatic refractor with an integrated color video camera. Its Sony IMX462 CMOS sensor has an array of 1,920 × 1,080 pixels, each 2.9 microns square. Given the telescope's 200-mm focal length, the system produces 3.99 arcseconds per pixel. The 2-megapixel chip offers a field of view of 1.6° by 0.9° — enough to accommodate the full Moon (or the Sun) with room to spare.

This shiny, white plastic device looks as if it were a prop from a science-fiction movie set in the near future. There are no sharp angles on the body when it's closed. The optical tube assembly and camera ride within a single-arm fork, and its base connects to a 20-centimeter (8-inch) tripod using a standard ⅜ thread, so users can mount the unit to their own tripod if desired. An optional extendable tripod is also available for $149. The Vespera is powered with an internal, rechargeable 7,000 milliamp-hour (mAh) battery. There's a single port near the bottom of the device for the charging cable.

Also built into the system is an electronic focuser, altitude and azimuth motors, and the associated electronics. Vespera weighs about 5 kilograms (11 pounds) and measures 38 cm (15 inches) tall, 20 cm wide, and 9 cm deep, not including the tripod.

Unlike its predecessor, this model does not include a built-in dew

ALL IMAGES COURTESY OF AUTHOR

control system. Instead, users in damp climates are encouraged to purchase the optional Vespera Hygrometer Sensor ($99), which keeps the optics free of dew and frost. Considering the device stands about 60 cm from the ground, it's pretty much a requirement for using it anywhere but in a desert.

How It Works

Before observing with Vespera, you need to download and install the *Singularity* app on whatever devices you'll use to control it. I used a Samsung Galaxy S21 smartphone and a Galaxy A7 tablet Lite. Each device controlled the telescope well. I also tried to load the app on my old iPad Mini III, but the software only runs on iOS 14 or later. The app loaded effortlessly on each Samsung device, and there was little difference between operating the telescope on each, except the larger screen of the tablet produces a much bigger picture — particularly handy if you're sharing the view with others.

You also need to charge the battery via the supplied USB charging cable. It connects to the unit via a magnetic interface, which will only attach when you line up the polarity of the magnets correctly. This wasn't too difficult when charging the Vespera indoors. However, Vaonis states the battery should power the telescope for roughly 4 hours, so users may need to connect an additional battery when the charge gets low. In the field, connecting the magnetic cord proved somewhat awkward since the socket is at a slight angle on the curve and near the base of the unit.

Once Stellina is secured to the tripod, you set the assembly on the ground or on a sturdy bench and level it by adjusting the three tripod feet, aided by the included bubble level, which connects magnetically to the power port. Once set, remove the level then touch the big round power button, whose rim will glow (annoyingly) blue.

To begin an observing session, launch the *Singularity* app. It'll first prompt you to input your email address and the activation code included in a card packed with the device. Next, the

▲ *Left:* Vespera includes a bubble level that magnetically attaches to the power port located near the bottom of the base. *Right:* Charging the Vespera's internal battery (good for 4 hours of use) requires connecting a magnetic power cable. While not a challenge indoors, the angle of the port makes it difficult to connect to if you need to add more power while the telescope is in use in the field.

app prompts you to connect to the telescope via Wi-Fi, which you do the same way you would with any other Wi-Fi network via your device settings.

Once the app successfully connects to Vespera, it begins its initialization process, determining your location and the current date and time via your mobile device. If it's not yet dark, the app warns you that the telescope may not be able to initialize until after astronomical twilight. There's also an option for Solar mode, which bypasses the star-alignment routine and finds the Sun based on the time and your GPS location. (Smartly, this mode will only work with the optional solar filter installed.)

Once it's dark enough, Vespera points about two-thirds the way to the zenith, rotates a little in azimuth, and shoots an image. The app then displays a series of notifications that report its progress, including "Field of star analysis" as its computer compares the image to an internal star atlas — a star-field recognition technique known as *plate solving*. Next, it takes a series of images and adjusts the focus to minimize the star sizes. After about five minutes, the app reports that it's ready for you to choose a target.

Touching the "ringed-planet" icon at the bottom of the screen presents a list of recommended targets, including Messier, NGC, IC, and Collinder objects as well as bright stars, dark nebulae, and the brightest comets visible. This is quite an improvement over the first release of Stellina several years ago, which was limited to slightly more than 125 objects. When you tap an object, the app gives information about it, including its various designations, a

▲ The tripod attaches to Vespera's azimuth axis via a ⅜ thread, commonly found on heavy-duty photo tripods. *Right:* Each tripod foot is adjustable to permit leveling on relatively flat surfaces.

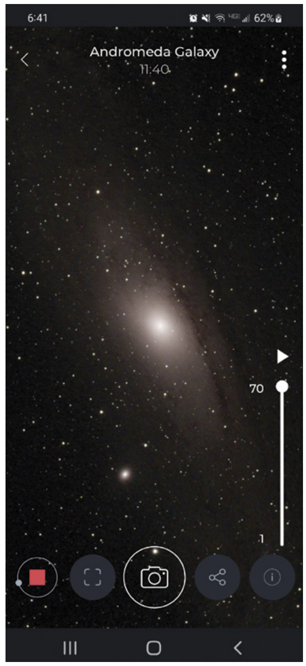
brief description, object type, discovery date, and its distance, size, magnitude, right ascension, and declination. If you tap the little blue triangle to the right of each listing, you get even more details.

Once you choose a target to observe, Vespera slews to its position in the sky, with the app displaying the message "Approaching (name of target)" and a little factoid below usually having something to do with the speed of light and how it relates to your chosen target (how long it would take to get there, or the size of the object in light-years). Then Vespera shoots an image, compares the star patterns to its onboard database ("Checking position accuracy"), and refines its pointing as needed to center the target in the camera's field of view. Finally, it begins recording a series of 10-second images and stacks them to accumulate more light and slowly improve the picture.

Easy Imaging

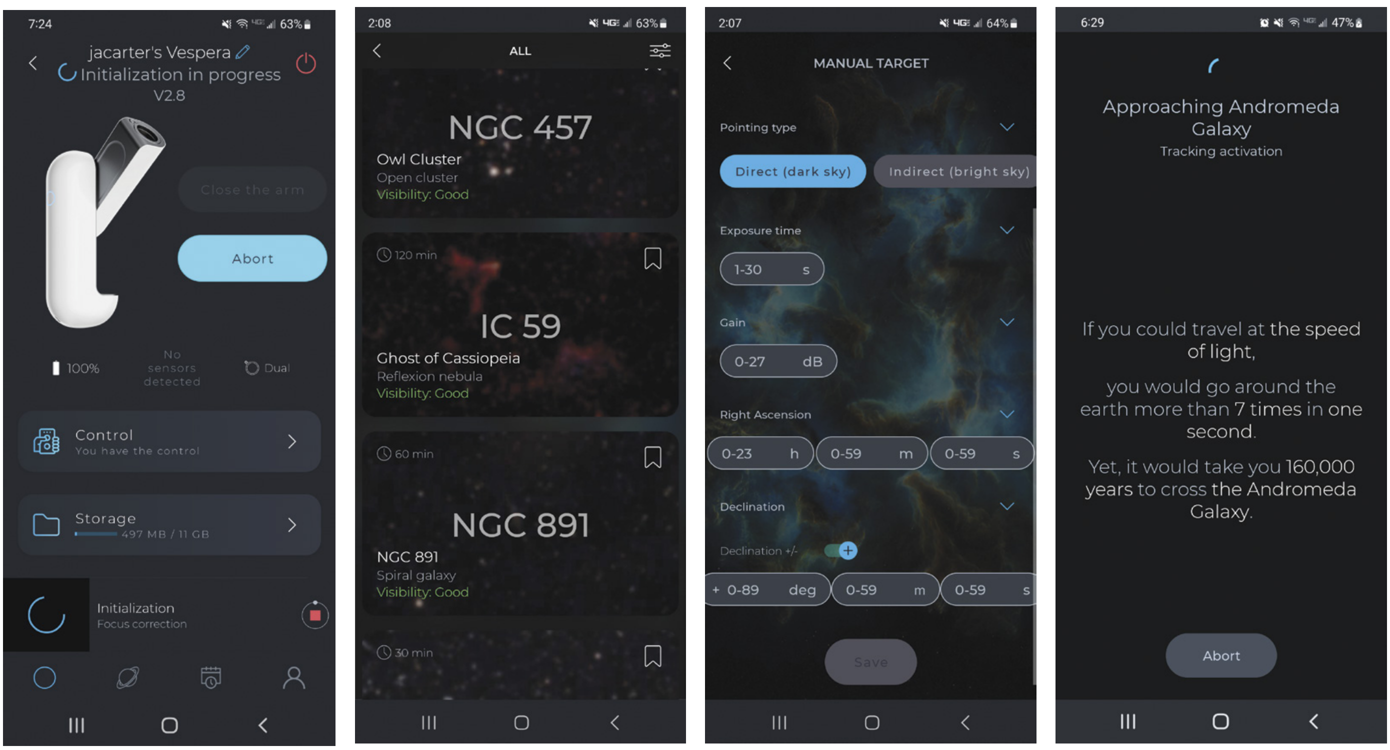
On my first evening with Vespera, I began by targeting M27, the Dumbbell Nebula in Vulpecula. When the initial image appeared on my phone's screen, it was a little off-center and kind of resembled a low-power eyepiece view, except it was in color. As each new 10-second exposure was added to the stack, additional stars appeared in the field, and the outer "wings" of the nebula began to become visible. As more exposures accumulated, a slider on the lower right edge of the screen permits you to step through earlier versions of the stack all the way back to the first image.

As the image accumulation continues throughout the observation, non-overlapping areas are cropped out, and the field of view shrinks a bit, which has the effect of slightly zooming in on the target.



◀ As the system stacks more exposures, the displayed image gets more detailed — dark lanes in M31 begin to become visible, for instance. At the lower right is a slider that lets you pan through all the states of your image as each new exposure is added. Hitting the camera icon saves the image to your device's photo gallery.

After 30 minutes of exposure, the image looked pretty good, particularly considering the limited effort it took to capture. The focus was sharp, and the results looked quite similar to some of my first successfully guided deep-sky astrophotos taken with an 8-inch Schmidt-Cassegrain back in the days of



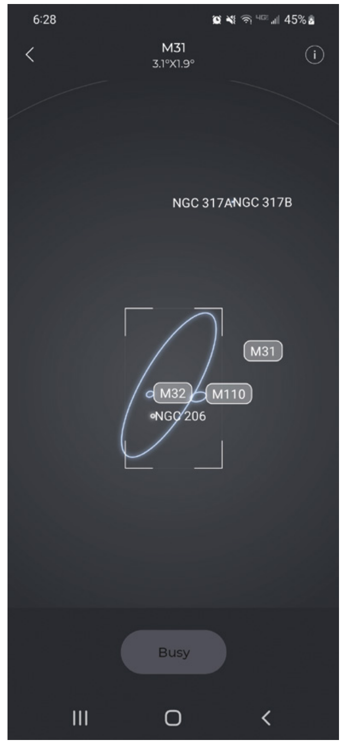
▲ *Left:* The *Singularity* control app connects to the Vespera via Wi-Fi and immediately enters an initialization process. The Saturn-like icon opens a long list of visible objects (shown middle left) selected from all of the popular catalogs, including Messier, NGC, IC, and more. You can sort the list by name and altitude, and you can hide targets as they drop below the horizon. *Middle right: Singularity* also offers manual controls over the system, with which you can change the exposure length and camera gain as well as input a target's right ascension and declination coordinates. *Right:* Once you've selected an object, the telescope begins to slew to it. As it does so, the app often shares some facts about the speed of light and how it relates to the object.

film photography and manual tracking. It was certainly a photo that any beginning astrophotographer would be happy with.

I then went on to a few other objects that night. With the very first 10-second exposure, the Double Cluster in Perseus looked much like the eyepiece view through a larger telescope. The gibbous Moon was up, so I slewed over to see how the scope performed on its cratered landscape. The first image wasn't quite in focus, so I slewed to the target again, which forces the device to also refocus, and after a minute the little scope produced a sharper lunar portrait. Sharper, but not really *sharp*. The image looked fine on my smartphone screen, but when I zoomed in, it was still rather soft. This is where the Vespera's limited 50-mm aperture and 200-mm focal length become apparent. Focus with the Moon was inconsistent and never very satisfying. And while it's good news that the Vespera is the first smart telescope that can automatically find and image the Sun (with the supplied solar filter), the images were not particularly impressive, and focus was a hit-or-miss endeavor, requiring re-targeting the Sun several times until I got an acceptably focused picture.

Fainter deep-sky objects weren't visible on the screen until Vespera had combined several images. The manufacturer offers several filter accessories for the Vespera. Unlike the Stellina, which claimed to have some form of built-in light-pollution correction, the Vespera requires adding the optional, $199 Vespera Light Pollution (or City Light Suppression) Filter to get better results under suburban conditions. I tried the filter on moonlit nights, and it seemed to improve the views. Also available is a Dual Band Filter ($399) that passes both hydrogen-alpha and oxygen III wavelengths.

With the CLS filter in place, I got a decent color image of NGC 6888, the Crescent Nebula in Cygnus, after about 30 minutes. On another moonless night, I captured a nice image of B33, the Horsehead Nebula in Orion, without needing a filter.



▲ Users can expand the field of view covered by the Vespera's detector by selecting the Mosaic button to the right of the Observe button. This opens a screen with a map of your field of view. Simply drag the brackets away from your target to expand the field. The resulting mosaic of M31 (left) covers almost three times as much area as a single pointing.

The Vespera diligently shot this 1-hour mosaic of NGC 1499 in Perseus while the author was observing with another telescope nearby.

▲ The Vespera can image the Moon and, with the optional solar filter, the Sun. However, the device had a hard time focusing on both targets, requiring several tries before a serviceable image was produced.

More than Automatic Imaging

The *Singularity* app lets you save images three ways. From within the app, you can select JPEGs and TIFF images that are saved within your personal gallery in the app itself. The third option is to save FITS images that you can process later. I found it was fairly easy to achieve a better result with FITS files by using my preferred astronomical imaging program. Exporting FITS images increases the usefulness of the Vespera as you gain more experience and desire better results than the JPEGs the *Singularity* app automatically produces.

The app also includes manual controls so that you can point and image pretty much any object in the sky as long as you know its right ascension and declination coordinates. You can also increase the individual exposure length and camera gain to achieve a better signal overall.

Although the 2-megapixel Sony IMX462 sensor is pretty small by today's standards, the *Singularity* app offers a mosaicking mode that lets you capture larger targets than can fit on the detector. I used this mode while imaging several objects, including M31 in Andromeda, M45 in Taurus, NGC 1499 in Perseus, and M42 in Orion. The app lets you define the entire field you wish to capture, then sets off recording, stacking, and stitching the images. It did a pretty good job, but it's worth noting that you would need a lot more exposure time compared to a single pointing in order to get a good signal-to-noise ratio in the resulting picture — it has to make several overlapping pointings to fill the designated field.

Up to five smartphones and tablets can connect to Vespera simultaneously, permitting everyone to watch the image build up on their own devices, which could be fun with a group of friends, family members, or attendees at an outreach event. It certainly increased interest among my neighbors when I showed them how to connect to the device and see the images appear on their own smartphones.

◀ The Vespera's power button, like the Stellina's before it, lights up blue when the device is on and connected. Unfortunately, it's still bright enough to ruin your dark adaptation. Thankfully, you don't need to be close by to connect to the device.

Final Thoughts

The Vespera is a completely integrated system suitable for many types of observers. Its light weight makes it extremely portable, particularly if you purchase the optional backpack ($149) and take the device hiking, camping, or on other trips. Experienced observers involved in outreach will value its ease of use and the color images it quickly produces. And it bridges the divide between most older amateurs and younger generations, which spend much of their time experiencing things through their smartphones and other digital devices.

So, is Vespera worth its price? Putting together your own setup that can do everything that Vespera does will cost about the same, and perhaps even a bit more. And each individual piece you buy will have its own learning curve. Compare that to this device, which you can purchase fully integrated. You can power up and be ready to go on your very first night out. And that convenience is hard to beat. The Vespera produces pretty good images of deep-sky targets right out of the box, and users can improve on the results if they desire. I feel that really expands Vespera's usefulness far beyond its initial "wow" factor.

■ Associate Editor **SEAN WALKER** images the night sky from his home in Litchfield, New Hampshire.

Shattering the Glass Ceiling

THE SKY IS FOR EVERYONE: *Women Astronomers in Their Own Words*

Edited by Virginia Trimble & David A. Weintraub
Princeton University Press, 2022
504 pages, ISBN 9780691207100
US$29.95, hardcover

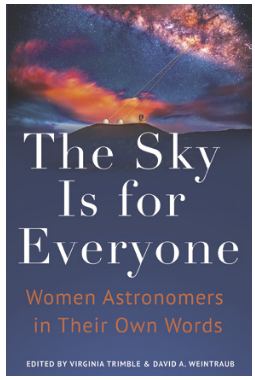
"DEAR MISS TRIMBLE: We have reviewed your qualifications and conclude that we cannot deny you admission to the California Institute of Technology. We think, however, you might be happier elsewhere."

So began the letter admitting *The Sky Is for Everyone* coeditor Virginia Trimble to graduate school in 1964. The familiar notes in her story — from this begrudging acceptance and the pressure to attain "undeniable" excellence, to Trimble's later scientific triumphs made possible by her firmly disagreeing with Caltech that she might be "happier elsewhere" — echo through all of this book's autobiographical essays.

In *The Sky Is for Everyone*, Trimble and coeditor David Weintraub present the stories of 37 professional women astronomers. The featured writers hail from 19 countries and have followed a variety of paths: We hear from theoretical astrophysicists, observers, telescope builders, and administrators. Their essays are organized chronologically by PhD year, spanning from 1963 to 2010.

Each writer has a distinctive approach and voice. Some offer clear chronologies of their careers, while others detail collisions with sexism, bureaucratic battles to carve out equitable working conditions, and triumphs of their professional and personal lives. Some emanate palpable frustration, others a radiant joy or a dogged determination to succeed.

Still, as one moves from chapter to chapter, it's striking to catch the common threads that run through a diverse array of stories, voices, and backgrounds. Women in astronomy are often asked to talk about their experiences as *women* scientists, with a sometimes stifling emphasis on the first word. In allowing the *scientist* side of their authors to come through as well, the editors have helped several unifying themes of the book rise authentically to the surface.



Nearly every chapter delves into its author's research specialty, and we learn what scientific mysteries propelled them through their careers. The result is a wonderful amalgam of the personal and the professional; even the book's pictures combine family snapshots, astronomers grinning in photos taken at telescopes or conferences, and scientific material drawn straight from journal papers and lab notebooks.

The harsh realities of sexism are also omnipresent. Salary inequities, antiquated attitudes towards marriage and family, and outright harassment regularly appear. One recurring comment I found telling was the number of women who related a tale of stark discrimination alongside disbelief that it had happened in their day and age, regardless of whether that day was in the 1960s or the 2010s. It's a subtle reminder that stories from decades past can't simply be written off as the "bad old days" and that regressive attitudes towards women in science can sometimes simply change rather than disappear.

The Sky Is for Everyone also tracks the steady evolution of how women scientists built a career in astronomy. The editors' introductory chapter highlights centuries of scientists who could only gain access to the world of research through their husbands, fathers, or brothers. Many stories chronicle the highs and lows of dual-astronomer couples navigating the job market. The shift from a literal "old boys' network" to today's formalized but crowded landscape of postdoctoral and tenure-track hires colors how the protagonists of *The Sky Is for Everyone* have forged their own career paths.

Finally, we see a powerful shift in the mentorship that authors describe. The early days feature famous and influential men whose support or discouragement profoundly influenced our narrators' careers. As the years progress, we begin to hear stories of peer support and strength in numbers as more women entered the field. Today women hold numerous leadership roles — we hear from four AAS presidents in the book — and offer guidance to younger generations.

Trimble and Weintraub note that they could surely collect enough autobiographies for a second volume, and it would be marvelous to read more accounts of how gender shapes astronomical careers. Still, the 37 stories of *The Sky Is for Everyone* come together to build a cohesive history of the field, highlight the voices of brilliant scientists and trailblazers, and enlighten readers on the evolving experiences of women in astronomy.

■ **EMILY LEVESQUE** is an associate professor in the Department of Astronomy at the University of Washington. Her book *The Last Stargazers* was reviewed in the April 2021 issue, page 57.

Fold Your Dob in Half

Here's a practical solution for portability and storage.

ONE OF THE GREAT advantages of John Dobson's telescope design is that it enables amateur astronomers to build big telescopes. New Zealand ATM Hamish Barker went that route some years ago with an 8-inch f/6 scope that he admits was "unpopular with my wife and son when we went camping in our 1976 VW camper."

So he bought an old but excellent 10″ f/5 Parks Optical mirror and set out to build something a bit more compact but still quick to set up. Hamish had seen Mel Bartels' elegant 13″ f/3 Zip Dob (*S&T:* Jan. 2012, p. 62), which curls up like a fern fiddlehead, and that inspired him to try folding his scope as well. He quickly realized that a single fold would make the scope short enough to suit his needs, and a little sketching showed him how two long plywood boxes could nest if the hinge is in the right place.

That place happens to be a pair of plywood disks glued to the bottom of the upper box, which fit tightly into holes at the top of the lower box. The lower box only has three sides, leaving one side open to accept the upper box when it's swiveled around on its hinge.

Hamish wasn't sure if a three-sided box would be stiff enough, but using 12-mm (½″) plywood proved sufficiently strong to make it nice and steady. When the scope is unfolded, a quick-release bolt from a bicycle hub clamps two projecting timber parts together, firmly locking the scope in its deployed position.

In order to fit inside the folded box, the focuser needed to be very low profile. Hamish originally tried a Dobson-style push-pull tube, but he later upgraded to a KineOptics HC-2 2-inch helical Crayford (**kineoptics.com/HC-2.html**). That provided a low enough profile when turned all the way inward to fit in the cut-off space on the corner of the upper tube.

The secondary spider is based on Nils Olof Carlin's hacksaw-blade design (**https://is.gd/sawspider2**), in which one blade runs all the way across the optical path, and another reaches out from opposite the focuser to brace the secondary.

The primary mirror cell is classic Dobsonian: Three bolts thread upward through a wooden base (cut from a sandwich-cupboard door) with protective squares of Masonite over the bolt ends, secured by a centrally fixed cardboard triangle. Edge support is a pair of narrow Teflon strips on wooden blocks set at 45° to either side of the centerline.

Of course, nothing goes perfectly on the first try. Hamish reports, "As luck/bad planning would have it, I got the balance point wrong when I fixed the altitude trunnions and rocker height, and I had glued them so I couldn't adjust them. Thus, the upper tube has had a lightweighting program of

▼ Hamish Barker's folding Dobsonian extends to full length and full usability in seconds.

The scope folds into itself to become only half as tall as otherwise. When folded and set in its rocker box, it stands just 86 centimeters (34 inches) tall.

ALL IMAGES COURTESY OF HAMISH BARKER

▲ A bicycle wheel's quick-release clamp locks the scope open. Note the round plywood hinge to the side.

hole-saw attacks. The random orientation of holes actually is kind of aesthetic, and some people think I should put some Saturnian rings on one of them."

A cover board with foam weather-stripping fits over the mirror cell when packed for transport, and a plastic container fits around the secondary/spider, covering all optics. An extra finder shoe is screwed inside the optical tube to allow storing the finderscope inside, and a hanging point allows storage of the eyepiece case inside as well. The nested boxes make the telescope its own rugged case for transport when packed up.

It's relatively heavy, about 17 kg (37 lb) in total, but that's how much my 10″ trackball weighs, and I can carry it in one hand, so I see no reason to complain. Even so, Hamish says if he was to build it again, he'd try high-quality plywood half as thick and just add local strengthening as necessary. In any case, the perfect is the enemy of the good, as they say. This build works great and has seen plenty of backyard use at home in Nelson, New Zealand, on camping trips in the VW camper, and even boat trips for a high-school astronomy camp. It survived its travels with only a bit of sand on the Teflon bearings, which a little brushing and cursing cleared up.

And now nobody complains about it taking up too much space in the camper van.

For more information, contact Hamish at **hamish.barker@gmail.com**.

■ Contributing Editor **JERRY OLTION** has trouble folding a T-shirt, much less a telescope.

How Can We Observe Objects Invisible to Our Eyes?

WHO DOESN'T LOVE a rainbow? When seeing that delicate sight arcing in the sky, you might intone the colors in their order: violet, indigo, blue, green, yellow, orange, red. Or maybe you start at the other end.

Regardless, it's easy to forget that those vibrant colors we're seeing represent only a tiny slice of the *electromagnetic spectrum*. Most of the universe's light comes to us in a form invisible to our eyes. While we can't *see* that radiation, we've built detectors and telescopes that can.

Visible vs. Invisible

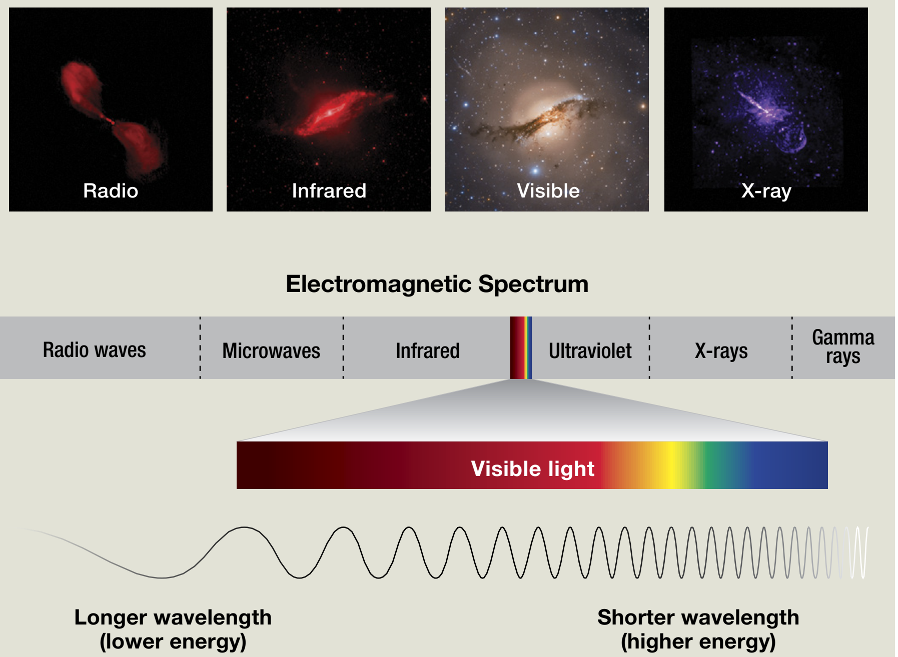
Amateur astronomers observe the universe at the familiar *visible* wavelengths (for the most part). That's what our eyes have adapted to. But the electromagnetic spectrum stretches far beyond the red and the violet, into both the long and the short wavelength ends. Capturing this radiation is challenging.

Earth's atmosphere blocks the transmission of much of the electromagnetic spectrum outside the visible range. (Thankfully for us, as some radiation is dangerous to life.) Early experiments in which scientists sent sounding rockets and balloons to the upper atmosphere first opened the ultraviolet, X-ray, and gamma-ray universe to us. But to effectively capture this radiation, we must loft satellites well above the atmosphere.

Most radio wavelengths (apart from the very longest) do reach Earth's surface, but we need large collecting areas in order to capture those long waves. That's why, for example, we build radio dishes with diameters of tens of meters. And to exploit their capabilities even further, we often operate them in sync with one another as a radio *interferometer* (as in the movie *Contact*, in which viewers got to see glimpses of the iconic Karl G. Jansky Very Large Array in New Mexico). Building and maintaining such large structures — let alone making them work together — is no mean feat.

Even the visible-light regimes suffer from our protective atmosphere. If you've ever tried to observe on a hot, humid night, you'll have noticed how moisture and turbulence in the atmosphere affect views of the stars and planets. This is even more pronounced for the longer-wavelength infrared bands; water vapor can block their passage entirely. In order to somewhat mitigate the disturbing effects of the atmosphere, we place telescopes as far above sea level as possible. Several locations around the world are renowned for their clutches of telescopes at high elevation: Hawai'i, the Canary Islands, a handful of mountaintops in Chile, and Siding Spring in Australia, to name a few of the better-known.

From Radio Waves to Gamma Rays



We only see a tiny slice of the electromagnetic spectrum, the visible. Everything beyond the red at one end and violet at the other is invisible to our eyes. Electromagnetic radiation propagates like waves that vibrate perpendicularly to the direction of motion. The *wavelength* is the distance between successive crests (tops of the waves) or alternatively troughs (bottoms). The number of crests (or troughs) that pass through a point per second is the *frequency*. Low frequency corresponds to long wavelengths, high frequency to short wavelengths.

EM SPECTRUM: LEAH TISCIONE / *S&T*; CENTAURUS A INSETS: NASA / CXC / SAO / NASA / JPL-CALTECH / NRAO / AUI / NSF / UOH / M. J. HARDCASTLE / ASTROPHOTOGRAPHY BY RON OLSEN (4)

The Big Picture

So why go to all this effort to see other wavelengths? The various wavelength regimes carry specific information on the physical processes underlying their emission. Professional astronomers exploit the full electromagnetic spectrum to probe all aspects of celestial sources and also to penetrate obscuring gas and dust to "see" what lies behind (a bit like pilots using radar to land in fog).

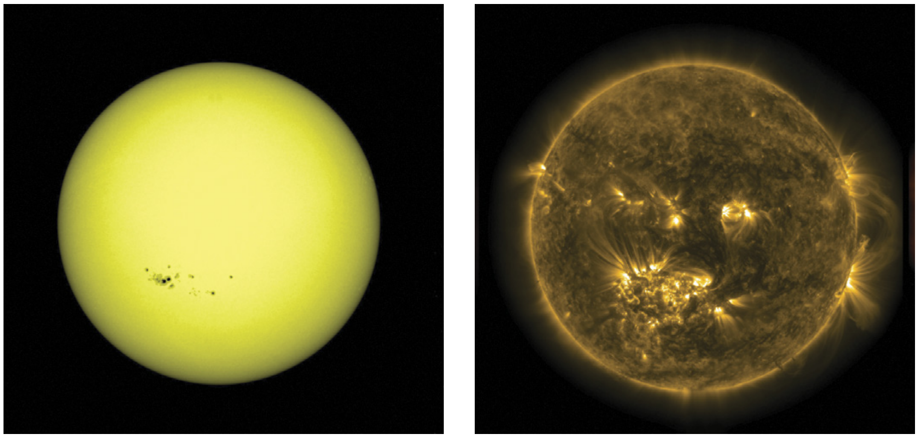
On the shorter-wavelength end of the spectrum, X-rays and gamma rays bring us information on very hot and violent processes. For example, before we even understand that an enormously massive star has ripped itself to shreds in a cataclysmic explosion, we observe a burst of gamma rays. Or a spurt of X-rays might tell us that material from a regular star has gone splat onto the surface of a white dwarf (a stellar remnant).

On the longer-wavelength end of the spectrum, astronomers observe in the infrared to trace the glow of warm dust or to see through cold dust. The infrared has been much in the news lately, what with the glorious images that the JWST is capturing. Certain types of radio waves instead alert us to the presence of magnetic fields, while others allow researchers to study clouds of cold gas.

Take Centaurus A. In the diagram at left, the four images above the electromagnetic spectrum capture the galaxy at different wavelengths. The visible-light image shows us how we'd see Centaurus A if we had Hubble eyes — its dusty disk obscures the core from view. The infrared light, on the other hand, highlights the distribution of dust in the galaxy as well as allows us to peer through the dust. Using radio telescopes and X-ray detectors we learn that powerful, magnetically guided radio jets emanate from the galaxy's central regions.

Even if we can observe objects at each wavelength separately, it's when we combine data from all wavelength regimes that we get a reasonably full picture of the physical processes involved. With Centaurus A, the "multiwavelength" scenario signals to us, among other things, that a supermassive black hole lurks at the center of the galaxy.

But exciting as all these wavelengths are, we mustn't forget our old friend, the visible. Visible light first alerted us to what's out there and, once new wavelenth regimes opened up, guided us to what we needed to investigate further. And, significantly, it's only at visible wavelengths that we can lay our own eyes on the wonders of the universe. ■



▲ **DIFFERENT VIEWS OF OUR SUN** The image above at left shows the surface of the Sun (its *photosphere*) at visible wavelengths — a cluster of sunspots peppers the lower hemisphere. The extreme ultraviolet image on the right instead probes the Sun's atmosphere and reveals coronal loops (arcs of plasma), associated with active regions and sunspots.

MIGHTY GALAXY Combining the images taken at the four wavelengths shown on the opposite page gives us a more complete view of the physical processes involved in shaping and powering celestial objects.

SUN: NASA / SDO / GODDARD SPACE FLIGHT CENTER (2); CENTAURUS A: NASA / CXC / SAO / NASA / JPL-CALTECH / NRAO / AUI / NSF / UOH / M. J. HARDCASTLE / ASTROPHOTOGRAPHY BY RON OLSEN

COSMIC PARADE WITH THE PYRAMIDS

Osama Fathi

Over Giza, Egypt, the clouds thinned just enough to reveal the lunar conjunction with two planets on February 22nd. Jupiter and the Moon hang above the Great Pyramid while Venus aligns with Khafre's pyramid.

DETAILS: *Nikon Z6 camera and Sigma 28-to-70-mm zoom lens. Total exposure: 1/30 second at f/2.8, ISO 200.*

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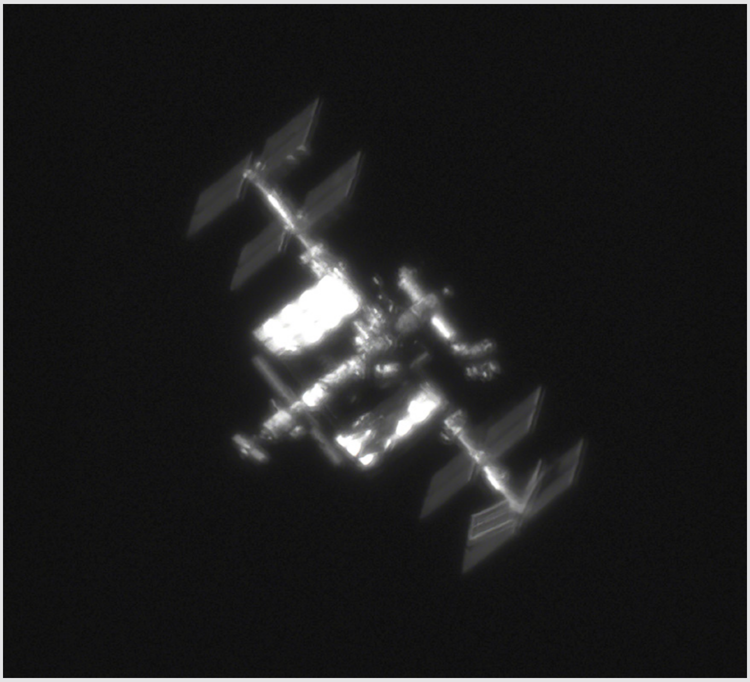

◁ **ISS CLOSE-UP**

Oleg Bouevitch

The docked service module (left), Multipurpose Laboratory Module (center left), and Japanese Experiment Module (right) can be seen in this incredibly detailed image of the International Space Station.

DETAILS: *Celestron EdgeHD 14-inch Schmidt-Cassegrain and ZWO ASI290MM MINI camera. Stack of around 100 frames through a Chroma red filter.*

▽ **COMET CROSSING**

Gerald Rhemann

The bluish ion tail of Comet ZTF (C/2022 E3) passes just to the right of reflection nebula VdB 31 in Auriga on February 9th. Above the bluish nebulosity are dark nebulae B27 and B26, respectively, while B28 is seen to its left.

DETAILS: *Astrosysteme Austria 12-inch Newtonian astrograph and Moravian C3-61000 CMOS camera. Total exposure: 32 minutes through LRGB filters.*

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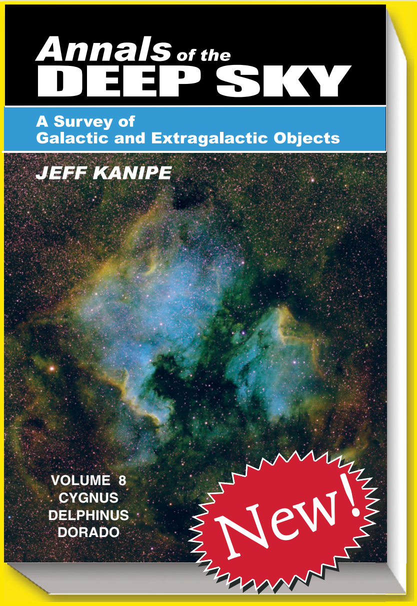

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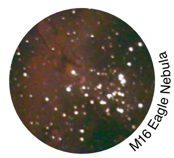

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Darkness Audible

The author's fear of the dark gets tested in the most memorable way.

WHEN I WAS A KID, I was afraid of the dark. Walking down the shadowy hallway to my bedroom was more than I could bear, so I always turned on the hallway light — which my older sister delighted in turning off when I was halfway to my room. I'd run the rest of the way and switch on the light in my room as fast as I could. Going outside at night by myself wasn't even a thought until I became interested in astronomy.

We lived in a brightly lit Denver suburb, so it wasn't all that dark at night. But even so I was afraid to go outside alone. When I got my first telescope, I set it up a few steps from our front door so I could make a quick escape within when being alone outdoors became too much. The slightest unexplained noise sent me into a quiet panic.

I soon discovered that a portable radio calmed my nerves and helped me better enjoy the views through my 3-inch refractor. A strange sound would still send me inside, though. No amount of rational thinking helped because my fear felt so irrational. Of course, it was an instinctual response — humans have evolved for good reason to beware of odd noises at night, but I was ashamed each time it happened.

Decades went by. I began observing more and more under dark skies but always with at least one other person, so my fear of the dark went into remission. A few years ago, I planned a trip to the inkiest high-elevation site in my part of Oregon that I can drive to in one day, and even though my regular observing companions couldn't come along, I felt brave enough to go alone.

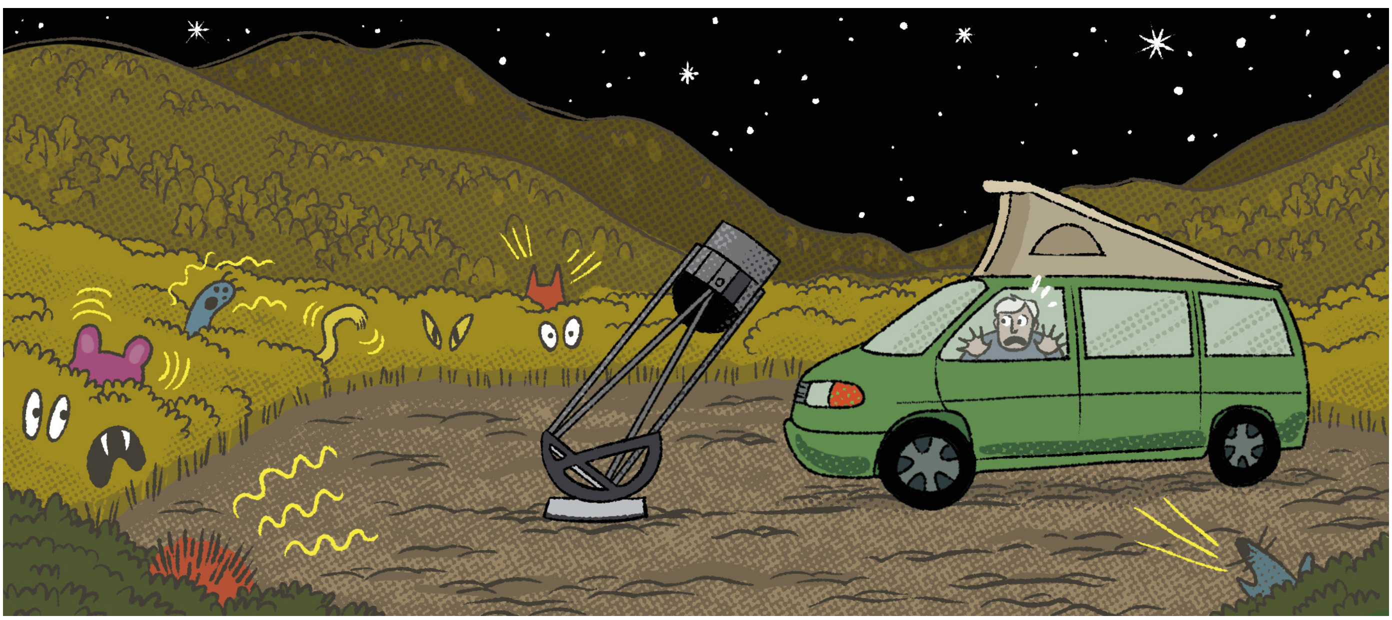
Everything went well at first, and I was feeling rather proud of myself out there in the wilderness, observing the universe all on my lonesome — and then the unexplained noise came. It was a long, deep rumble that was frighteningly close, and the image of a cougar flashed into my now fear-frozen brain. My legs and arms worked just fine, though, and I was in my van in record time, heart pounding with fear.

I looked out the window, totally expecting to see the beast, but saw nothing. By now I realized that a cougar wouldn't have growled before pouncing, so it must have been a different creature — maybe the huge porcupine I'd encountered on my drive up?

As I continued looking out the van window for whatever was out there, I heard the same long, deep rumble again — coming from my abdomen. To my embarrassment, it was my stomach doing the growling. Deeply chagrined, I ate a small snack and went back out to observe. The sky was uncharacteristically poor, so it wasn't long before I called it a night anyway.

Since then, I've observed alone in the wilderness twice without a similar panic. Maybe I've gotten a little braver, but my fear of the dark is still a significant factor to overcome. I accept that that's the way I am, and I'm encouraged that the more I observe alone, the less fearful I've become.

■ Contributing Editor **HOWARD BANICH** now makes sure to have a snack before observing alone.



LEAH TISCIONE / *S&T*