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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

JUNE 2024

In Search of Undiscovered Nebulae

Page 62

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ON THE COVER

Amateurs discovered this nova shell, called Nebula PaStDr 1.

PHOTO: MARCEL DRECHSLER

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A Shared Pursuit

WITH ALL THE GIANT telescopes and major automated surveys coming online these days — see Govert Schilling's feature about the Rubin Observatory on page 34 — it can seem like there's not much that amateur astronomers can still discover. That's been true in recent years for new comets and supernovae, which automated surveys such as ATLAS and Pan-STARRS usually (but not always) detect.

But as Associate Editor Sean Walker details in his cover story on page 62, amateurs continue to harvest phenomenal, mostly faint finds from the deep sky. This is possible because of the highly advanced imaging capabilities at their disposal as well as the amount of telescope time they can devote to the hunt. Amateurs are regularly snagging never-before-seen planetary nebulae, supernova remnants, emission and reflection nebulae, and other objects.

Sean himself has played a modest part in this wave of novel sightings. Together with Senior Contributing Editor Dennis di Cicco and the late David Mittelman — his partners on the MDW Hydrogen-Alpha Sky Survey (*S&T:* Oct. 2019, p. 20) — Sean has helped bring to light everything from the exploded stellar shreds of supernovae to a 30°-long ultraviolet arc in Ursa Major (see **mdwskysurvey.org**).

▲ WD-1, the hydrogen-alpha emission nebula named for Sean Walker and Dennis di Cicco

MASIL IMAGING TEAM

Those discoveries and the ones Sean describes have one standout trait in common: collaboration. Unlike solo stargazers spending pre-dawn hours alone scoping for new comets, say, the amateurs spotting these new objects are small groups who work together to discover, verify, and publish such wispy treasures.

Collaboration can go further: Sometimes professional astronomers reach out to amateurs to help confirm a new object, and they may even join with the amateurs to write up their detection in a peer-reviewed paper, with the discoverers listed as coauthors. When this happens, as it has with several MDW Sky Survey finds, Sean says "it feels like I'm an actual astronomer. I don't just play one on TV — I mean, at the office!" Altogether, this synergistic attribute exemplifies one of our hobby's finest qualities: sharing with others.

Yet the private thrill of discovery still occurs. Sean recalls plotting objects in his first large imaging project with Dennis, and one bit of nebulosity failed to come up when he searched online databases. After months of research and verification, the emission nebula he stumbled upon earned the official moniker WD-1, acknowledging the Walker–di Cicco partnership (*S&T:* July 2010, p. 39).

Imagine your name tied to a celestial object! To all amateur astronomers who deem that prospect irresistible, here's to fruitful searching.

Peter

Editor in Chief

SKY & TELESCOPE

The Essential Guide to Astronomy

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

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▲ Benjamin Franklin (center) and Thomas Jefferson (left) served as the first two United States ambassadors to France. Meanwhile, Charles Messier (right) was working on his famous list of comet-like objects (see page 76).

Historic Happenings

Both Thomas Jefferson and Benjamin Franklin served time as diplomats in France around the time of the American Revolution. Both were interested in science and well known at the French court. This was also the time of Charles Messier. I have often wondered if either Jefferson or Franklin met him. A few years back I persuaded some researchers at Monticello, the home of Thomas Jefferson, to see if they could find any connection between Jefferson and Messier. They could not find any specific reference to such.

But I have been doing some work on my own on Franklin and have picked up something of a trail. Franklin apparently had a talk delivered to the French Academy of Sciences in 1779 on his experiences with the aurora borealis. Then Antoine-Jean Amelot de Chaillou, President of the French Academy of Sciences, wrote a letter to Franklin on April 8th, 1779. He told Franklin that it had come to his attention that Franklin planned to have a paper read at the public session of the Academy on April 14th. Amelot said that he was going to have a dinner on April 12th with members and officers of the Academy (including Charles Messier). At the dinner, members of the Academy would discuss their own experiences with the aurora borealis. He invited Franklin to attend. But I can find no record of a reply from Franklin.

Did Franklin attend the private dinner with Amelot on April 12th? Did he meet Messier there? Did Amelot introduce him to Messier at the meetings on either the 12th or 14th? It would appear that the chances of Franklin having at least met Messier are reasonably good.

The interaction of Franklin with the French Academy of Sciences is worth noting in regard to Jefferson. According to the Monticello website, Jefferson, during his own stay, "befriended the Marquis de Condorcet, Permanent Secretary of the French Academy of Sciences, who introduced him to the leading scientific figures of France" (**https://is.gd/CondorcetJefferson**). Any further reader insights would be appreciated.

Ted Wolfe • Naples, Florida

Impact Potential

"How Are Asteroids Named?" (*S&T:* Mar. 2024, p. 74) is an excellent article from Monica Young. And I happened to read it just as news about an impact in Germany by an asteroid roughly one meter in size appeared on the *S&T* website in "Asteroid 2024 BX1: From a Light in the Sky to Rocks on the Ground" by Bob King (**https://is.gd/AsteroidLanding**). What particularly caught my eye about this juxtaposition was your inference that, technically speaking, asteroids are objects one meter and larger (the reasoning being that the IAU defines meteoroids as smaller than one meter). This has now enabled me to put two and two together to realize that an asteroid of any size is able to reach the surface of the Earth.

Since even a small stone can kill someone, the hazard of asteroid impact is, in this sense, total — any asteroid that intersects Earth is a potential threat. Of course, the threat from asteroids on the small end presents a minuscule risk. But for the sake of theoretical completeness, I find this an interesting conclusion.

Joel Marks
Milford, Connecticut

Editor's Note: *Between the initial reporting of this story and the version printed on page 11, the estimate of the impactor's size reduced from 1 meter to 0.4 meter.*

Asteroidal Accolades

I was honored with having one of [former planetary scientist at NASA's Jet Propulsion Laboratory and discoverer or co-discoverer of 872 asteroids and 3 comets] Eleanor Helin's many asteroids, 4897 Tomhamilton, named for me. But two of my former students, Fred Espenak and Sheldon Schafer, have also had asteroids named after them. So did my late professor from Columbia University, Jan Schilt. As I later learned, his professor back in the Netherlands, Jacobus Kapteyn, has an asteroid, as do at least five other of Kapteyn's former students. In fact, pursuing this further back, Kapteyn is only a couple of professors away from Carl Friedrich Gauss, who also has an asteroid named for him. And this academic heritage goes all the way back to Kepler! I have described this as an asteroid collective, since *asteroid families* is already in use.

Thomas Wm. Hamilton
Staten Island, New York

Accessible Astronomy

Isabel Swafford's article "Seeing the Universe Without Sight" (*S&T:* Mar. 2024, p. 26) brought back emotions experienced at a slow, weather-affected star party. As the Library Telescope Coordinator for the Springfield Astronomical Society in Missouri, I had set up a 4.5-inch, tabletop Dobsonian. A cute young couple appeared from behind me asking what I was observing. The man took a turn at the eyepiece then asked, "May my wife touch the telescope?"

JEFFERSON: MATHER BROWN / NATIONAL PORTRAIT GALLERY / PUBLIC DOMAIN; FRANKLIN: DAVID MARTIN / THE WHITE HOUSE HISTORICAL ASSOCIATION / PUBLIC DOMAIN; MESSIER: ANTOINE ANSIAUX / STOYAN R. ET AL. *ATLAS OF THE MESSIER OBJECTS: HIGHLIGHTS OF THE DEEP SKY* / PUBLIC DOMAIN

I was suddenly aware she was visually impaired, and we began exploring the scope. I narrated an impromptu tour while her nimble fingers deftly explored it, and he guided. I felt totally inadequate, but she seemed enthralled.

For a brief moment, I was let into her world of curiosity, bravery, and dignity. I hope she gained something in return for all I received in those few minutes.

Michael Sweaney
Springfield, Missouri

As a music professor, I was delighted to read "Seeing the Universe Without Sight." The efforts being made to make the universe more accessible should be applauded, not only for use by the visually impaired but also for outreach.

The musical notation representing the Trappist-1 system on page 27 is reminiscent of the planetary ranges of Johannes Kepler in his *Harmonices Mundi* of 1619. Using a different approach, he also matched planetary orbits with musical intervals. He employed his laws of planetary motion in assigning a series of pitches to each planet based on its apparent angular velocity as seen from the Sun, allowing for the eccentricity of each orbit and the corresponding changes in speed (and musical pitch). After 400 years, we can accuse Kepler of being too enthusiastic in seeking the "music of the spheres," but he certainly anticipated the melding of music and astronomy.

Congratulations on featuring a broad, interdisciplinary approach to astronomy!

George Rogers
Southwick, Massachusetts

Southern Skies Return

As I do with every issue of *Sky & Telescope*, I perused the first issue of 2024 from cover to cover before reading. It was a special surprise to see the return to your magazine of the Southern Hemisphere Sky Chart (*S&T:* Jan. 2024, p. 44)! If memory serves, there was a time years ago when it was included in every issue. It was always a mystery to me why that feature suddenly disappeared. Thank you for bringing it back!

It was, and now is again, very gratifying to see the famous stars, galaxies, constellations, and Magellanic Clouds of the sky Down Under. It's satisfying to once again see the southern objects that I can't see from home and their positions relative to their northern brethren. The rest of the night sky is no longer missing!

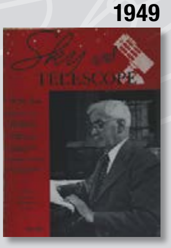
For me, there truly is nothing like *S&T*, and now you've made it even better! Please let all the staff there know the wonderful job everyone does of making *Sky & Telescope* an exceptional publication every month, year in and year out.

Wade Roloson
Lakewood, Colorado

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

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

1949



1974

1999

June 1949

Neptune's Nereid "Harvard Announcement Card 994 transmits a telegram received from Dr. G. P. Kuiper, McDonald Observatory, on May 5th: 'Plates taken on May 1st show object magnitude about 19 to 20, being 168 seconds west 112 seconds north of Neptune and having nearly same motion as planet. Additional work scheduled to determine [if it] is a new satellite.'"

Named generically for any of the sea nymphs in Greek mythology, Nereid was the second moon of Neptune found; 14 are known today.

June 1974

Earth Trojans? "As has long been known, a particle can travel around the sun indefinitely in the same orbit as Jupiter, provided it is either 60 degrees ahead of or 60 degrees behind the planet, so that the three bodies form an equilateral triangle. These stable positions are called the L_4 and L_5 Lagrangian points. This idealized situation is approximated by the Trojan asteroids, which remain near one or the other of Jupiter's Lagrangian points, circulating about it in a complex curve.

"Are there possibly asteroids moving around the sun with one-year periods in the vicinity of the earth's L_4 and L_5 points? Yes, say Paul R. Weissman and G. W. Wetherill . . . Their extensive calculations show that certain such orbits should be stable against perturbations by Jupiter and Venus for at least 10,000 years . . ."

The existence of Earth Trojans eluded astronomers for the next 36 years. Today just two are known; the bigger is about a kilometer across.

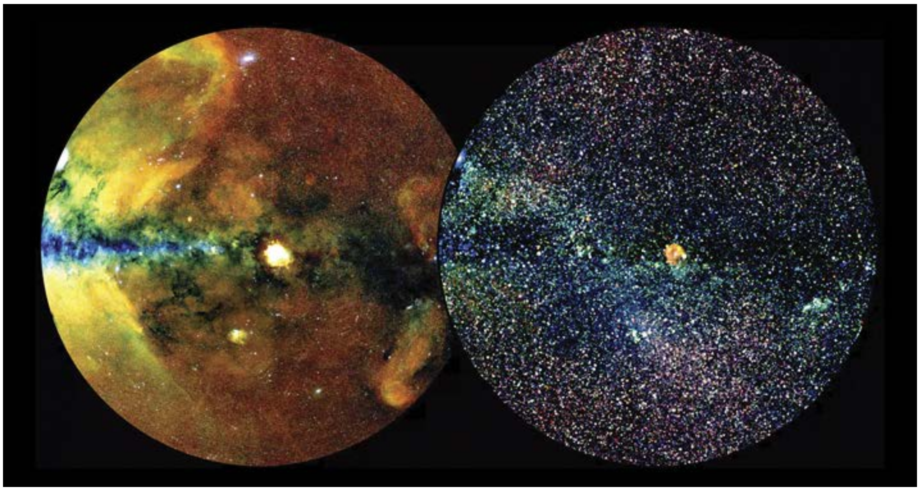
June 1999

Celestial Bonanza "[Star] distances before [the Hipparcos space mission] could be called astronomy's great embarrassment. [We] did not know the 3-D arrangement of individual stars beyond our very nearest interstellar neighborhood — something the rest of the world probably assumed that astronomers mapped out long ago. . . . Of the 118,218 stars in the Hipparcos catalog, the distances of 22,396 are now known to better than 10 percent accuracy. Before Hipparcos the distances to fewer than 1,000 stars were known so well. . . .

"Almost everything in astronomy depends in some way on knowing star distances. This is particularly true of the cosmic distance scale extending out to the farthest galaxies and quasars. And the cosmic distance scale determines how well we know the true sizes, brightnesses, and energy outputs of nearly everything in the universe. . . .

"One elegant byproduct of the Hipparcos positional measurements has been the confirmation of light-bending by the Sun's gravity to about one part in a thousand . . ."

As project scientist for the recently finished Hipparcos mission, Michael Perryman went on to assess its stunning impact on various branches of astronomy.



◀ The German consortium has released an X-ray catalog, tabulating nearly 930,000 distinct sources within half the sky. The left image shows extended X-ray emission while the right image shows point-like X-ray sources.

MPE / J. SANDERS (GERMAN EROSITA CONSORTIUM)

COSMOLOGY

Largest-ever Catalog of X-ray Sources Tests Cosmology

THE TEAM BEHIND the eROSITA X-ray observatory has just released a list of more than 900,000 distinct high-energy sources — the largest X-ray catalog ever published. Alongside the catalog, the consortium also released a series of scientific papers, including one study that delves into the evolution of the largest structures in the universe. The results relieve tension between observations and the standard cosmological model.

In that study, to appear in *Astronomy & Astrophysics*, Vittorio Ghirardini (Max Planck Institute for Extraterrestrial Physics, Germany) and collaborators probed the mass of 5,259 galaxy clusters surveyed by eROSITA. By investigating how those masses change over time, the researchers pinned down contested cosmological parameters.

To calculate the mass of a galaxy cluster, Ghirardini's group measured the X-rays emitted by hot gas trapped between the cluster's galaxies. They then compared those X-ray counts to those from clusters whose masses were previously determined by how much the cluster's gravity bends the light of background galaxies. In doing so, they determined how many X-rays they would detect for different masses. This process allowed the astronomers to use X-rays as a proxy for cluster mass, enabling them to tabulate masses for both more and more distant clusters.

The team then measured the change in cluster mass over cosmic time to get at a contested parameter called *sigma-8* (*S8*). Higher values of *S8* indicate a universe in which matter clumps together more, while lower values correspond to a smoother distribution of matter. Previous observations have found today's universe to be smoother than expected (*S&T:* June 2023, p. 11).

But eROSITA doesn't see such a discrepancy. "Interestingly, we do not see any hint of *S8* tension," says Esra Bulbul (also at Max Planck Institute), "or any departures from the standard model of cosmology, the cold dark matter model with a dark-energy component." So far, eROSITA is the only probe of the relatively nearby universe that does *not* report that tension.

The study also produced tighter constraints on other parameters in the standard model, such as the dark energy equation of state (*w*). They found that dark energy exerts a uniform repulsive force (with *w* between -1 and -1.24). Bulbul says this measured range is consistent with recent results from the Dark Energy Survey (*S&T:* May 2024, p. 8), within the two probes' accuracy.

This study is one of 50 new scientific publications released by the German eROSITA Consortium, which consists of about 250 scientists. The projects are wide-ranging and include the effects of X-ray irradiation on planets, an analysis of the flickering of supermassive black holes, and the discovery of a giant filament of warm gas between two galaxies as well as two supermassive black holes showing almost regular eruptions.

All of this comes from eROSITA's first six months of data, during which the telescope conducted its first full survey of the sky; however, the German consortium only has access to the western galactic hemisphere (Russia has proprietary rights to the eastern half). While eight all-sky surveys were initially planned, each one probing the early universe more deeply, only four and a half surveys had been completed when the Max Planck Institute put the telescope in hibernation after Russia invaded Ukraine in 2022.

■ ARWEN RIMMER

COSMOLOGY

Astronomers Find "Big Ring" 1.3 Billion Light-Years Across

CLOSE TO THE HANDLE of the Big Dipper, there's a huge ring on the sky that shouldn't be there. The coil-shape structure is an apparent overdensity of distant galaxies with a circumference of 4 billion light-years. The size is at the boundary of what the standard model of cosmology can explain — if the structure is gravitationally bound.

PhD student Alexia Lopez (University of Central Lancashire, UK) presented the result at the meeting of the American Astronomical Society in January. Now, the study has been posted to the arXiv astronomy preprint server.

Two years ago, the same team published the discovery of a giant arc spanning 3 million light-years. It's at a

FAST RADIO BURSTS

Neutron Star "Glitch" Precedes Mysterious Radio Flash

WHEN A KNOWN highly magnetized neutron star, or *magnetar*, emitted a *fast radio burst* (FRB) in 2020, astronomers suddenly had an example of these usually distant flashes of radio waves coming from our own backyard. Since then, astronomers have been waiting for a repeat.

In October 2022, they struck it rich once again — and this time, they were ready. Chin-Ping Hu (National Changhua University of Education, Taiwan) and colleagues pointed two NASA space telescopes — the Neutron Star Interior Composition Explorer (NICER) and the Nuclear Spectroscopic Telescope Array (NuSTAR) — toward the magnetar.

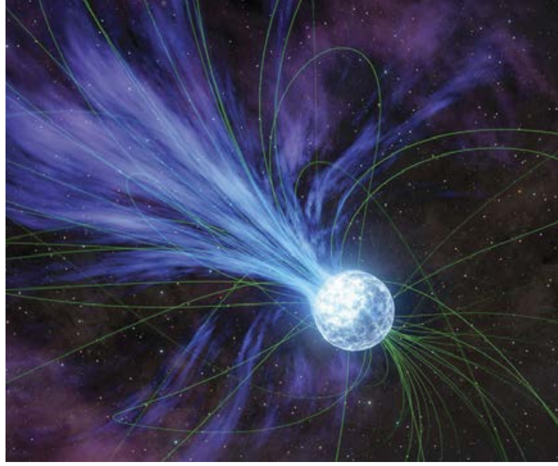
The team watched the star rotate by virtue of a hotspot on its surface. As the hotspot spins in and out of view, the neutron star brightens and fades. Meanwhile, spectra helped distinguish whether the emission was coming from the hotspot itself or from charged particles writhing in the neutron star's powerful magnetic field.

While monitoring the city-size star's spin, the astronomers caught a *glitch* — when the star suddenly started spinning faster. X-rays at this time were coming primarily from the hotspot.

Following the glitch, the rotation rate decreased over the next four hours, leading into a burst of radio waves (detected by radio telescopes on the ground). During this time, the emission from magnetically trapped particles strengthened.

Neutron stars are known to glitch when the surface syncs up with a faster-spinning interior, perhaps via a cracking of its crust. But SGR 1935's glitch dissipated within hours, instead of the usual weeks or months. The fast recovery might mean the glitch was accompanied by a blast of charged particles — a sudden wind that then robbed the star of its spin almost as quickly as it had gained it.

All of those particles hanging around in a powerful magnetic field resulted in an extreme event: the sudden creation



▲ A magnetar is depicted ejecting a blast of charged particles in this artist's concept. The magnetar's strong magnetic field (shown in green) influences the flow of these particles.

of lots of matter-antimatter particle pairs. That avalanche could have led to the sudden burst of radio waves.

The observation of this sequence of events, published in the February 15th *Nature*, "provides a clear avenue for further investigations of FRB generation," says Laura Spitler (Max Planck Institute for Radio Astronomy, Germany), who wasn't involved in the study. "Whether this applies to all FRBs is still an open question, but observationally it is fantastic progress."

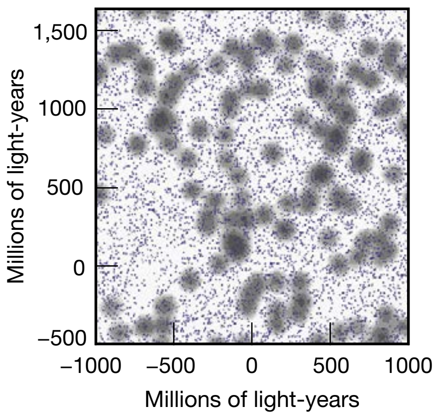
■ MONICA YOUNG

---

similar distance of 7 billion light-years and in roughly the same part of the sky as the ring. Both the "Giant Arc" and the "Big Ring" show up indirectly, via the absorption lines seen in the spectra of many thousands of distant active galaxies known as quasars.

In particular, the team looks for the absorption of ionized magnesium atoms both in and around galaxies. Due to the expansion of the universe, the light that these atoms absorb shifts to redder (longer) wavelengths when the absorbers themselves are farther away. By measuring these redshifts, the team can calculate the distance to the matter that's doing the absorbing.

Lopez and her collaborators conclude that the Big Ring they've found is "real and statistically significant" — a finding that might strain the standard model of cosmology, which includes the effects of dark matter and dark energy. According to this model, there hasn't



▲ The small blue points show background quasars from the Sloan Digital Sky Survey. Gray regions show the locations of intervening galaxies about 7 billion light-years away that are absorbing light at a specific wavelength. The Big Ring is roughly at center.

been enough time since the Big Bang to form gravitationally bound structures larger than 1.2 billion light-years or so. (Since large-scale structures grow as the universe expands, the dimensions given are for the present epoch.)

James Peebles (Princeton University), who won the 2019 Nobel Prize in Physics for pioneering the standard model, says it's possible the Big Ring and Giant Arc are real, or the team might be "finding apparent structure in pure noise."

"Patterns like these are seen in sufficiently large cosmological simulations," adds theorist Carlos Frenk (Durham University, UK), who was not involved in the study. "However, they are not bound structures."

So are there any problems for the standard model? "None of note," answers Frenk.

Firmer results await a thorough exploration of the full database of quasar spectra obtained by the Sloan Digital Sky Survey; the findings so far are based on a relatively small subset.

■ GOVERT SCHILLING

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

MAGNETAR: NASA / JPL-CALTECH; PLOT: A. LOPEZ (UNIVERSITY OF CENTRAL LANCASHIRE, UK)

EXOPLANETS

Hubble Reveals Possible Water-Vapor World

NEW HUBBLE SPACE TELESCOPE observations of a planet 100 light-years from Earth have revealed water vapor in its upper atmosphere. But astronomers are still working out exactly how much water vapor there is — and what this world's atmospheric composition means for others like it.

With a radius just about twice Earth's, GJ 9827d lies right on the line dividing super-Earths (rocky worlds more massive than our own) from gas-enshrouded sub-Neptunes. The planet is a candidate "water world" — not the kind of ocean world inhabited by Kevin Costner, but rather one with a hot, steam-filled atmosphere.

Using Hubble to observe the planet as it transited its host star 11 times between 2017 and 2020, a team led by Pierre Alexis-Roy (University of Montreal, Canada) measured the size of the planet at near-infrared wavelengths from 1.1 to 1.7 microns. Around 1.4 microns, the transiting planet appears larger, indicating that water molecules in its upper atmosphere are absorbing the star's light. The research is published in the *Astrophysical Journal*.

◀ GJ 9827d, pictured in this artist's concept as the blue world up top, is a candidate "water world" 100 light-years from Earth. The water in this case is hot vapor rather than liquid oceans.

However, Alexis-Roy and colleagues couldn't distinguish how much water there is. It's possible there's a trace of it high up in a Neptune-like atmosphere. But stellar radiation should have long since stripped away such a light atmosphere. More likely, the observations are picking up vapor farther down in the atmosphere, where some 60% of the molecules could be water.

Prajwal Niraula (MIT), who led the team that discovered GJ 9827d but wasn't involved in the current study, notes that the detection of water vapor is "weaker than we'd like it to be." But he also notes that, given the featureless spectra of other small sub-Neptunes, even a hint is promising. "This is a good start to warrant further investigation of this target," he adds.

The team is now analyzing observations of the world with the James Webb Space Telescope, which should clarify the water's abundance.

■ **MONICA YOUNG**

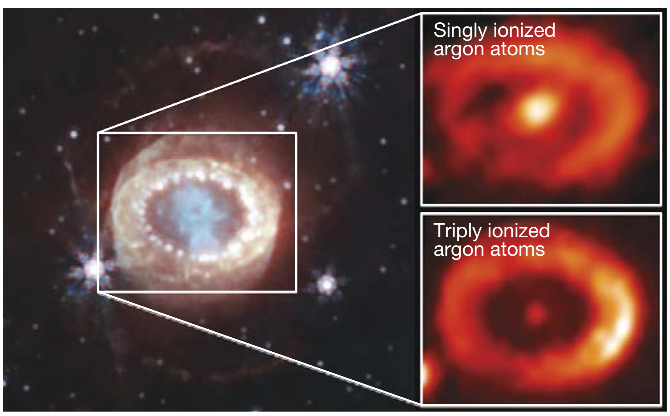
SUPERNOVAE

Firm Evidence for a Neutron Star in Supernova 1987A

ACCORDING TO NEW observations from the James Webb Space Telescope (JWST), Supernova 1987A left a neutron star behind. It's what astronomers have assumed ever since they first observed the stellar explosion on February 23, 1987. However, conclusive evidence has been elusive.

Now, a team led by Claes Fransson (Stockholm University) says they've clinched the case. "I think it is fair to say that this marks the discovery of a neutron star," comments Dennis Alp, who previously studied 1987A but was not involved in the new research.

At a distance of some 168,000 light-years, 1987A was the nearest supernova observed in modern times. But due to obscuring dust, previous studies have only hinted at a neutron star (rather than a black hole) at its center.



▲ At left is a 2023 near-infrared image of supernova 1987A from the James Webb Space Telescope. The inset at top right shows mid-infrared light from singly ionized argon; the bottom right inset shows multiply ionized argon captured at near-infrared wavelengths.

Webb's sensitive infrared spectrographs have now detected emission lines of ionized argon and sulfur atoms from the very center of the remnant, indicating the presence of a nearby X-ray source. According to Fransson, the only possible source is a young neutron star with a surface temperature of 1.5 million to 3 million kelvin. The results appear in the February 23rd *Science*, on the supernova's 37th anniversary.

Thanks to JWST's high angular resolution, Fransson's team is sure that previously observed X-rays, which ionize the argon and sulfur, must originate very close to the explosion site, either from the surface of the neutron star itself or from a surrounding nebula of charged particles.

Interestingly, the JWST results might also indicate that the neutron star is racing toward us at between 200 to 600 kilometers per second (500,000 to 1 million mph). Such a "kick" can result from an asymmetric explosion.

Jacco Vink (University of Amsterdam), who was not involved in the study, notes that, like earlier results, the new JWST observations are still indirect evidence. "But they support each other," he says. Direct evidence, such as the detection of radio waves or X-rays that come from the pulsar itself, awaits the clearing of dust. "The fact that the emission is observed close to the center looks already quite convincing."

■ **GOVERT SCHILLING**

BLACK HOLES

Most Luminous Quasar Hosts What Might Be Fastest-Growing Black Hole

THE MOST LUMINOUS and voracious quasar compared to any found to date is reported by astronomers in a study published February 19th in *Nature Astronomy*.

Quasars' brightness comes from the hot gas swirling into supermassive black holes at the centers of distant galaxies. With the advent of all-sky surveys, astronomers are increasingly detecting rare quasars, and the hunt is on for extreme examples of an already extreme phenomenon. The latest find is the most superlative yet.

Christian Wolf (Australian National University) led a team that used data from the European Space Agency's Gaia mission as well as spectra taken by the European Southern Observatory's Very Large Telescope in Chile to construct a picture of the quasar J0529-4351.

The team established that J0529-4351 dates back to 1.6 billion years after the Big Bang, and its extreme brightness combined with that distance makes it the most luminous quasar known. It's one of the most massive, too, with the equivalent of 17 billion Suns.

Some quasars only appear to be bright because of *gravitational lensing*, when they are magnified by a foreground galaxy or cluster. The researchers checked this possibility but largely ruled it out, concluding that there's a more than 99% chance that J0529–4351 really is that bright.

Based on the quasar's extreme luminosity, the team estimates the black hole is pulling in mass at a rate of some 413 solar masses per year — feeding on more than a Sun's worth per day. That's near the maximum possible for a black hole of this mass — if it pulls in any more, the infalling gas's radiation will start to push surrounding gas away.

Astronomers have long been intrigued by how supermassive black holes can grow to such large scales so quickly and so early on in the history of the universe. Anna-Christina Eilers (MIT), who wasn't involved in the study, explains: "Finding these extreme objects, such as J0529-4351, is therefore very valuable to test different black hole growth models."

■ KIT GILCHRIST

ESO / M. KORNMESSER

▲ This artist's impression shows the record-breaking quasar J0529-4351, the bright core of a distant galaxy that is powered by a supermassive black hole.

IN BRIEF

Moonshots: Sideways and Upside Down

The second of NASA's Commercial Lunar Payload Services (CLPS) missions — Intuitive Machines' lander, named Odysseus — landed successfully on the Moon on February 22nd. (The first CLPS mission, Astrobotic's Peregrine mission, launched Jan. 8th, experienced a fuel leak shortly after launch.) However, Odysseus pitched over upon landing; as a result, its solar panels couldn't fully charge. The mission ended after a week on the surface. As of press time, NASA states that all six of its science payloads collected data. Earlier, on January 19th, Japan's Smart Lander for Investigating Moon (SLIM) had similarly nailed a pinpoint lunar landing, but, due to the loss of one of the main engines during approach, the lander ended up nearly upside down. SLIM was able to conduct two days of science operations once the changing angle of sunlight enabled it to start up again, as well as some additional observations collected after it (surprisingly) survived lunar night. Two mini-rovers, which separated during SLIM's approach, also completed their objectives.

■ DAVID DICKINSON

Small Meteoroid Impacts Near Berlin

A 0.44-meter (1.44-foot) object slammed into Earth's atmosphere over Germany early on January 21st, producing a spectacular fireball. What made this event even more remarkable was that the meteoroid, designated 2024 BX1, had been discovered less than 3 hours before impact. Krisztián Sárneczky at the Konkoly Observatory in Hungary first recorded the asteroid when it was still just an 18th-magnitude blip in the constellation Lynx. Other observations began to come in as word spread, and NASA's and ESA's systems soon flagged the new object as a potential impactor. Additional observations narrowed down the fall location to 60 kilometers (37 miles) west of Berlin. Social media lit up with the news, alerting viewers in the area who had only to walk outside at the appointed time to witness the asteroid's tumultuous end. Then, after days of scouring the predicted fall site, a team of Polish meteorite hunters successfully recovered the first fragments. Analysis showed the fragments were part of a rare aubrite meteoroid.

■ BOB KING

 by Morgan MacLeod

A glance at the daytime sky is enough to convince us that our Sun is a single star. But not so for many of the stars in our galaxy and beyond: About half of all stars live their lives with at least one stellar companion.

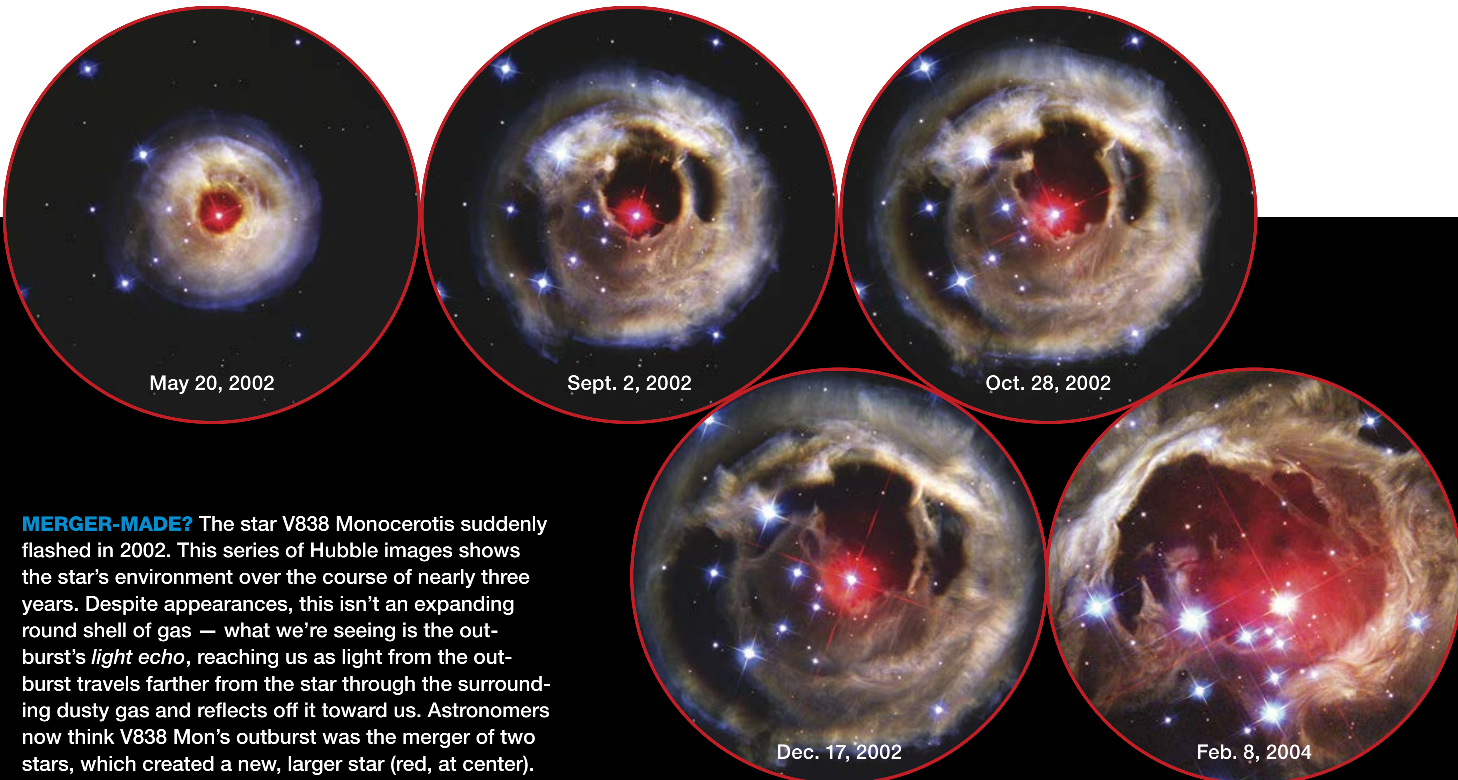
Our census of binary stars reveals that these systems come in a variety of arrangements. The orbits of some pairings are wide enough that the stars never directly interact — they're linked but separate, in a stellar version of toddlers in "parallel play." The tightest binaries have stars in constant communication, their gas transferred from one star to the other or even sheathing them both in a communal envelope.

In the wildest of these situations, the stars actually merge. In the last 15 years or so, we've begun to spot these stellar mergers. Powered by a revolution in how we do astronomy — a change from mapping the seemingly "static" sky to watching it change in real time — we are learning that when stars merge, they power brief but violent outbursts so bright they stand out even in distant galaxies. When the dusty aftermath of these events clears, what's left behind is a single, bigger star, assembled from the gas of the former pair.

The chance to see these events as they happen has opened a window for us into understanding the lives of binary stars, which are more surprising and transformative than we ever imagined.

When Stars Collide

Astronomers have caught a handful of binary stars merging. Many stars may someday suffer the same dramatic fate.



MERGER-MADE? The star V838 Monocerotis suddenly flashed in 2002. This series of Hubble images shows the star's environment over the course of nearly three years. Despite appearances, this isn't an expanding round shell of gas — what we're seeing is the outburst's *light echo*, reaching us as light from the outburst travels farther from the star through the surrounding dusty gas and reflects off it toward us. Astronomers now think V838 Mon's outburst was the merger of two stars, which created a new, larger star (red, at center).

NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA) (6)

Evolution Interrupted

Stars expand as they evolve. This is due to the complex interplay of conditions in their interiors as they cycle through stages of fusion. As its hydrogen supply depletes, our Sun will swell and become a giant star. Its puffy outer envelope will reach past the orbits of Mercury, Venus, and perhaps even Earth, swallowing the planets along the way.

Eating our terrestrial planets won't even cause a blip for the evolving sun. When a star swallows a planet, the planet deposits energy in the star, much as a meteoroid slamming into the ground does. But while the energy released by a whole planet's destruction seems like a big deal to us, on the scale of a giant star it'll be just a tiny drop in the immense bucket of energy being constantly shuttled from the nuclear burning core out to the surface.

But if the thing eaten is another star, dramatic changes are in store.

Stars in tight pairs can nestle as close to each other as the inner solar system planets do to our Sun. As a star in this environment evolves and expands, it fills up more and more of the space between it and its binary companion. Now more tenuous, it is increasingly distorted by its companion's gravity, in a stellar version of the tides in our oceans. Eventually, the gravity of the companion becomes so strong that it tears gas from the near side of the star and siphons the material off, creating a gaseous stream that falls onto the companion.

This trickle of gas represents a fork in the pair's evolutionary road. When a star is alone, its birth mass determines its fate, with more massive stars burning through their fuel faster. But as mass streams from one star to the other in a close binary, the transfer changes the stars themselves, subtracting gas from one and adding it to the other, all while fusion is still burning away deep inside. Stars that gain mass are effectively rejuvenated with new hydrogen fuel for their nuclear reactions, while stars that are stripped of their outer layers can be hastened toward the end of their evolution. Redistributing the mass also changes the pair's orbit, because the gravitational balance between them shifts.

Sometimes, the interaction pushes the stars apart: Their orbits slowly widen as gas transfers between the stars, which keeps the trickle of mass at a gentle, steady state. But if the orbit shrinks instead, then what starts as a gradual trickle of gas becomes a cascade.

In these cases of runaway, unstable mass exchange, the flood of gas accelerates the shrinking of the orbit. The pair draws together faster and faster until the two stars plunge into each other with a violent splash, the cores churning like an eggbeater in their shared gaseous envelope before finally merging to make a single core.

What's left behind is a new, extra-massive star: the composite of the two stars that fell together. The merged star spins rapidly, its equator bulging and its poles flattened by the excess angular momentum left over from its time as a separate, orbiting pair. It's bloated and puffy — mimicking, for a brief time, a very extended red giant star as it radiates away the extra energy added by the infall.

STELLAR PEANUT This artist's impression shows the binary VFTS 352, a pair of hot, massive stars in the Large Magellanic Cloud that orbit so close together that they share material.

ESO / L. CALÇADA

Inside, the new star is dramatically mixed up by the violent moment of merger. The burning cores unite, and new hydrogen fuel churns in to replenish the comingled core.

Splash and Crash

For a long time, those splashy stellar mergers remained just out of astronomers' reach. We saw the "before": the ubiquity of stellar pairs, including ones so closely conjoined that their shared surface would look like a peanut. We saw what seemed like the "after": weird-looking stars with anomalous properties like masses too large, magnetic fields too strong, or spins too fast for their ages.

But for decades, direct observations of the merging process in action remained elusive. This was in part because we didn't have cameras large enough to cover large swaths of sky and in part because we weren't sure what to look for.

Until recently.

The first breakthrough was a rapid expansion in digital imaging — something that amateur astronomers know well. New, larger cameras are now being attached to existing telescopes, widening the view captured in a single picture. And telescopes are being devoted to the art of surveying the sky, looking for changes. In practice, this involves tiling the sky with telescope pointings, building up an enormous mosaic of images and — most importantly — returning to the same locations night after night.

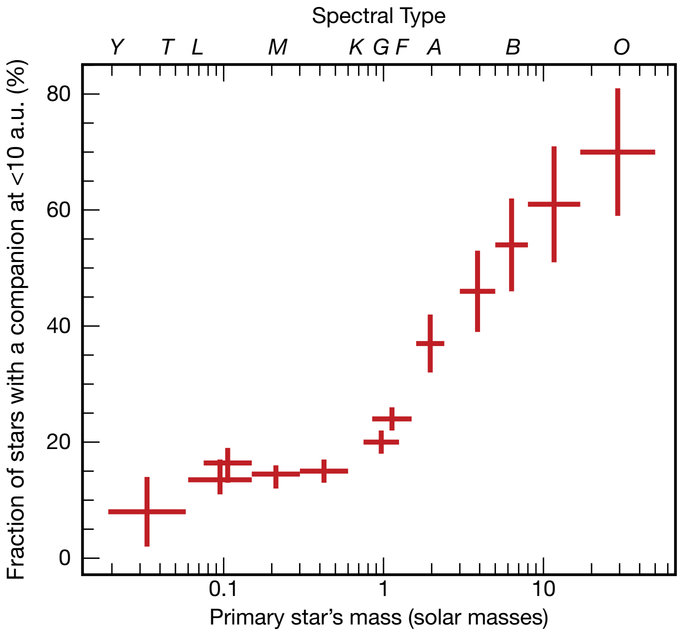
What this means is profound: Whereas astronomy was once a science of taking still images of the sky, it's now becoming cosmic cinematography. With a movie, we can look for sources of light that vary in time on a human scale — not just over the millions or billions of years that we think of as a stellar lifetime, but over days, weeks, or months as we watch. This new perspective is giving us unprecedented insight into the dramatic, transformative events that happen in stars' lives, such as stellar mergers.

The second breakthrough came when we saw the before, the during, and the after of a merging pair — for the first time connecting each part of the timeline, and identifying the signs, of a stellar merger.

The story begins with an outburst of light caught in late 2008. Somewhat suddenly, an otherwise humble star in the constellation Scorpius brightened to 10,000 times its normal level. It reached a peak around 7th magnitude, just short of naked-eye visibility. As it faded over the following weeks, it became progressively redder in color, indicating cooler and cooler temperatures.

In reporting on the outburst, Elena Mason (now Astronomical Observatory of Trieste, Italy) associated the object with an enigmatic class of stellar outbursts with very red colors called *red novae*. At the time, astronomers were debating what red novae were. This star, which became known as V1309 Sco, would help answer the question.

Shortly after Mason's team's paper, a different group of researchers, led by Romuald Tylenda (Nicholas Copernicus Astronomical Center, Poland), used the backlog of data from



▲ **BINARIES GALORE** The more massive a main-sequence star is, the more likely it is to live in a binary system. Those stars in close binaries (shown) will directly interact at some point, either by exchanging gas or by merging completely.

a survey telescope to recreate the history of V1309 Sco before the outburst. These data revealed V1309 Sco was a *contact binary* — a pair of stars actually touching as they orbited — that was fortuitously aligned to our line of sight. Twice during each orbit, one of the stars passed in front of the other in an eclipse, modulating the brightness we observed. Over six years of data, the pair's orbit tightened — at first slowly, then more rapidly leading up to the great brightening in 2008.

In the outburst and its aftermath, all traces of the orbital period vanished. Thus, V1309 Sco's flash was a flag post between the contact binary and the single star that emerged.

Astronomers realized that to get as bright as it had, the light from V1309 Sco's outburst could only have come from gas flung outward quite suddenly at the moment of merger. Tylenda and his collaborators imagined a violent and luminous stellar merger in which some of the stars' gas splashed outward as the pair fell together.

Detailed analysis of gas motions and chemistry in V1309 Sco's spectrum confirmed this story. Early spectra showed hot gas flying outward at hundreds of kilometers per second away from the star. Later, features characteristic of cooler material emerged: absorption lines from molecules too fragile to withstand high temperatures. The expansion and cooling of the splashed-out gas made V1309 Sco appear redder as time went on.

Finally, heavy elements in the cooling ejecta solidified out of the gas into grains of dust. This opaque dust completely masked the star in visible light. Light from the star now leaks out of this dusty envelope at infrared wavelengths. Even now, 16 years later, V1309 Sco remains dramatically brighter in infrared light than it was before the merger.

Mergers, Mergers Everywhere

With a prototype identified, merger hunters set to work searching for more. Just like the Rosetta Stone enabled scholars of ancient Egypt to decipher hieroglyphics, V1309 Sco enabled astronomers to search for the telltale signs of mergers: the distinctively red colors of the bright outbursts, and the formation of molecules and dust in the aftermath.

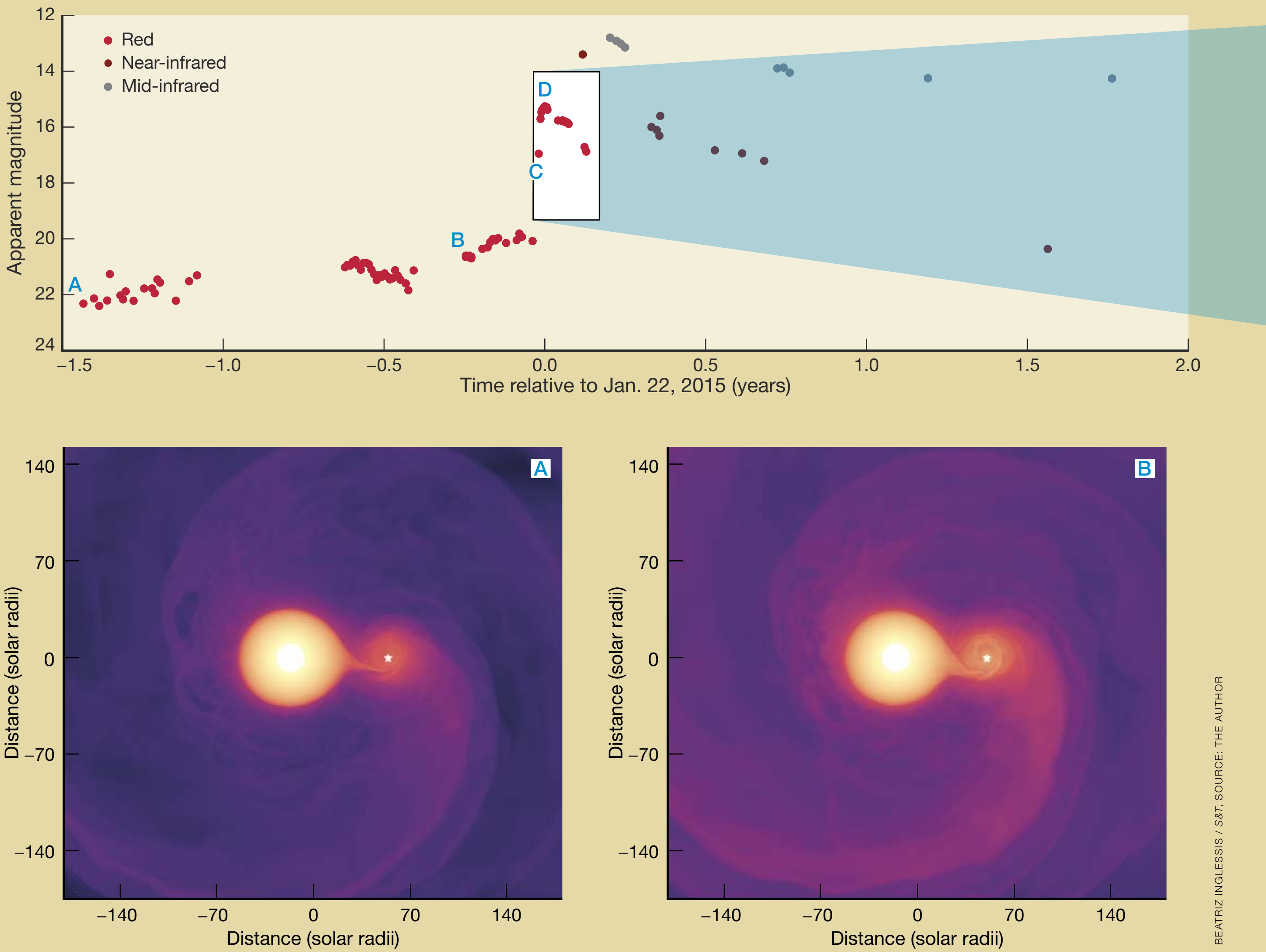
They started finding more by the handful.

V1309 Sco was a fairly typical binary pair, including a roughly solar-mass star and a smaller companion in our galaxy. But since it was first spotted, astronomers have discovered a wide variety of other merging stars.

Surprisingly, many of these are bright enough to stand out in other galaxies. In early 2015, for example, a merger was spotted in the Andromeda Galaxy that involved a giant star several times more massive than our Sun. At its peak, the star shone for a couple of weeks at about 1 million times the intrinsic brightness of the Sun, reaching an apparent magnitude of 15. Another event that same year, discovered in M101, reached magnitude 17 and involved an even larger star, nearly 20 times the mass of the Sun.

These sources were bright enough not only to distinguish themselves from the fuzzy background of unresolved stars around them but also to allow us to take detailed follow-up observations. To date, about a dozen of these extragalactic mergers have been bright enough to study in detail, with about twice that number just on the cusp of detection in more distant galaxies.

Some of the features of these events held closely to the prototype of V1309 Sco. Each seemed to show a progressive ramp-up in brightness before the outburst, an extremely sudden brightening, and a red, dusty aftermath. But the stars'



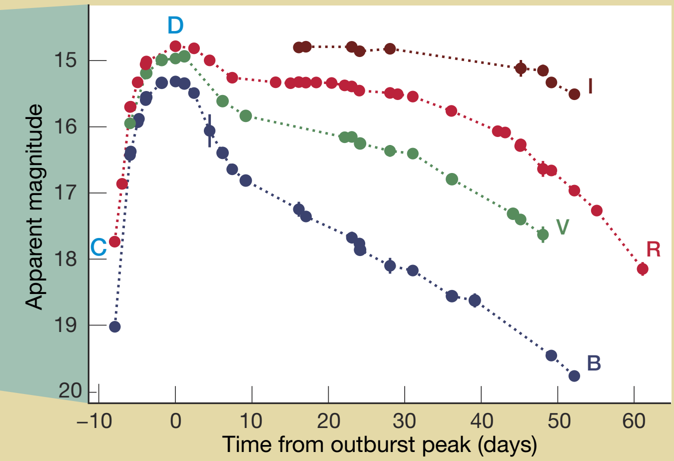
BEATRIZ INGLESSIS / S&T, SOURCE: THE AUTHOR masses in these extragalactic events were larger than galactic sources like V1309 Sco. It emerged that the more massive the stellar pair, the brighter a flash they produced as they fell together. In fact, a merger of a 10-solar-mass star with a companion is about 1,000 times brighter than a similar event involving a 1-solar-mass star.

Recently, other similarities have come to light. Despite their range of masses, all of the stars' pre-outburst rises in brightness shared similar colors. The members were also relatively compact stars that had just stopped burning hydrogen in their cores, partway along their evolution toward becoming red giants. They tended to be blue or yellow stars, of spectral types *B* through *G*.

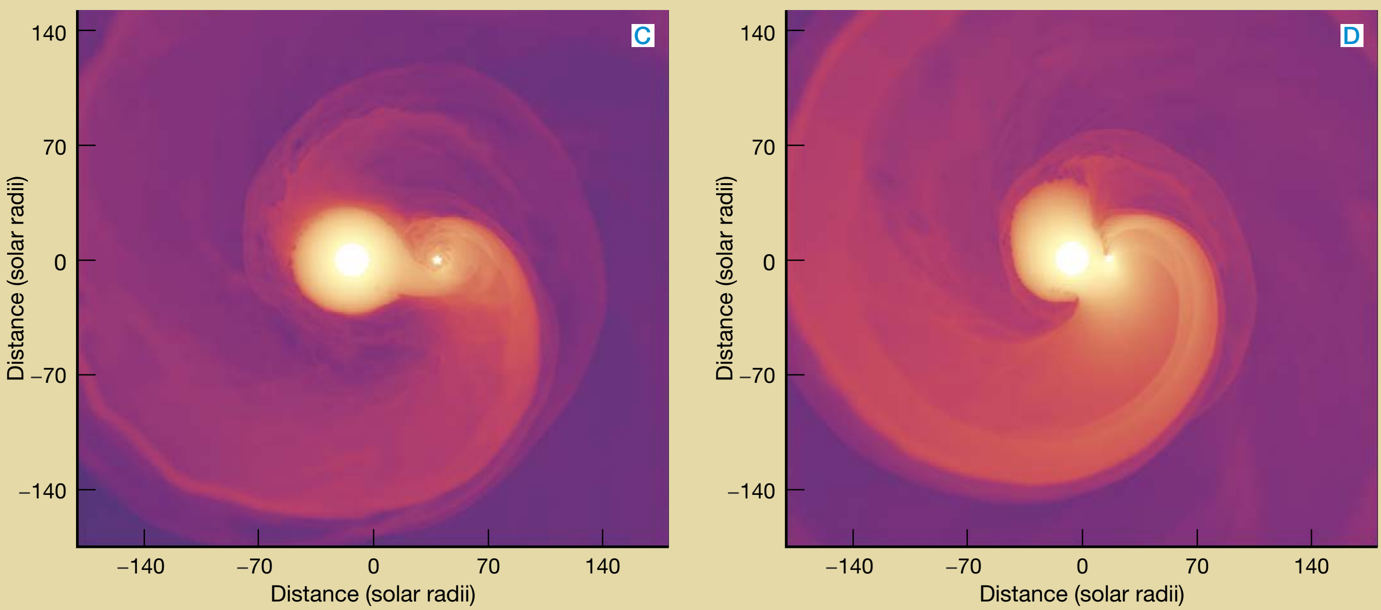
Missing among all of these blue and yellow progenitor stars, however, were the puffiest, reddest giants — stars like what the Sun will evolve into in another several billion years. These missing events are now turning up as "redder than red" novae: outbursts that happen at such cool temperatures that they only glow in infrared light.

Searches for these events began with NASA's Spitzer Space Telescope and are continuing now using NEOWISE and the James Webb Space Telescope. These discoveries have taught us that collisions involving aging red stars look substantially different than the other stellar crashes we've seen.

When a relatively hot star like the Sun merges with a companion, we see a red nova that starts out bright in visible light before eventually giving way to a dusty, infrared-bright aftermath. When a cooler star (like an old, fluffy red giant) swallows a companion, the whole process is slower and less energetic. The traces are dusty and infrared-bright from the start, with visible light enshrouded by the curtain of dust the stars spew out as they coalesce.



◀▼ **ANATOMY OF A RED NOVA** As the stars spiral in toward each other, they throw off gas, and the binary brightens. Here, light curves at different visible and infrared wavelengths for the red nova in M31 are paired with the author's simulation snapshots, which show the lead-up to the stars' merger. The simulation looks at the binary from above, showing gas density in the orbital plane. Brighter areas show where gas is denser. The white circle is the primary's core; the white star is the secondary's core. (In the inset light curve, BVRI are specific visible and near-infrared filters, from bluer to redder in color.)



Observe, Model, Repeat

The more mergers we find, the better we can understand what happens physically during the crash. But to really have a handle on what's going on, we need to watch mergers up close. Smashing two stars together in a lab is out of reach. The next best thing is smashing simulated ones together on a computer. My own research uses this sort of computer modeling to try to interpret and reconstruct the signals we see.

Compared with a star's lifetime, all of these splashy stellar mergers seem incredibly sudden: A star goes through its immensely long life, only to collide with its companion over the course of a few days. To find out what's causing the sudden brightness changes, I built computer models of the very beginning of a stellar merger — the phase during which the pair just starts to fall together. These models reveal that the progressive pre-outburst brightening starts when the stars are still separate but spiraling closer together, spilling out some of their gas into their surroundings as their orbits tighten. The flashy outbursts themselves come from the moment of splashdown, when the smaller star first falls inside its companion.

With that general picture in mind, we're now working hard to understand the growing population of events and their differences. Right now, our best predictions for the light a merger event should produce don't quite match the real thing. Eventually, through a mix of crime-scene reconstruction and trial and error, we hope to improve our computer models to the point that we're able to see the light from a merger in a distant galaxy and use the models to infer the nature of the colliding system, including the stars' masses, radii, and other properties.

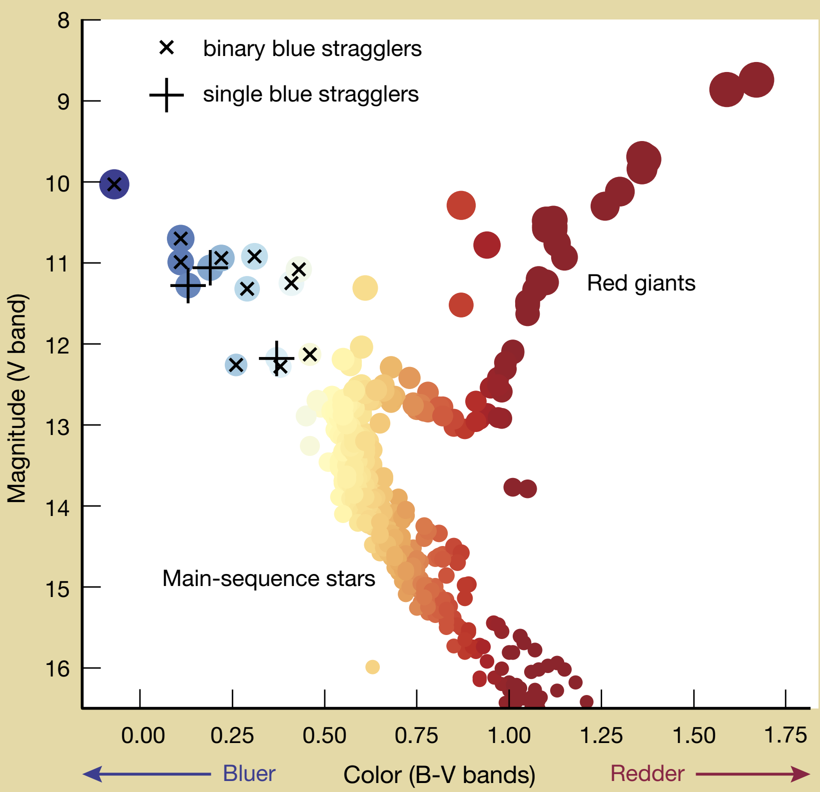
Old Stars Made Young Again

Despite all of the advances, merging stars are rare enough that we're still not often lucky enough to catch them in the act. Instead, we often have to look for telltale signs that reveal a star was created by a merger. If Mason and Tylenda are merger hunters, other astronomers are merger archaeologists, searching for traces of past stellar mergers in populations of stars.

For a short time, merged stars remain surrounded by evidence of the act. So, if not quite caught red-handed, they're at least easier to identify. One such example is the star TYC 2597-735-1 and its surrounding nebula in the constellation Hercules. This object probably merged a few thousand years ago. That is long enough that the literal and metaphorical dust is starting to clear, letting us see through the ejected gas to the newly remade star. The star itself is fading slowly as the extra heat deposited by the most dramatic moments of merger leaks out.

When mergers have occurred further back in a star's history, the traces are still there but are perhaps more subtle. Merger-made objects, by virtue of the fact that they are two stars stuck together, tend to be more massive than those

▶ **BLUE STRAGGLERS IN M67** *Near right:* As stars age, they first stop fusing hydrogen in their cores, then swell and redden. Plotting a cluster's stars by color and brightness reveals this turnoff point (rightward kink). Because a star's lifetime depends on its mass, astronomers can tell how old a cluster is based on which stars have stopped fusing hydrogen and moved rightward on the diagram. Here, the upper left of the diagram for the cluster M67 ought to be empty, because all the most massive stars have already evolved rightward. Yet some "blue stragglers" remain. These stars have been rejuvenated by binary interactions. *Far right:* The blue stragglers of M67 are circled. Blue circles mark blue stragglers with detected binary companions. Pink circles mark blue stragglers that don't have companions — these are potentially merger-made. North is up.



PLOT: THE AUTHOR

▲ **BLUE RING NEBULA** This false-color image combines ultraviolet (blue and yellow) and hydrogen-alpha (red) observations to reveal a nebula around the star TYC 2597-735-1. The ring is actually an hourglass-shaped outflow, with the star at the central pinch point, and was ejected by a merger. It looks like a ring because of our point of view.

around them. With the influx of extra hydrogen fuel, merged stars also burn bluer and brighter. They therefore look younger than the other stars in their surroundings, which in many cases should have been born around the same time. In the context of star clusters, astronomers call these oddly youthful stars *blue stragglers* — seemingly left behind by the march of stellar evolutionary time.

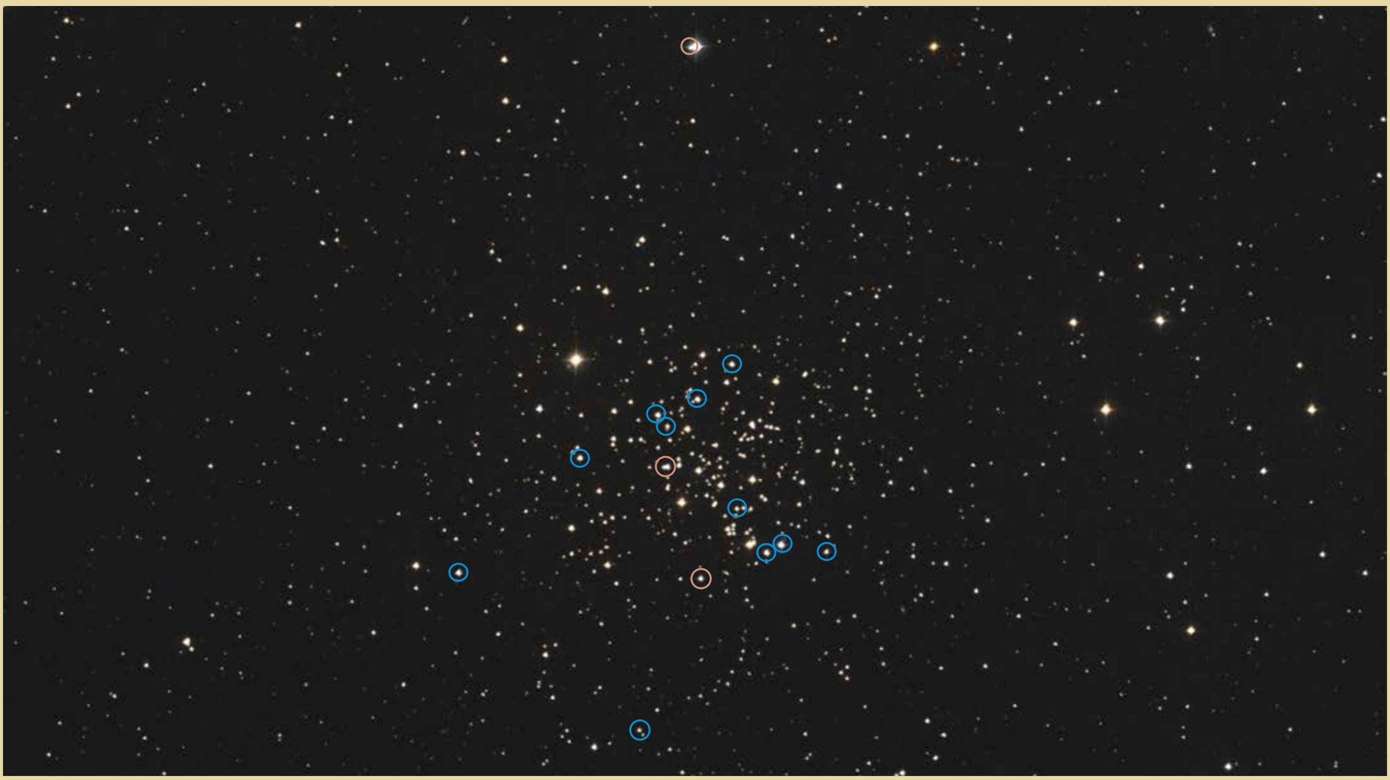
Merged stars initially have rapid spins, which also make them appear young. In general, stars tend to spin down as they age — a trend so powerful that we use *gyrochronology* as a cosmic clock (*S&T:* Nov. 2020, p. 28). Yet, a merger winds this cosmic clock back up, thanks to the conservation of the spin from the pair's orbit. By measuring stellar spins, astronomers have shown that blue stragglers do, in fact, spin faster than the other stars around them. We also suspect that the merger stirs up stars' material in such a way that it whips up a particularly powerful stellar magnetic field.

Perhaps the most surprising discovery of all is that these seemingly exotic events are a remarkably common part of the evolution of stars, shaping and transforming the populations that we see. Among massive stars, we think anywhere from 10% to 50% will merge with a companion at some point in their lives.

Astronomers are now speculating that the "refresh" effect of past mergers might explain some of the puzzling diversity in massive stars' properties — like why the range of spin rates and magnetic-field strengths is much broader than we'd otherwise expect. It could be that the study of mergers will help us crack the code for a much larger population of stars than the handful we've actually seen collide.

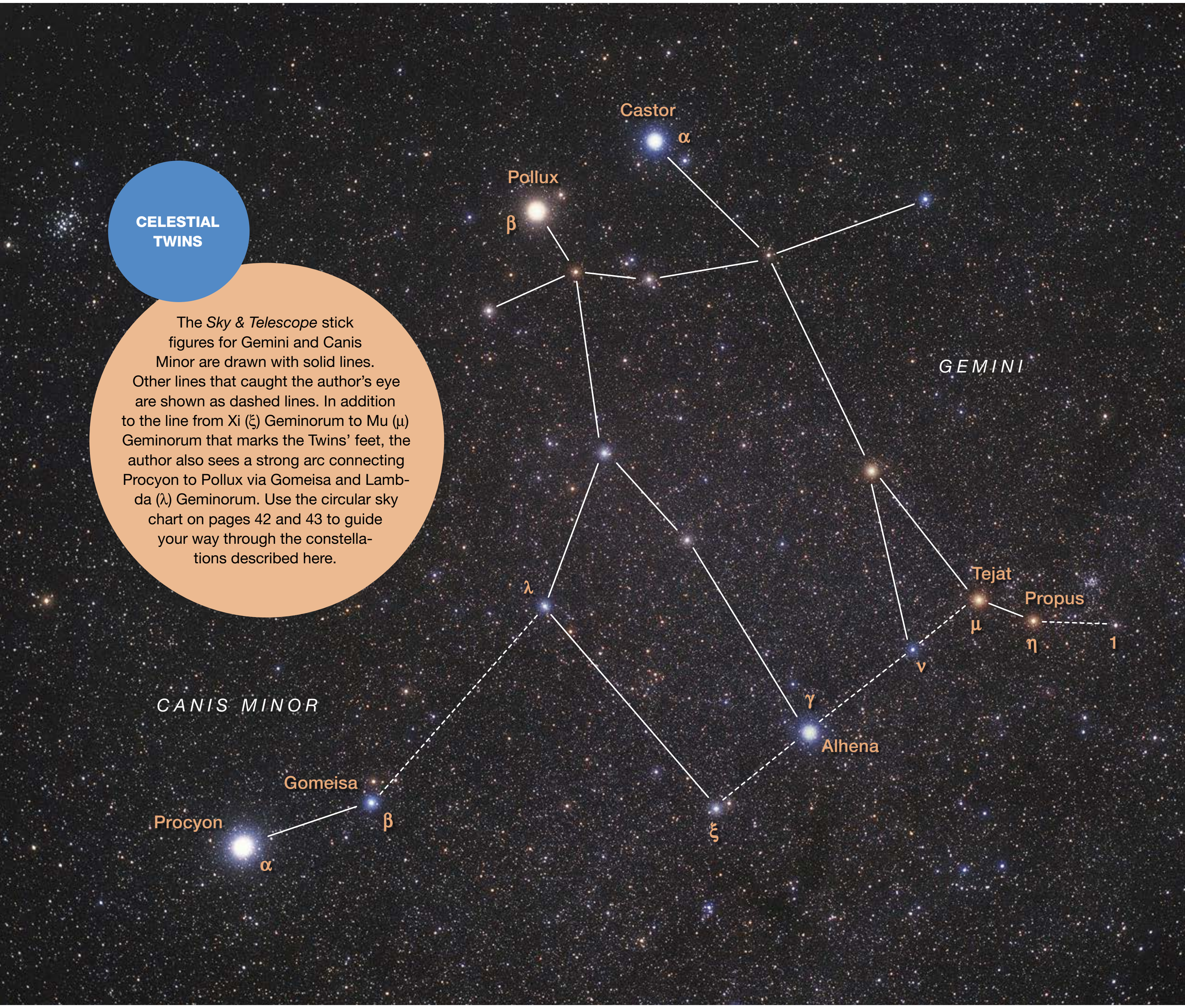
■ **MORGAN MACLEOD** (Center for Astrophysics, Harvard and Smithsonian) feels lucky to spend his time daydreaming about the stars.

BLUE RING NEBULA: NASA / JPL-CALTECH / M. SEIBERT (CARNEGIE INSTITUTION FOR SCIENCE) / K. HOADLEY (CALTECH) / GALEX TEAM; M67: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY



Seeking Star Pairs

Cast your gaze skyward to admire some inspiring, naked-eye stellar duos.



CELESTIAL TWINS

The *Sky & Telescope* stick figures for Gemini and Canis Minor are drawn with solid lines. Other lines that caught the author's eye are shown as dashed lines. In addition to the line from Xi (ξ) Geminorum to Mu (μ) Geminorum that marks the Twins' feet, the author also sees a strong arc connecting Procyon to Pollux via Gomeisa and Lambda (λ) Geminorum. Use the circular sky chart on pages 42 and 43 to guide your way through the constellations described here.

One morning last fall my wife asked me which two stars she'd seen rising over the hill the previous night. When I told her it sounded like Castor and Pollux, she said, "I thought so! They looked like they belong together." And indeed, they do.

Castor and **Pollux** are the classic example of a star pair — two stars much closer to each other than they are to any other, comparably bright star. Pairs are the simplest possible star patterns, eye-catching and easy to describe. They're widely recognized by different cultures and often play key roles in the traditional Western constellations.

When I approach a star pair, I like to first estimate the stars' vital statistics: brightness, color, and separation from each other. Then I like to think how they fit into the rest of the night sky.

The Twins and the Lesser Dog

Castor and Pollux are the Alpha and Beta stars of Gemini, the Twins. (The sidebar at right lists the Greek alphabet.) This constellation is very low in the west by June, so it's best to view it in April or early May when you most likely bought or received this issue. At first glance I find the bright Gemini pair pretty evenly matched, but a closer look reveals that Pollux is significantly brighter and also has a warmer hue than Castor. I happen to know that the stars are 4½° apart, and I use that fact to estimate the separations of other stellar doubles. Alternatively, I can measure the separation with my index and middle fingers, each of which appears about 2° wide when held at arm's length.

As for their relation to the rest of the sky, 1.1-magnitude Pollux and 1.6-magnitude Castor are roughly 20° from the closest comparably bright star: 1.9-magnitude Gamma Geminorum, also called Alhena. Gamma forms a straight line, parallel to the Castor-Pollux line, with Xi to its southeast and Nu and Mu to its northwest. The line then zigs west from Mu to Eta and zags west-northwest to 1 Geminorum.

Just as human eyes are naturally drawn to star pairs, so too they love to string stars together into lines whenever possible. Both tendencies combine in the case of Mu and Eta Geminorum, also known as **Tejat** and **Propus**, respectively. They're significantly closer to each other than to the stars on either side, and quite a bit brighter, too. That makes them a good example of what I like to call "beads on a string." Both stars are red giants that vary slightly in brightness, but Tejat, typically magnitude 2.9, is probably always brighter than Propus, which is typically magnitude 3.3.

Like many star duos, the appearance of Tejat and Propus depends considerably on sky conditions. In urban skies the 4.2-magnitude suns on both sides of the pair (Nu and 1 Geminorum) are either subtle or completely invisible, making Tejat and Propus stand out in isolation. But under very dark, transparent skies even 4th-magnitude stars can appear quite bright, which tends to camouflage the pair.

In most cultures the stars Castor and Pollux are full-fledged beings in their own right; the idea of extending their

Bayer Letters and Flamsteed Numbers

If you're a regular reader of this magazine, you might have noticed that we've departed from our usual practice of including the Greek symbol for the corresponding letter in the body of the text. This was to avoid calling out nearly half the Greek alphabet in the article! So, for clarity, we decided to omit them and instead provide the table shown here.

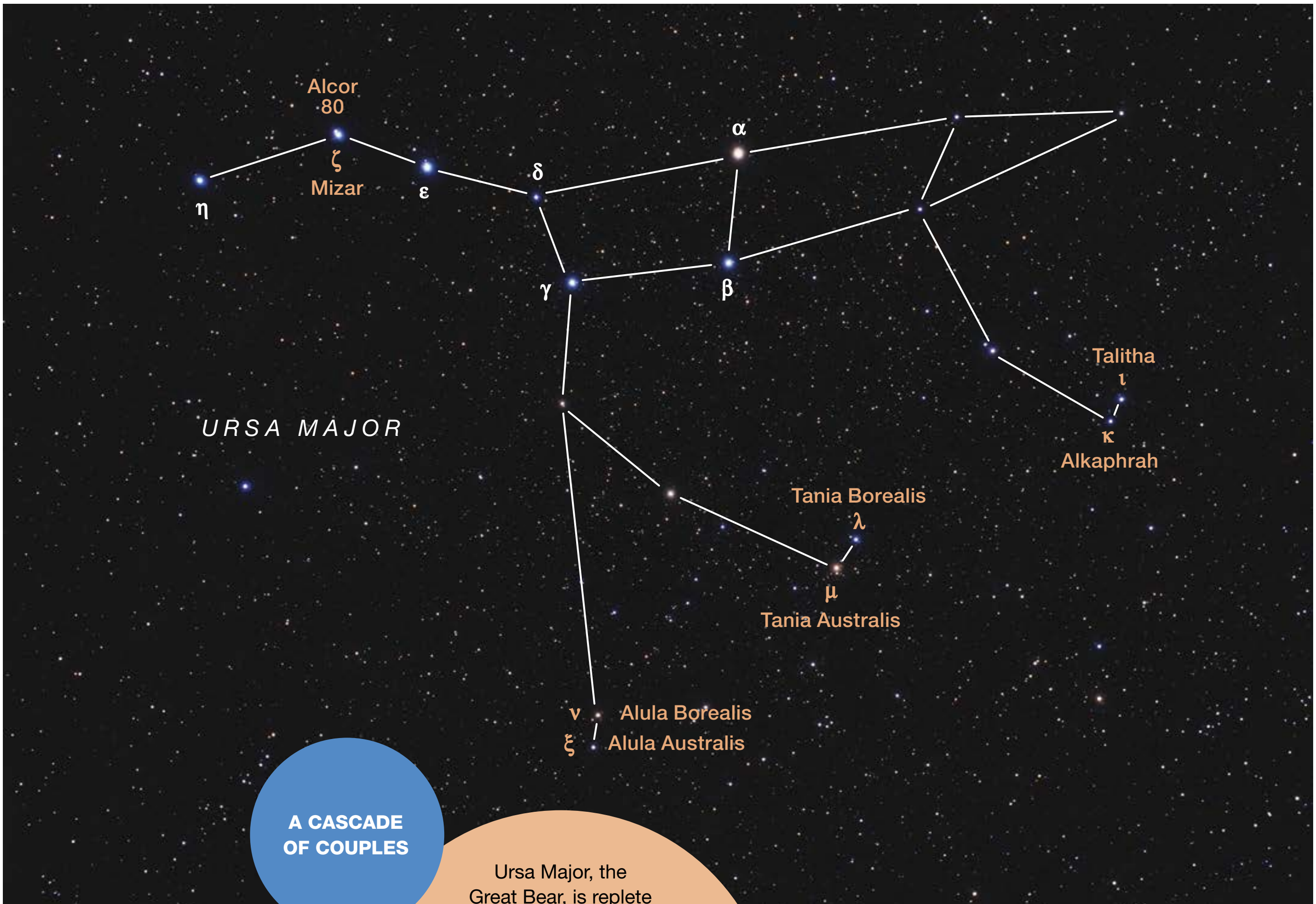
Star charts use lowercase Greek letters to label most constellations' brightest stars, a practice Johannes Bayer introduced in his 1603 atlas *Uranometria*. Bayer usually assigned the first few letters in order of brightness — for instance, Alpha and Beta Leonis are Regulus and Denebola, Leo's brightest and second-brightest stars. But there are plenty of exceptions — he often assigned consecutive letters to star pairs, with the westernmost star first. That may be why Castor and Pollux are Alpha and Beta Geminorum respectively, even though Pollux is brighter than Castor.

Stars without Greek letters are often labeled with numbers, most of them from Edmund Halley's unauthorized 1712 publication of John Flamsteed's star catalog.

Greek Alphabet (Greek Letter & Symbol)

Alpha α	Beta β	Gamma γ	Delta δ
Epsilon ε	Zeta ζ	Eta η	Theta θ
Iota ι	Kappa κ	Lambda λ	Mu μ
Nu ν	Xi ξ	Omicron ο	Pi π
Rho ρ	Sigma σ	Tau τ	Upsilon υ
Phi φ	Chi χ	Psi ψ	Omega ω

ALL CONSTELLATION IMAGES ARE BY AKIRA FUJII



A CASCADE OF COUPLES

Ursa Major, the Great Bear, is replete with stellar duos. A good test of the acuity of your eyesight is whether you can split Mizar and Alcor without optical aid. Celestial cartographer Johannes Bayer assigned Greek letters to Ursa Major not in order of brightness but on geometric principles: The stars of the Big Dipper are lettered clockwise, as are the stars of the pairs that mark the Great Bear's paws.

twin-ness to form an entire constellation seems to have originated in Mesopotamia. I assume the fact that the line from Xi to Mu Geminorum is more or less parallel to the Pollux-Castor line, plus the fact that the Xi-Mu line contains a second pair (Tejat and Propus), is what first prompted some unknown Mesopotamian astronomer to create Gemini, the Twins, in the first place. The Greeks then inherited the constellation and associated it with various sets of brothers — most often the heroes Castor and Pollux, but also quite a number of others.

According to Claudius Ptolemy's 2nd-century *Almagest*, the foundation of Western astronomy, Alpha and Beta represent the Twins' heads; Xi, Gamma, and Nu represent three of their feet; and the Mu-Eta pair marks the heel and toe of the foremost foot, just as shown in the *Sky & Telescope* stick figure. As for the rest of the Twins, if you're determined to see all the stars between the heads and feet as their bodies and arms, it's easy enough to concoct ways to do so. Nonetheless, the constellation as a whole — like almost all our constellations — is fairly arbitrary. The probability that a person with no preconceptions would independently invent the *S&T* stick figure for Gemini is vanishingly small.

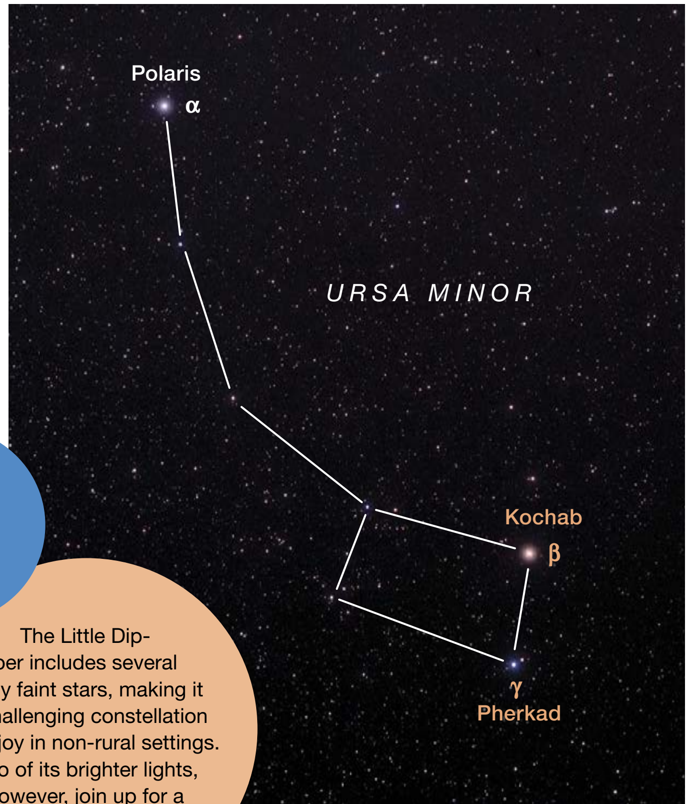
I find that dazzling Procyon (Alpha Canis Minoris) bonds strongly to Pollux and Castor. Procyon is only a little farther from Pollux than Alhena is, and it's much brighter. Moreover, Procyon forms a weak, unevenly bright pair with Beta Canis Minoris (Gomeisa). **Procyon** and **Gomeisa** have almost exactly the same separation as Castor and Pollux, but to my eyes, this coupling is far less impressive because 2.9-magnitude Gomeisa is only one-tenth as bright as +0.4-magnitude Procyon. The Pollux-Castor duo is much more than the sum of its parts, but as far as I'm concerned, Procyon would be more impressive shining in solitary splendor without Gomeisa. No doubt others will disagree. That's the beauty of naked-eye stargazing: We all live under the same night sky, but each of us sees it differently.

The Great Bear's Twosomes

Uneven star pairs may seem unconvincing when the components are far apart, but most people find them striking when they appear very close together. The classic example is **Mizar** and **Alcor**, Zeta and 80 Ursae Majoris, respectively, which mark the bend in the handle of what most North American readers call the Big Dipper. In England (and many other countries), the same striking asterism is called the Plough.

At magnitude 2.1, Mizar is roughly six times brighter than 4.0-magnitude Alcor, but the two stars are just 12′ apart. When I was younger, I saw them as a very obvious, spectacularly close pair, but at age 70 I can only separate them with difficulty, even under dark skies. The Roman army used these two stars to test soldiers' eyesight.

Again, binoculars come to the rescue when the unaided eye fails; they should show both stars easily in all but the worst conditions. Indeed, all the stellar twins described in this article are worth viewing through binoculars, and some are tight enough to fit in the field of view of telescopes as well. Mizar and Alcor prove particularly rewarding through telescopes at 30× or higher, which will also show that Mizar is itself a double star — the first one ever discovered telescopically, in fact, by Benedetto Castelli and Galileo Galilei in 1617 (*S&T:* July 2004, p. 72). And spectroscopic data prove that Alcor and both components of Mizar are themselves binary stars with short orbital periods, much too close to separate with any normal telescope. That makes Mizar a doubly nested binary system with a total of four stars, compared to two for Alcor.



PAIR AT THE POLE

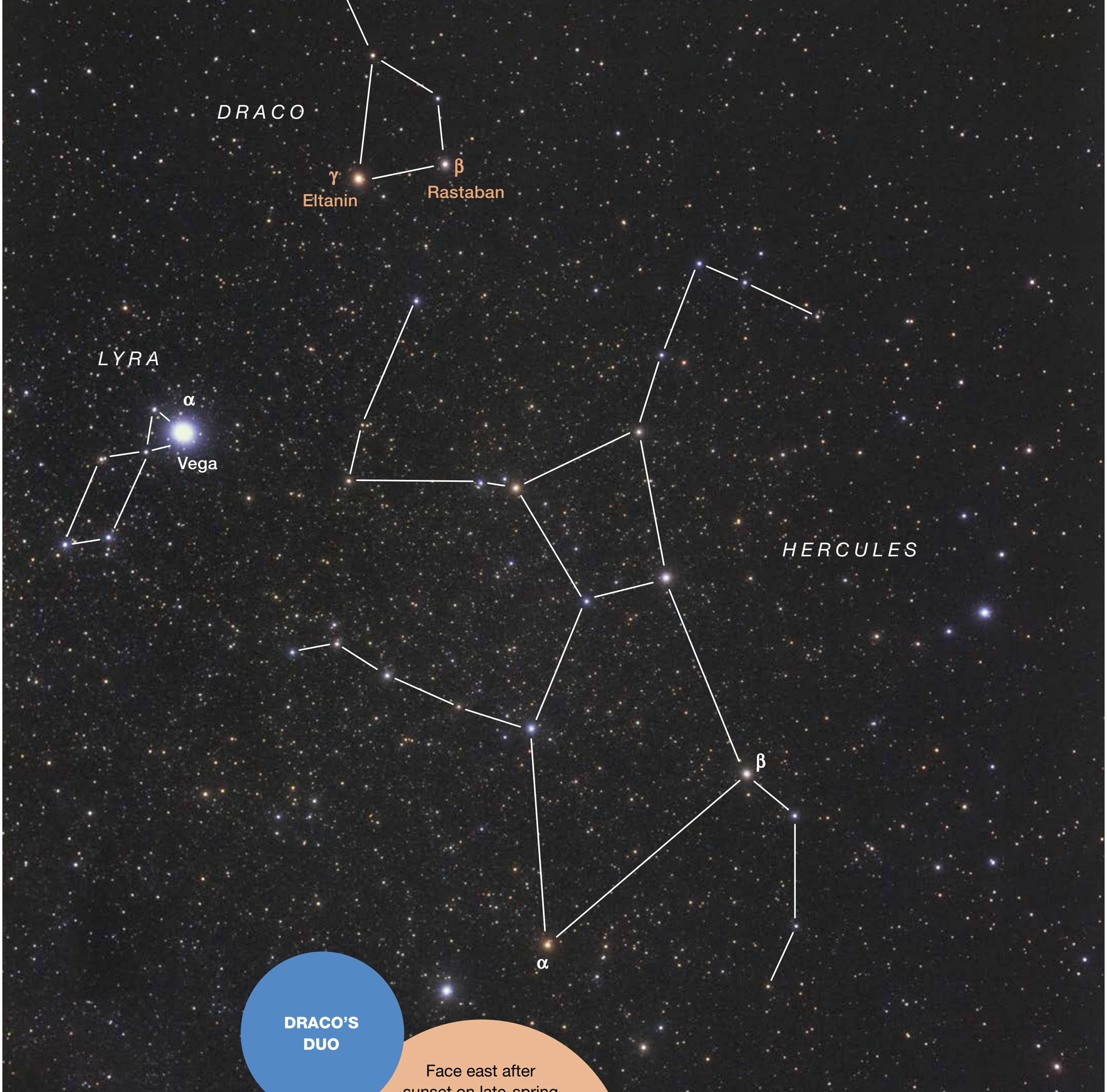
The Little Dipper includes several fairly faint stars, making it a challenging constellation to enjoy in non-rural settings. Two of its brighter lights, however, join up for a pretty pairing.

The components in most of the pairs that I'm describing here are completely unrelated. For instance, Pollux is 34 light-years from Earth, compared to 50 light-years for Castor. They only *appear* close to each other from our perspective in space. Mizar and Alcor, however, are both about 83 light-years away, move through space in the same direction, and are roughly the same age — as are four of the other bright Big Dipper stars, and a few of the fainter ones. Presumably all these stars, known as the Ursa Major Moving Group, were born together, but unlike with true clusters their mutual gravitational attraction isn't strong enough to keep them from drifting apart. So, the Big Dipper is one of the few star formations that isn't entirely

Star Pairs

Pairs' Names	Designations	Separation	Mag(v)	B–V	RA	Dec.
Pollux, Castor	β, α Geminorum	4.5°	1.1, 1.6	1.0, 0.0	$07^h\ 45.3^m$	+28° 02′
Tejat, Propus	μ, η Geminorum	1.9°	2.9, 3.3	1.6, 1.6	$06^h\ 23.0^m$	+22° 31′
Procyon, Gomeisa	α, β Canis Minoris	4.3°	+0.4, 2.9	0.4, –0.1	$07^h\ 39.3^m$	+05° 14′
Mizar, Alcor	ζ, 80 Ursae Majoris	12′	2.1, 4.0	0.0, 0.2	$13^h\ 23.9^m$	+54° 56′
Talitha, Alkaphrah	ι, κ Ursae Majoris	1.2°	3.2, 3.6	0.2, 0.0	$08^h\ 59.2^m$	+48° 02′
Tania Borealis, Australis	λ, μ Ursae Majoris	1.7°	3.0, 3.4	1.6, 0.0	$10^h\ 22.3^m$	+41° 30′
Alula Borealis, Australis	ν, ξ Ursae Majoris	1.6°	3.5, 3.9	1.4, 0.6	$11^h\ 18.5^m$	+33° 06′
Kochab, Pherkad	β, γ Ursae Minoris	3.2°	2.1, 3.0	1.5, 0.0	$14^h\ 50.7^m$	+74° 09′
Eltanin, Rastaban	γ, β Draconis	4.1°	2.2, 2.8	1.5, 1.0	$17^h\ 56.6^m$	+51° 29′
Yed Prior, Posterior	δ, ε Ophiuchi	1.4°	2.7, 3.2	1.6, 1.0	$16^h\ 14.3^m$	–03° 42′
Rigil Kentaurus, Hadar	α, β Centauri	4.4°	–0.3, +0.6	0.8, –0.2	$14^h\ 39.6^m$	–60° 50′
Shaula, Lesath	λ, υ Scorpii	36′	1.6, 2.7	–0.2, –0.2	$17^h\ 33.6^m$	–37° 06′

Data are from The Yale Bright Star Catalog, 5th Edition. Pairs are listed with the brighter star first. Magnitude and B–V for multiple stars are combined values for components. The coordinates are for the brightest component of the brighter star, and are accurate for equinox and epoch 2000.0.



DRACO'S DUO

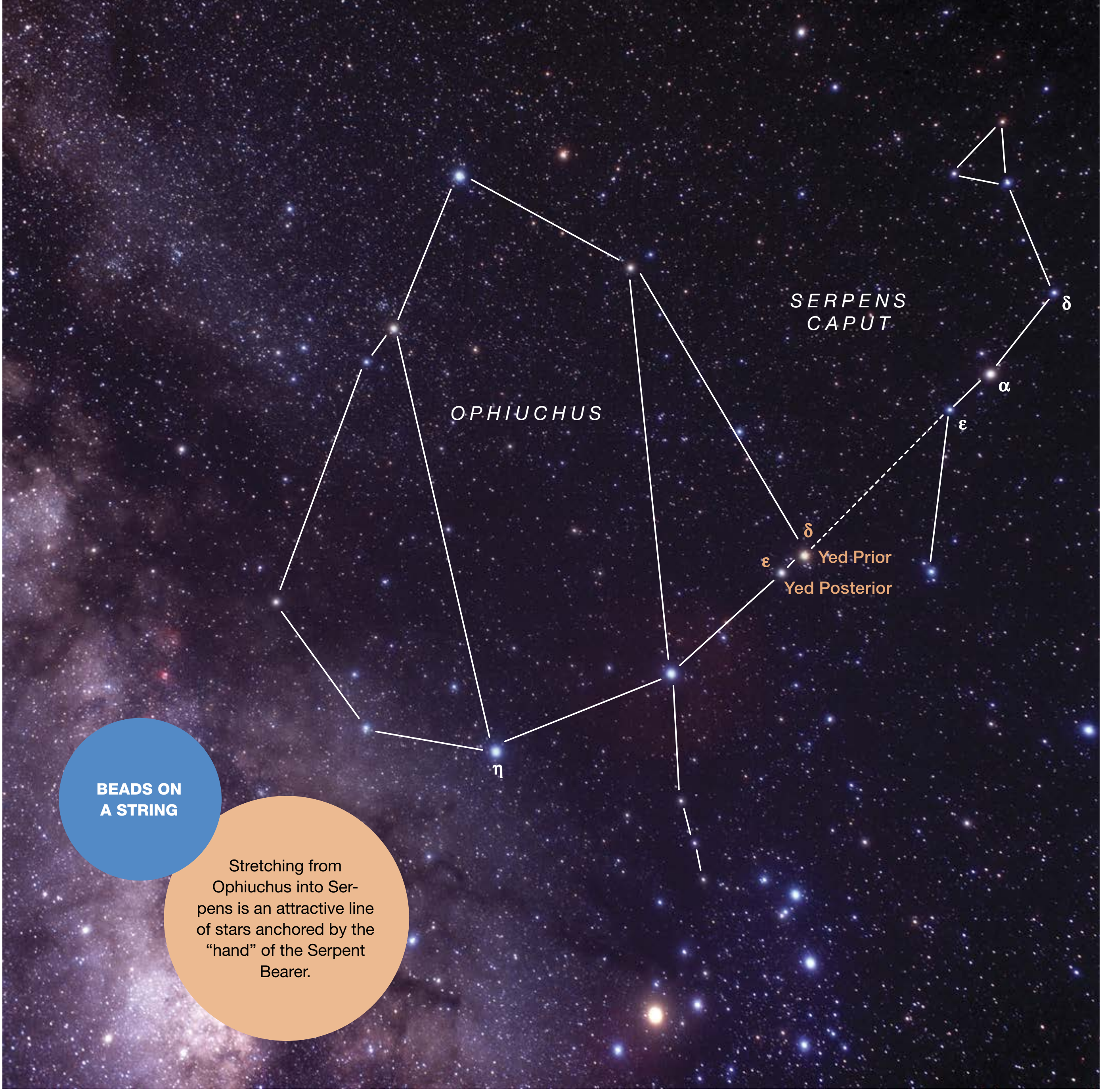
Face east after sunset on late-spring or early-summer evenings — about 15° (the distance between your index and pinkie fingers held at arm's length) above the Lyre's lucida, Vega, you should spot the stars that mark the Dragon's eyes.

accidental. It also seems likely that the Mizar system and the Alcor system orbit each other, forming a triply nested binary system, with a total of six components. If so, Mizar-Alcor is one of the very few true binaries that can be split without optical aid.

Legends about Mizar and Alcor generally treat them in the context of the larger asterism. That's true of all the many Mizar-Alcor stories in Dorcas S. Miller's handy sourcebook *Stars of the First People*, a compendium of Native American star lore collected by many different anthropologists. Often the Big Dipper's Bowl is a bear, Mizar is one of a line of hunters in pursuit, and Alcor is his wife, sister, dog, or cooking pot.

Three other famous star pairs in Ursa Major are **Talitha** and **Alkaphrah** (Iota and Kappa Ursae Majoris); **Tania Borealis** and **Tania Australis** (Lambda and Mu); and **Alula Borealis** and **Alula Australis** (Nu and Xi). None of these are especially bright, but they stand out well in the vast sea of more challenging stars between the Big Dipper, Leo, and Gemini due to the fact that they're all reasonably tight and evenly matched.

The *S&T* stick figure for Ursa Major, the Great Bear, reflects Ptolemy's *Almagest*, which describes Tania Borealis and company as marking three of the bear's paws. (The fourth paw is mysteriously missing.) Can you make out the bear? I've always had trouble doing so; the standard assignments seem all wrong. According to Ptolemy, the bear has a



BEADS ON A STRING

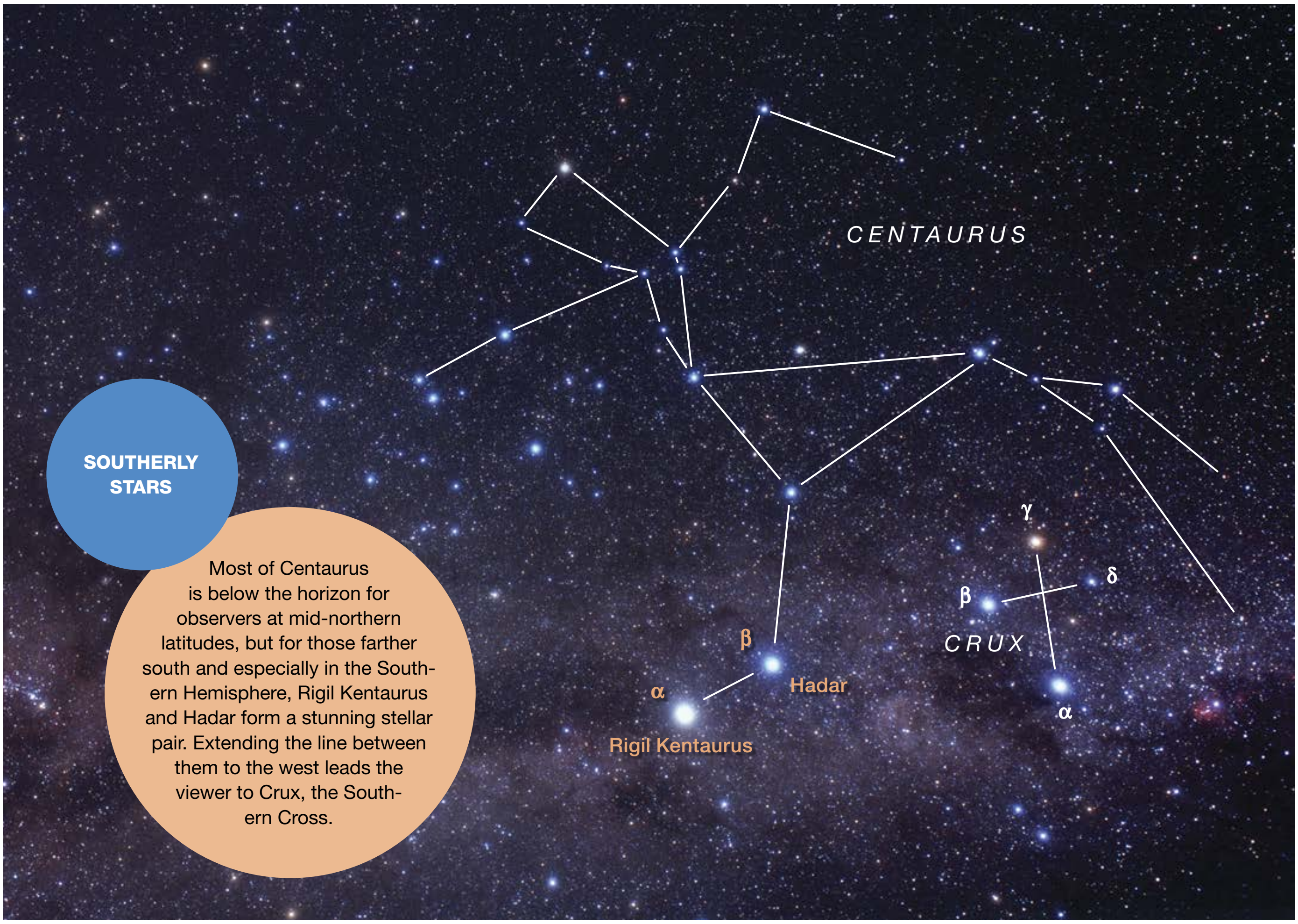
Stretching from Ophiuchus into Serpens is an attractive line of stars anchored by the "hand" of the Serpent Bearer.

On Brightness and Color

Much of a star pair's appearance depends on its relation to the surrounding stars, which is hard to quantify. But a pair in isolation can be described by five numbers, all of which are shown in the table on page 23: the separation (angular distance) between the stars, and each star's brightness and color.

Brightness is measured using the familiar magnitude scale, in which a bigger number means a fainter object (*S&T:* May 2023, p. 72). A 0.0-magnitude star is precisely 100 times brighter than a 5.0-magnitude star. Estimating magnitudes accurately takes considerable practice. Pollux's magnitude is 0.5 lower than Castor's, meaning that it's 1.6 times brighter, but the difference may well seem smaller to you due to the fact that the human eye's response is not linear.

Astronomers usually express color as *B–V*, short for "blue minus visual." The higher the number the redder the star. For reference, the Sun has B–V = 0.7. So, Betelgeuse, with B–V = 1.8, is redder than the Sun and Rigel, at 0.0, is bluer than the Sun. Most stars are too faint to stimulate color vision, but binoculars should enhance their colors greatly — especially if you defocus the view slightly.



very long tail, a small body, and three extremely long legs. In fact, bears have massive bodies, fairly short legs, and extraordinarily short, stubby tails.

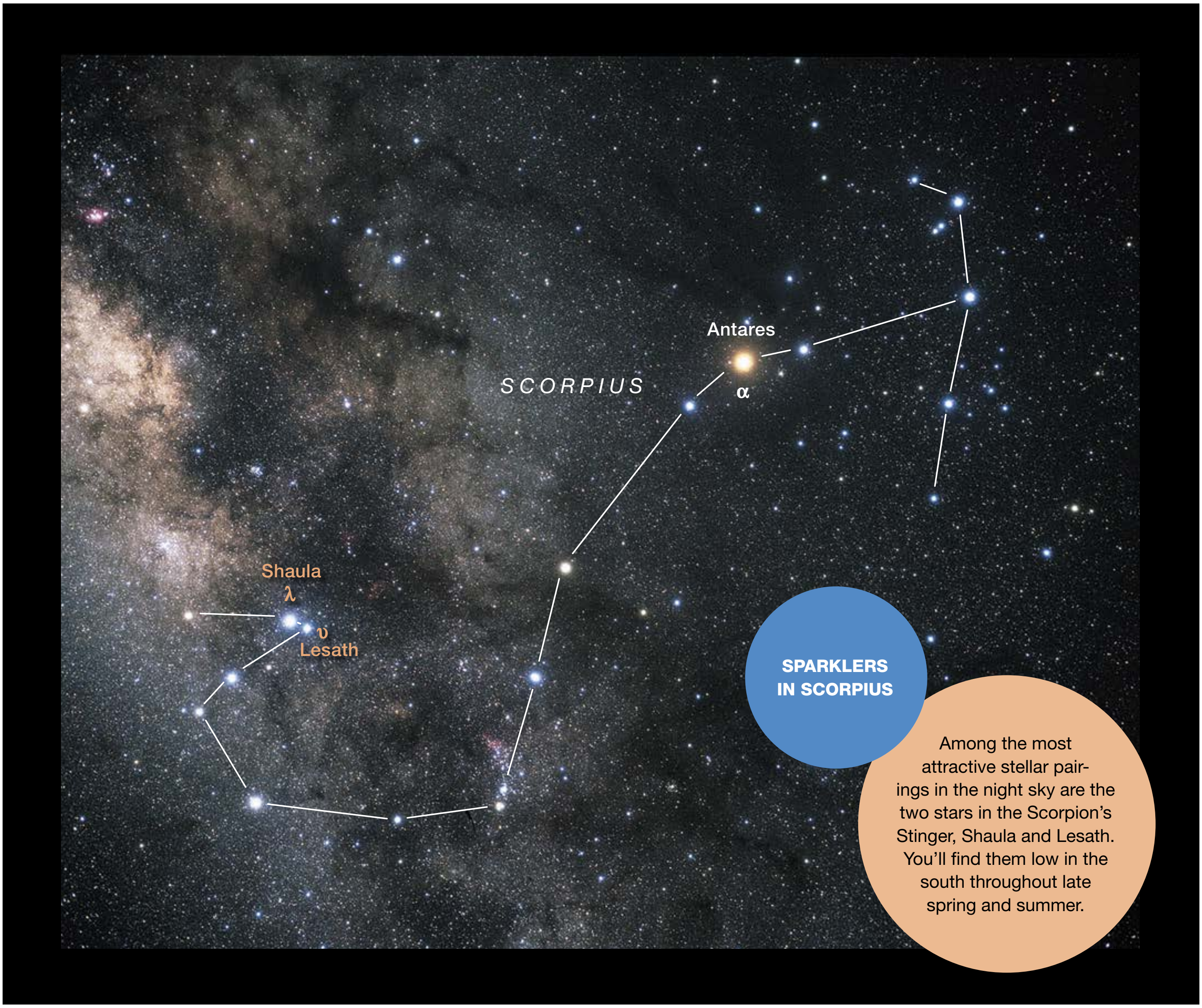
I much prefer the explanation from traditional Arabic astronomy, which describes the three pairs as the footprints left by the Gazelle as it leaps away from the celestial Lion, a huge constellation of which Leo is just a small part (*S&T:* Apr. 2024, p. 45). This explains why the "footprints" form an almost straight, evenly spaced line — something that's rarely true of a quadruped's paws. The leaps were numbered *al-ula*, *al-thaniya*, and *al-thalitha*, meaning "first," "second," and "third," respectively, giving rise to the modern Alula, Tania, and Talitha. The rarely used name Alkaphrah comes from the Arabic *al-qafzah*, meaning "the leap," and Borealis and Australis were added to Alula and Tania during the Renaissance to denote the northern and southern star of each duo.

Let's look at two more star pairs before we leave the far-northern sky. Under typical urban or suburban skies, the Little Dipper is effectively a three-star constellation consisting of 2.0-magnitude Polaris (Alpha Ursae Minoris) at the end of the Handle, plus 2.1-magnitude **Kochab** (Beta) and 3.0-magnitude **Pherkad** (Gamma) at the far end of the Bowl. The remaining stars are magnitude 4.2 or fainter, rendering them subtle at best in poor conditions. Kochab and Pherkad, by contrast, are easy to see in all but the worst skies, and their 3.2° separation makes them a fairly striking pair. I find Kochab clearly orange or reddish compared to Pherkad's neutral white.

From the Dragon to the Scorpion

Much like the Little Dipper's Bowl, the head of Draco, the Dragon, consists of two 4th-magnitude stars plus a bright pair: **Eltanin** and **Rastaban**, Gamma and Beta Draconis, which shine at magnitudes 2.2 and 2.8, respectively. As with Kochab I find that Eltanin, the brighter of the two, seems distinctly orange-red to me.

Turn the all-sky map on pages 42 and 43 so that you have "Facing SE" at the bottom, and we find my personal favorite star duo: **Yed Prior** and **Yed Posterior**, Delta and Epsilon Ophiuchi, where the hand of Ophiuchus, the Serpent Bearer, holds Serpens, the Serpent. The names are derived from *al-yad*, Arabic for "the hand," plus qualifiers noting that Delta precedes Epsilon in their nightly east-to-west trek across the sky. The Yed stars are a good example of beads on a string, the string in question stretching 35° in an almost straight line from Eta Ophiuchi in the south through the two Yed stars to Epsilon, Alpha, and Delta Serpentis.



Let's end with a couple of far-southern star pairs depicted on our Southern Hemisphere chart, presented on page 44. Alpha Centauri and Beta Centauri, also known as **Rigil Kentaurus** and **Hadar**, are 4.4° apart — almost exactly the same separation as Castor and Pollux — but at magnitudes –0.3 and +0.6 they're much, much brighter. They point to Crux, the Southern Cross, less than 10° west of Hadar — together they form the sky's most spectacular star grouping, with five of the sky's 25 brightest stars, all inside an 18°-diameter circle. That's not entirely an accident, since Beta Centauri and most of the Southern Cross stars are members of the Scorpius-Centaurus OB Association, a group of related stars roughly 400 light-years distant — much like the Ursa Major Moving Group, but on a much grander scale.

Alpha Centauri, by contrast, is the closest star system to our own Sun, barely 1⁄100 the distance of Beta. (The two brightest components, which form a magnificent telescopic double, are 4.3 light-years away, and their faint red dwarf companion Proxima Centauri is just 4.2 light-years distant.) Because Alpha Centauri is so close to Earth, its motion through space is obvious. In ancient Greek times Alpha appeared 50% farther from Beta than it does today.

For observers too far north to see Alpha and Beta Centauri, the tight duo that marks the Stinger of the Scorpion's Tail is a great consolation prize. **Shaula** and **Lesath**, Lambda and Upsilon Scorpii, are both members of a different subgroup of the huge Scorpius-Centaurus Association. With a separation of just 36′, these two stars, sometimes known as the Cat's Eyes, form one of the finest pairings in the night sky.

This article has only mentioned a handful of the most prominent star pairs. Next time you find yourself outside on a clear, dark night, try discovering a few of your own.

Contributing Editor **TONY FLANDERS** loves to lie on his back and view the night sky as a whole.

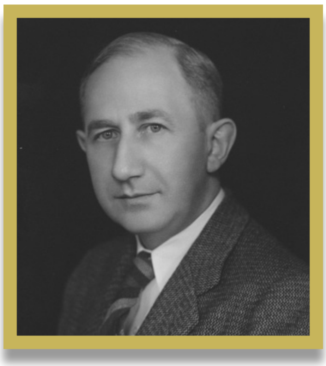
A Faint Scattering of Stars

Walter Baade's dogged curiosity helped unveil a bigger and older universe.

It's September 1952 and Walter Baade is presenting his research to the International Astronomical Union General Assembly meeting in Rome, Italy. His results were published six years earlier, but now he's ready to explain their impact on the size and age of the universe. His work will energize the field of stellar evolution. Baade's presentation bookends a scientific journey that started in Germany and concluded at Palomar Observatory in California. But while Baade's meticulous observation skills were formidable, it was the personnel demands and blackout conditions of World War II that contributed to his biggest discovery.

Coming to America

Walter Baade was born in Schröttinghausen (now a district of the city of Bielefeld), northwestern Germany, in 1893, and, as the son of a schoolteacher, he acquired a solid background in math and science. A congenital hip problem kept him out of military service during World War I, so Baade spent those years working for the German Army Technical Center while studying at the University of Göttingen. In 1919, he earned his PhD in astronomy and accepted a position at Hamburg Observatory working with the institution's 1-meter (40-inch) reflector, then one of the biggest on the continent. Although he certainly knew about the powerful telescopes operating at the time in America, gaining access to such instruments wasn't a realistic ambition for a post-war German citizen.



▲ **A REVOLUTIONARY RESEARCHER** This portrait of Walter Baade was captured around 1935, on the eve of his most productive decade, in which he advanced the study of supernovae, confirmed the existence of two distinct populations of stars, and energized the field of stellar evolution.

CARNEGIE OBSERVATORIES COLLECTION, HUNTINGTON LIBRARY, SAN MARINO, CALIFORNIA

European astronomers in the early 20th century primarily focused on astrometry, and so Baade's initial duties were dedicated to measuring star positions. He nevertheless still found time to dedicate to his research interests — globular clusters and nebulae. One of his early notebooks (likely from 1921) was entitled "Stellar Evolution" and contained charts of variable stars and the spectra of nebulae. Harlow Shapley, then an astronomer at Mount Wilson Observatory, maintained that nebulae were simply glowing gas — Baade, on the other hand, suspected the presence of stars in the galaxy M33 in Triangulum, based on a photograph taken in 1920 with Mount Wilson's 60-inch telescope. Archival photographs of other nebulae indicated to him that these objects, too, held stars. Confirming these beliefs would drive his research for decades.

At Hamburg Observatory, Baade devoted most of his energies throughout the 1920s to observing globular clusters. Like Shapley, he thought that RR Lyrae stars — variables whose period-luminosity relationship served to make them effective "standard candle" measures of distance — were markers of these clusters and began a search for them in 1926. Expanding his search, Baade soon found RR Lyrae stars in the plane of the Milky Way as well. Detecting them was challenging, but it provided early evidence for what was then a nascent idea in astronomy — *interstellar extinction*, the attenuating effect of gas and dust on stellar brightness measurements.

In 1925, Baade visited the U.S. while on an expedition to observe the January 24th total solar eclipse. During his stay, he met Shapley, now Director at Harvard College Observatory. Shapley arranged a fellowship for Baade for 1926–27, which would allow him to work at several American facilities, including Mount Wilson Observatory, before returning home to Germany.

Seminal research was underway at Mount Wilson. In 1918, Shapley had used the period-luminosity relationship of Cepheid variables, discovered by Henrietta Leavitt just six years earlier, to calculate distances to globular clusters around the Milky Way (*S&T:* Dec. 2020, p. 12). Edwin Hubble used the same method in 1924 to measure distances

KEY TO THE UNIVERSE The magnificent Andromeda Galaxy (M31) is a familiar sight to amateur and professional astronomers alike. Walter Baade updated the true size and age of the universe through his determined search for stars at the hearts of Andromeda and its companion galaxies, M32 (left of core of the main galaxy) and M110 (below right).

GARY SERONIK

to several “spiral nebulae,” including Andromeda, and found them to be too far away to belong to our galaxy; they must therefore be galaxies themselves, and the universe must be much bigger than astronomers had believed. In 1929, Hubble related a galaxy’s distance to the redshift of its spectra, showing that the universe was expanding as well (*S&T:* Sep. 2023, p. 20). But while these revelations made Hubble a science superstar, his calculations implied a universe that was younger than the oldest stars in it. It was a dilemma that Baade would help resolve two decades later.

Hubble’s results made galaxies a hot topic and generated a need for more research staff at Mount Wilson Observatory. Based on Baade’s track record and on the good reputation he’d built during his fellowship year, the German astronomer was offered a position at the observatory in 1931.

Not long after his arrival at Mount Wilson, Baade formed a collaboration with Fritz Zwicky, a California Institute of Technology physicist. Zwicky was also a recent (1925) arrival to the U.S. from Switzerland and shared Baade’s interest in stellar evolution and supernovae. Their collaboration proved productive, and, in 1934, the duo published three influential papers that established supernovae as a new class of object, postulated that cosmic rays were generated by supernovae, and hypothesized about how neutron stars were the remnants of the stars that underwent the supernova explosion. They later partnered on a project in which Zwicky would search for supernovae from Mount Palomar using the facility’s new 18-inch Schmidt telescope and Baade would perform follow-up measurements of their light curves from Mount Wilson. It was another fertile endeavor, and Baade’s light curves laid the foundation for using supernovae to determine distances to stars.

Baade collaborated with Hubble in 1938 and 1939 on a program to study stellar systems in the constellations Sculptor and Fornax using photographic plates that Shapley had obtained with Southern Hemisphere telescopes. Baade was convinced that these systems were dwarf elliptical galaxies — identifying stars in them would confirm their hypothesis. The plates yielded no blue or red supergiant stars — reminiscent of the central bulge of the Andromeda Galaxy and its elliptical companions — which led them to speculate that such stars might be absent in all elliptical galaxies. The presence or absence of supergiants in these difficult-to-resolve objects was an important clue that hinted at distinct stellar populations. Baade was moving closer to big discoveries, but he needed better data.

◀ **A PRODUCTIVE PIONEER** Harlow Shapley made seminal contributions to astronomy, including using Cepheid variables to estimate the size of the Milky Way and our solar system's location within it. Shapley arranged a fellowship for Baade, which allowed the German astronomer to work at Mount Wilson Observatory.

Making the Most of a Dark Time

America's involvement in World War II, which began in 1941, forced most Mount Wilson scientists, including Hubble, into defense projects. As a result, telescope access opened up dramatically. Furthermore, homes and businesses in the Los Angeles Basin were now required to dim their lights at night to protect against Japanese aerial attack, leading to darker skies. Although these circumstances favored astronomy, wartime laws threatened to keep Baade off the mountain altogether — as a German citizen, he was classified as an enemy alien and subject to stringent restrictions. Worst of all, he was required to be at home during nighttime curfew hours — exactly when he should have been observing. Fortunately, Milton Humason, another Mount Wilson astronomer, was on good terms with the local military representative and coaxed him into granting an exception for Baade, and he was able to continue his research.

While the wartime absence of many of Baade's colleagues deprived him of rewarding collaborations, it also offered a greater degree of work autonomy. He would make good use of his independence.

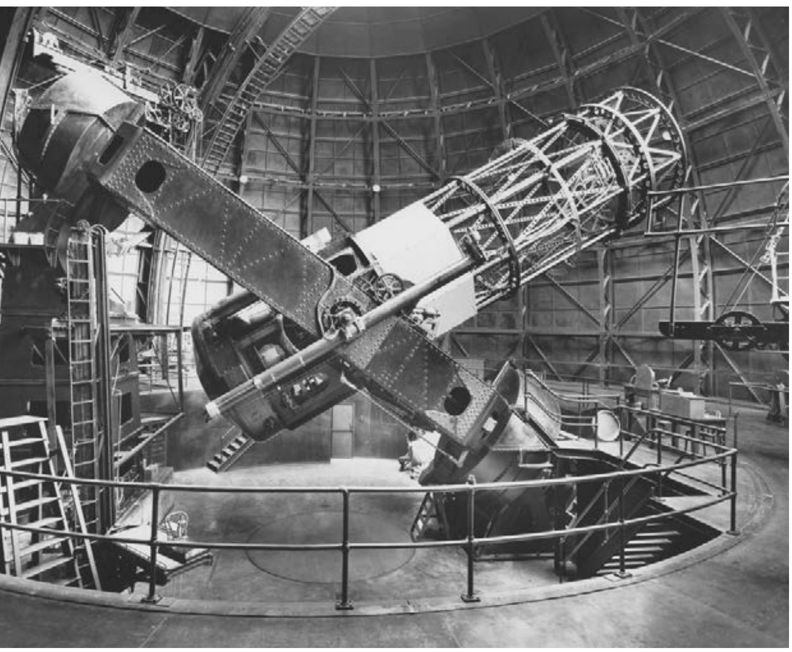
The photographic plates Baade and Hubble had used for the Sculptor and Fornax studies were sensitive to the blue colors of stars that dominate the arms and disks of spiral galaxies. But the plates showed little in the central regions of these objects, and Baade suspected that a different population of cooler, less luminous red stars resided there. Extending his thinking, he believed that the RR Lyrae variable stars he'd been studying for so long in globular clusters might also be found in the central regions of elliptical galaxies, but that the luminous blue Cepheids found in the arms and disks of spirals would be absent. To confirm his ideas, however, he had to resolve stars in the dense, central regions of these galaxies.

Baade kept up-to-date on new photographic emulsions and was often able to acquire the most advanced plates directly from manufacturers before anyone else. He spent time experimenting with red-sensitive plates, hoping to resolve fainter stars than Hubble had been able to do. Although he had previously managed to record stars in the outer nucleus of Andromeda, resolving them within that galaxy's heart remained tantalizingly out of reach. Even the 100-inch Hooker Telescope — the largest in the world at the time — hadn't been up to the task.

But Baade continued to refine his methods and tools, and in the summer of 1943, he was ready to try again with the 100-inch. He scheduled his observing runs to coincide with moonless nights during Los Angeles blackout periods. He pre-treated his photographic plates with dilute ammonia to increase their sensitivity and spent hours preparing the telescope for his four-hour exposures. Then he timed his sessions to match when Andromeda would be highest in the sky.

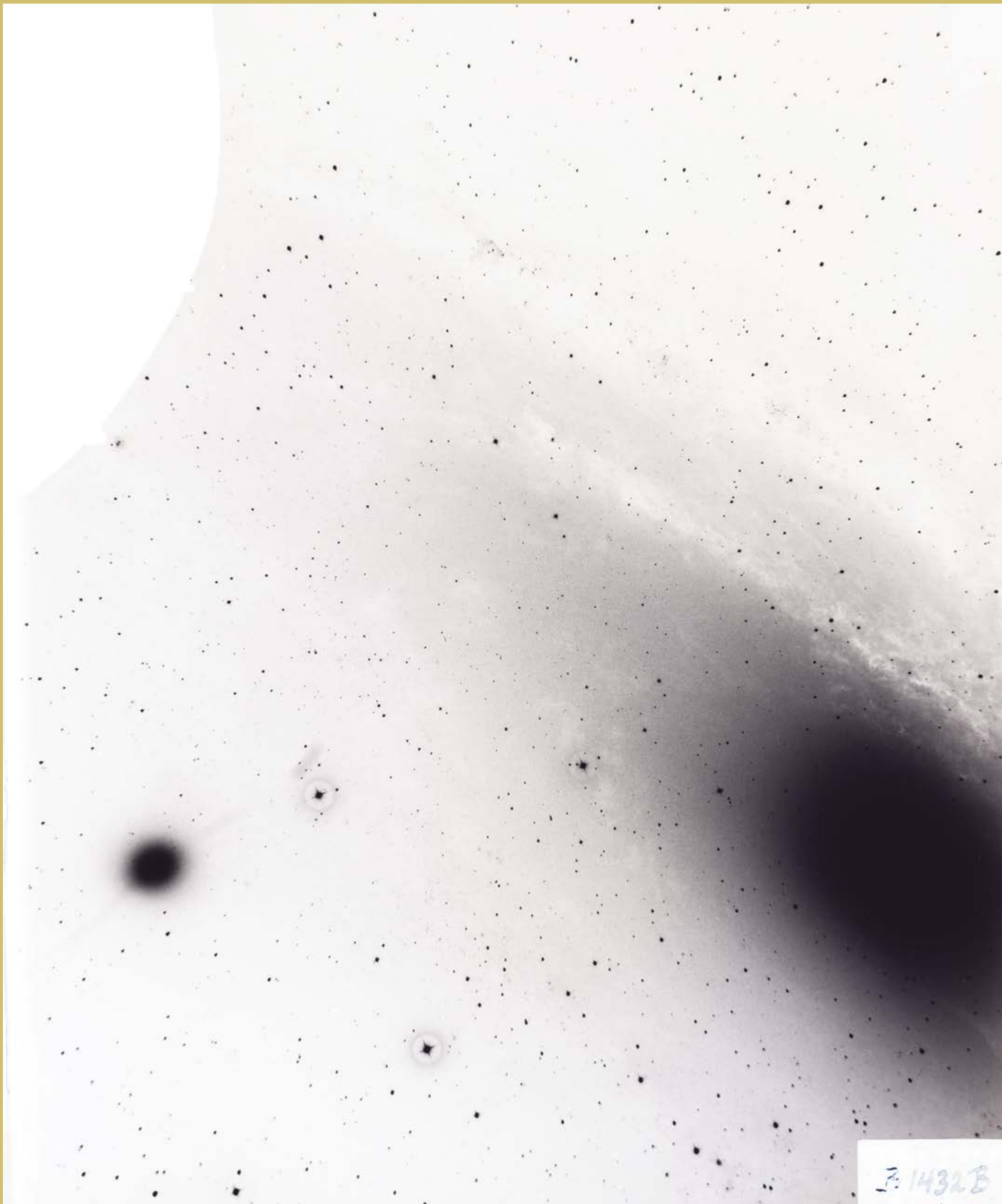
Finally, on August 25, 1943, he succeeded. A photographic plate of M32, Andromeda's dwarf elliptical companion, revealed a faint scattering of stars in its central bulge. Baade later recalled that every step of his preparation was essential to the achievement — he had to get everything right, and he did. Even so, the stars he recorded were so indistinct that the *Astrophysical Journal* needed his original plates for publication, not trusting reproductions.

Baade augmented his results through the autumn of 1943. The central regions of the Andromeda Galaxy, neighboring M110, and the dwarf spherical galaxy NGC 185 revealed yellow giants but no luminous blue or red stars. By distinguishing a family of objects lacking these stars from others containing them, he had confirmed the existence of two stellar populations, an idea that had simmered in his thinking for 25 years. Baade defined Population I, or "normal" stars, as those found in the arms and disks of spiral galaxies, which were also home to classical Cepheids. Population II stars were found in galaxies' central bulges, also the location of RR Lyrae variables.



▲ **A POWERFUL PORTAL** The second telescope to be built at Mount Wilson Observatory, the 100-inch Hooker reflector was the catalyst for some of the greatest advances in astronomical knowledge. The existence of other galaxies besides the Milky Way, the expansion of the universe, evidence for dark matter, and Baade's confirmation of stellar populations were all realized with the instrument.

SHAPLEY: SMITHSONIAN INSTITUTION / SCIENCE PHOTO LIBRARY; 100-INCH HOOKER TELESCOPE: CARNEGIE OBSERVATORIES COLLECTION, HUNTINGTON LIBRARY, SAN MARINO, CALIFORNIA



CARNEGIE SCIENCE

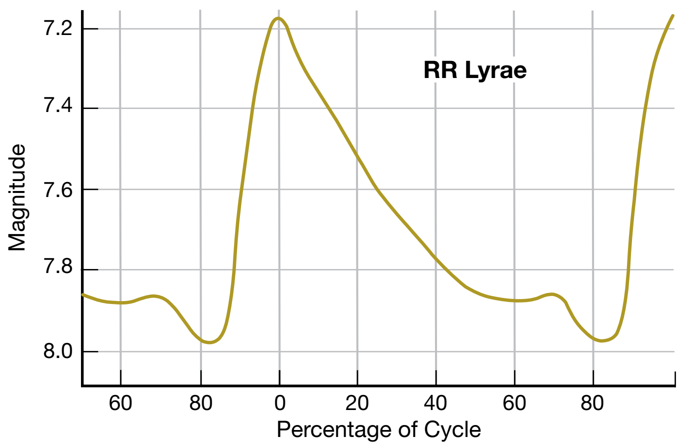
A CRUCIAL FIND Baade's 1943 detection of individual stars within M32 was the key piece of evidence for proving the existence of two distinct populations of variables. Although a magnifying glass was needed to see fine detail in the blob of M32, the plate nevertheless revealed the first evidence for what Baade had been seeking.

In 1944, Baade published two papers in the *Astrophysical Journal* that made him famous. But while he had solid data for the existence of two stellar populations, he didn't have an explanation for their differences. It was George Gamow who provided him with one soon after reading Baade's papers. Population I stars were young, whereas Population II stars were old. Although the physics of stellar energy production (fusion) wasn't fully worked out at the time, some scientists had speculated as early as 1939 on how this process might bear on younger and older stars, but Baade apparently wasn't aware of these discussions. In fact, Baade himself initially resisted the idea that age explained the population difference, and it took years for him to finally accept it. Nevertheless, it was Baade's work that provided the empirical foundation for stellar evolution, and once he was convinced of the idea, he became its leading advocate.

The Big Test

After giving an invited talk at the 1947 meeting of the American Astronomical Society in Ohio, Baade got back to work. By this time, he had succeeded in finding RR Lyrae stars in the nucleus of the Milky Way, but he was reluctant to publish anything more until he had also found them at the center of Andromeda — the 100-inch Hooker was not quite powerful enough for the job. With the start of operations of the 200-inch at Palomar Observatory in 1948, he would continue his searches with the bigger telescope and work out the consequences of his discovery.

Both Shapley and Hubble had made their respective distance measurements using a single model of the period-luminosity relation for Cepheid variables. This approach, while reasonable, resulted in distances that were much closer than



▲ **DISTANCE MARKERS** Astronomers can estimate distance by using variable stars that serve as "standard candles." The two main types of standard-candle variables are the RR Lyrae stars (whose curve is shown above), which have periods on the order of hours, and Cepheids, which have periods measured in days or weeks. The intrinsic luminosity of each such star is tied to its period — measure the period and you know that star's intrinsic brightness. By adding a star's apparent brightness to the mix, you can then calculate its distance. This period-luminosity relation, now commonly called the Leavitt Law, enables astronomers to measure distances to any object containing these variables.

those yielded by later methods using two different populations of variable stars. In fact, Hubble and Baade had earlier noted that globular clusters in the Andromeda Galaxy seemed to be 1.5 magnitudes fainter than those in our own galaxy, but it was Baade's work that pointed to the likely reason — those globular clusters harbored another type of variable.

Shapley resisted the idea, as it cast doubt on his distance calculations for the Andromeda Galaxy. According to Shapley's estimates, any RR Lyrae variables present within Andromeda's nucleus should have been well within the detection capabilities of the 200-inch. Indeed, he believed that the new instrument would validate his calculations. And so, Baade set to work in 1949, seeking to identify RR Lyrae stars at the center of the Andromeda Galaxy. The Hale telescope was still new, so Baade's work would test both the theory and the instrument.

Baade didn't find any RR Lyrae stars, even with the 200-inch — the Andromeda Galaxy had to be much farther away than Shapley had calculated. The Hale Telescope had revealed an important insight into the size of the universe by failing to find stars!

Baade's later observations at Palomar showed that Andromeda's Cepheid populations had a period-luminosity relationship that differed by about 1.5 magnitudes from the stars that Shapley and Hubble had used — a similar discrepancy to the one he had encountered in his globular cluster work. Now, however, the difference could be used to obtain a quantitative measure of Andromeda's distance: The galaxy was roughly twice as far away, and the universe was twice the age previously thought. Although it was bad news for Shapley, the results resolved a major dilemma in cosmology.

These were the findings that Baade announced at the 1952 International Astronomical Union conference in Rome. Classical Cepheids were found in regions rich with Population I stars, while *short-period* Cepheids and RR Lyrae stars resided alongside Population II stars. His findings were confirmed in real time, when an astronomer rose from the audience to report that they had also resolved RR Lyrae stars in the Small Magellanic Cloud, a Southern Hemisphere galaxy. Baade's results were finally published in 1956.

Baade continued to actively study galaxies with the 200-inch. He also began a radio-astronomy collaboration with German-American astronomer Rudolph Minkowski in 1952, identifying the optical counterparts of several radio sources. But while Baade continued to spread his ideas through lectures and discussions more than through published papers, an accumulation of photographic plates and notes awaited analysis.

A German Heart

Baade retired in 1958 at the age of 65, in compliance with Carnegie's personnel policy. Even though he was offered several teaching opportunities, Baade was firmly set on returning to his native Germany. Nevertheless, he spent the first year of his retirement lecturing at Harvard, then briefly at Princeton, and finally in Australia. He arrived in Germany

BEATRIZ INGLESSIS / *S&T*

in October 1959, but his travels had taken a physical toll. His hip had grown worse with age, and now he suffered from spinal bone spurs that, by January 1960, required surgery. During a slow convalescence, he suddenly collapsed and died in June of that year.

It now fell to others to finish analyzing Baade's considerable backlog of documents. Henrietta Swope, his longtime assistant and collaborator, continued the job of processing the piles of photographs and data, listing Baade as co-author on all resulting articles.

◀ **COLLEAGUE AND COAUTHOR** Cecilia Payne-Gaposchkin was a British-born astronomer who studied under Shapley. The first person to earn a doctorate at Radcliffe College (in Cambridge, Massachusetts), she performed pioneering research into the chemical processes of stars and on the nature of variable stars. It was Payne-Gaposchkin, an admirer of Baade's, who collected and edited his notes after his death.

Cecilia Payne-Gaposchkin, the Harvard astrophysicist whose findings revolutionized our understanding of stellar composition, had arranged Baade's post-retirement visit. In addition, she converted his lecture notes into the book *Evolution of Stars and Galaxies*, which Harvard University Press published in 1963, with Baade listed as the primary author.

Walter Baade may not be as well-known as some other astronomers, but his legacy is as profound as that of any of his contemporaries. Today's astronomers still continue along the scientific paths he established, refining calculations of galactic distances and the age of the universe using Cepheid variables and supernovae. Among them is Wendy Freedman (University of Chicago and former Director of the Carnegie Observatories). "It's not quite fair to say he single-handedly came on to this idea of [stellar] evolution," she says about Baade's legacy. "But he significantly broadened our thinking by showing, through differences in star populations between elliptical and spiral galaxies, that there were different routes to evolution.

"He enabled people to ask more detailed questions about how galaxies change with time," she adds, "and inspired countless young astronomers to flesh out these areas with new ideas and data."

Baade wanted to establish a Southern Hemisphere observatory as far back as 1927, but he never realized his dream. He tried to observe the southern sky from Argentina during World War II but was barred from traveling there because of his citizenship. And although his lifelong advocacy eventually helped establish the European Southern Observatory, he never worked in that part of the world. In 2000, however, the 256-inch (6.5-meter) Walter Baade Telescope began operating at Las Campanas Observatory in Chile, where it will gather data from the southern sky for decades to come.

■ **STEVE MURRAY** is a freelance science and technology writer who stargazes from his home in San Diego, California. He also provides STEM presentations to a variety of audiences as a NASA/JPL Solar System Ambassador.

THE SEARCH GOES ON Twin 6.5-meter Magellan Telescopes scan the skies from Las Campanas Observatory, located in the Atacama Desert of Chile at an altitude of nearly 2,400 meters (8,000 feet). The Walter Baade Telescope (on the left) was the first of the two instruments to be completed and saw first light in 2000.

Rubin's Revol

The Rubin Observatory is set to bring astronomers a data deluge on everything from asteroids to dark energy.

The future of astronomy is under construction on a mountaintop in Chile. Soon after this issue goes to press, the largest digital camera in history will arrive on Cerro Pachón, a mountaintop 2,700 meters (8,900 feet) high in a rugged and remote area just south of Chile's Elqui Valley. Engineers will integrate the camera with the 8.4-meter Simonyi Survey Telescope, the main instrument of the Vera C. Rubin Observatory. First light for the new facility is expected in early 2025, and by the end of that year, the 10-year Legacy Survey of Space and Time (LSST) will commence, providing astronomers with an unprecedented view of the cosmos.

Every three nights or so, the huge observatory will image the whole visible sky down to 24th magnitude. Its survey will discover countless transient phenomena like remote supernovae, stellar flares, and *tidal disruption events*, in which whole stars are shredded and feasted upon by gluttonous supermassive black holes. It will bring to light millions of previously unknown small bodies in the solar system — asteroids, comets, and Kuiper Belt objects. And it is expected to shed light on the mysterious dark energy that is currently speeding up the expansion of the universe, as well as on the equally puzzling dark matter that holds galaxies together. "Nothing like this has ever been done before," says the observatory's operations director, Robert Blum (National Optical-Infrared Astronomy Research Laboratory, or NOIRLab).

Back in the 1960s and 1970s, American astronomer Vera Rubin, the observatory's namesake, showed that spiral galaxies, like our own Milky Way and nearby Andromeda, are dominated by invisible stuff. In fact, back in 1996 when Chief Scientist J. Anthony Tyson (University of California, Davis) first proposed what would eventually become the

▶ **NEARLY READY** The Rubin Observatory looks out from its perch on Cerro Pachón at sunset. The round dome to Rubin's left holds the Auxiliary Telescope, which will use stars' spectra to measure how well different wavelengths pass through the atmosphere where Rubin is looking.

Rubin Observatory, he called it the Dark Matter Telescope. “After the discovery of the accelerating expansion of the universe in 1998, we immediately knew that the telescope would also be a key tool in probing the physics of dark energy,” Tyson says. “We were going to open up a whole new window on the universe.”

Both of the independent teams that discovered dark energy made use of observations with the Big Throughput Camera on the 4-meter Blanco Telescope at the Cerro Tololo Inter-American Observatory in Chile — an earlier project led by Tyson. “We realized that we could do better,” he says, “with a larger telescope, a wider field of view, and bigger CCD mosaics.” The astronomical community agreed, endorsing the project in both the 2001 and 2010 decadal survey reports, which present astronomers’ funding recommendations to the government.

And now, almost three decades after Tyson first envisioned it, the Rubin Observatory is finally nearing completion.

Galactic Archaeologist

Among its many goals, the LSST survey will catalog more than 10 billion stars in our own Milky Way, all the way out into our galaxy’s halo and even into neighboring galaxies. (The European Gaia mission, in comparison, has pinpointed nearly 2 billion stars. Rubin is more sensitive, but Gaia’s positions are more accurate.) Measuring stars’ distances, motions, colors, ages, and chemical compositions will yield valuable information on *galactic archaeology* — the way in which our home galaxy has grown by devouring smaller dwarf galaxies in the past — as well as on stellar populations, and even on exoplanet statistics.

A Telescope Like No Other

To carry out an all-encompassing multi-year survey of the night sky, you need to put your telescope on a site with consistently good observing conditions throughout the year, explains the observatory’s project manager, Victor Krabbendam (Association of Universities for Research in Astronomy, or AURA). “For us, average good seeing is more important than incidental excellent seeing,” he says. “Also, you don’t want to be on a site where you lose the same period of each year due to periodic poor weather conditions.”

NOIRLAB / NSF / AURA / P. HORÁLEK

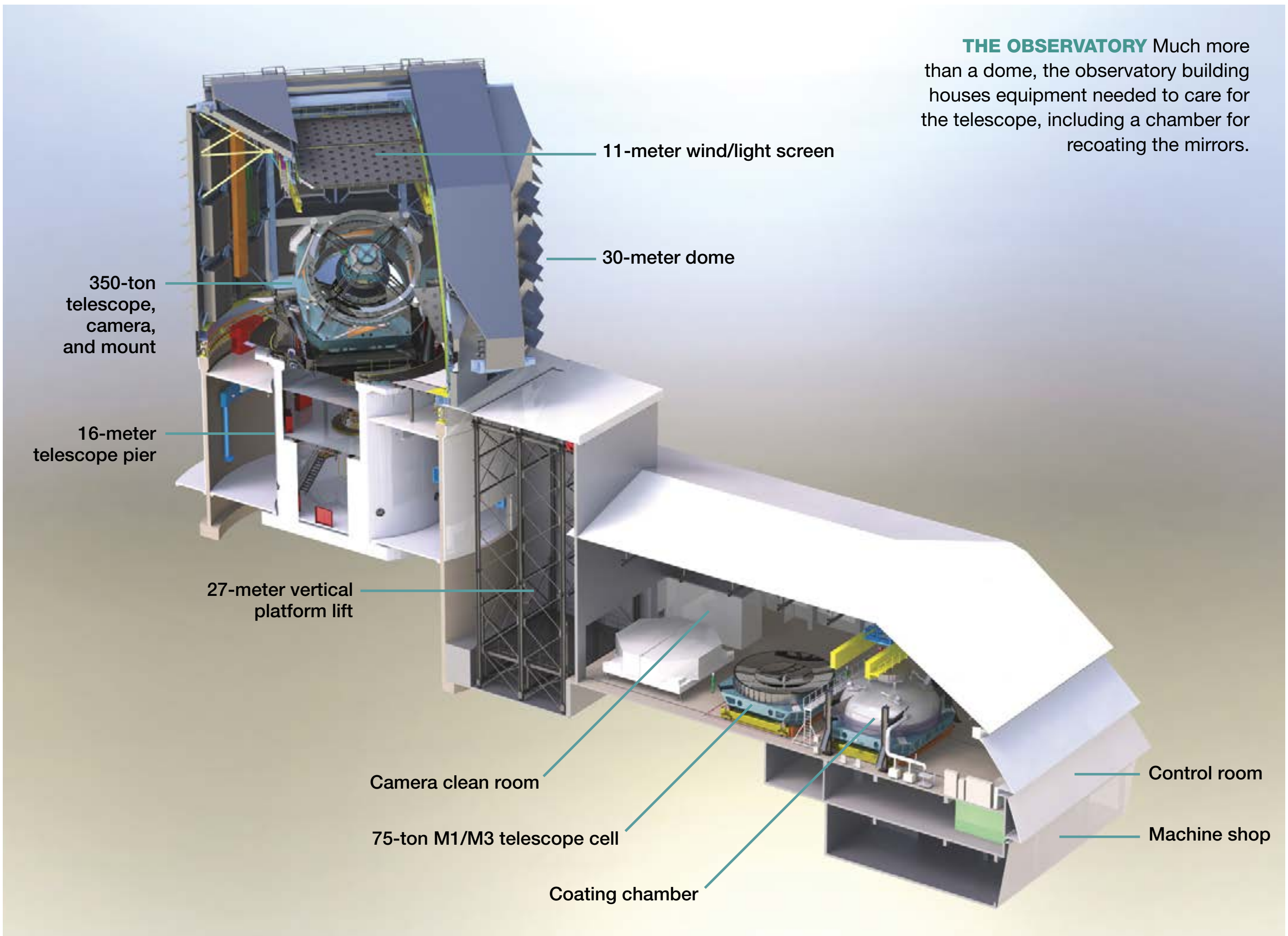
After considering locations in Mexico, the Canary Islands, and Chile, astronomers selected Cerro Pachón in 2006 as the best location for Rubin. This was partly because of the existing infrastructure — the mountaintop (not too far from Cerro Tololo) is already home to the 8.1-meter Gemini South telescope and the 4.1-meter Southern Astrophysical Research Telescope (SOAR).

The project received the official green light in August 2014, and the ceremonial "unveiling of the first stone" was done on April 14, 2015, by Chilean president Michelle Bachelet. The lion's share of the $670 million construction cost has been ponied up by the National Science Foundation (NSF) and the Department of Energy (DOE), with smaller contributions from private donors like Microsoft's Bill Gates and Charles Simonyi, after whom the telescope is officially named. NSF's NOIRLab will operate and manage the facility.

Back in 2014, planners hoped the observatory would be ready in 2022. "The COVID pandemic has been the major source of construction delays," says Krabbendam, "but right now, everything is coming together quite nicely."

The telescope's three-mirror design is like no other. Its 8.4-meter primary mirror (M1) is among the largest monolithic telescope mirrors ever built, and it's actually two mirrors in one: The central part, 5 meters in diameter, has a much stronger curvature and acts as the instrument's tertiary mirror (M3). Grinding and polishing both mirrors from one huge slab of glass ensured a very stiff optical system. Although it's impressively large, the telescope is also extremely compact: The 3.4-meter convex secondary (M2) sits less than 6.5 meters above M1, resulting in a very wide field of view 3.5 degrees across — as wide as seven full Moons. Each image obtained by Rubin will cover almost 10 square degrees, which is about as large as the head of the constellation Hydra, the Water Snake.

To capture such an enormous area of sky in full detail, the Rubin Observatory LSST Camera, designed and built by the DOE's SLAC National Accelerator Laboratory in California, features a 25-inch-diameter focal plane, covered by 189 CCDs of 16 million pixels each. As large as a car and weighing almost 3 tons, it is the largest astronomical camera ever built, sporting a whopping 3.2 billion 0.01-millimeter-wide pixels in total, with a resolution of 0.2 arcsecond per pixel. According to Beth Willman, the CEO of the LSST Discovery Alliance, in order to display one Rubin image at full resolution



THE OBSERVATORY Much more than a dome, the observatory building houses equipment needed to care for the telescope, including a chamber for recoating the mirrors.

RUBIN OBSERVATORY / J. ANDREW

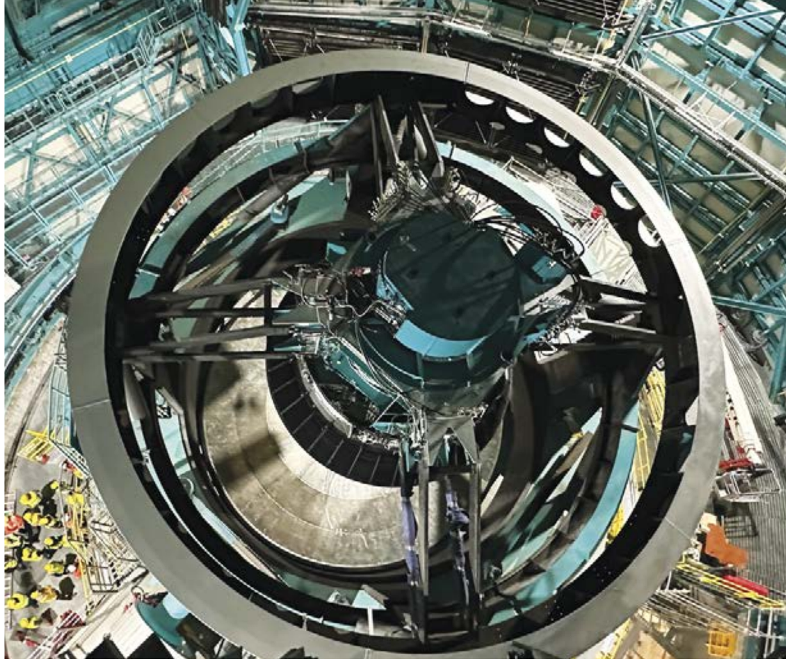
you would need 10 of the largest LCD screens on Earth.

The detector array will be cooled to −100°C (−150°F) during operations, to enhance its sensitivity. Images are captured through six broadband filters, registering stars as faint as 24th magnitude in just 15 seconds of exposure time.

"To test the entire optical system with real sky data, we will use a smaller commissioning camera that has already been installed in August 2022," says Krabbendam. "This makes it easier to solve potential problems that you don't want to run into with the full survey camera. First you crawl, then you walk, then you run." Rubin's *technical first light*, using this so-called ComCam, is foreseen in the summer of 2024; the survey camera should be installed in the fall. Incidentally, ComCam is quite impressive by itself: Even though it has a "mere" 144 million pixels, it is about the same size as its more powerful successor.

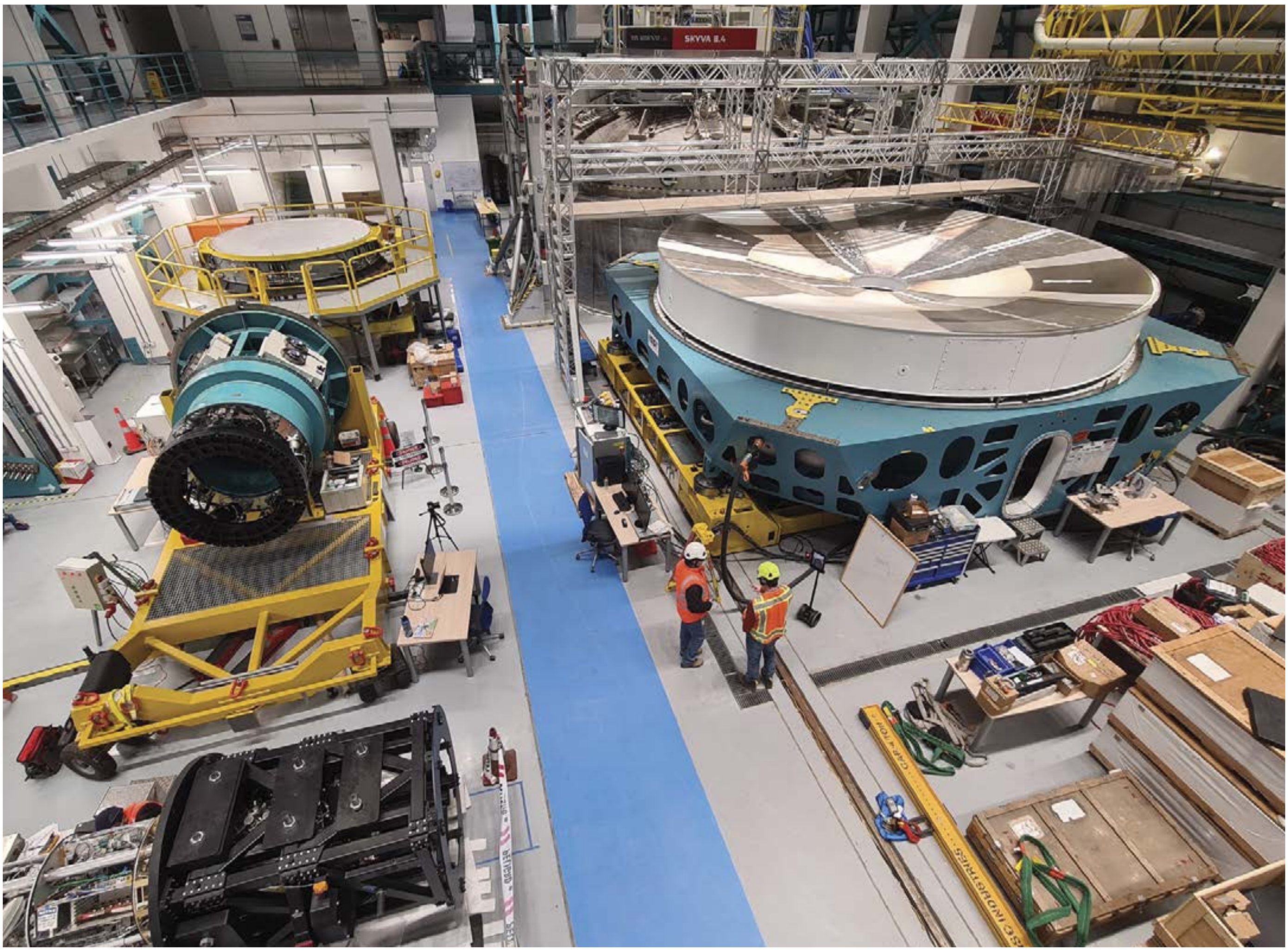
Transformational Science

Most large astronomical telescopes carry out a wide variety of research programs, carefully selected from hundreds of observing proposals from astronomers all over the world. Not so with Rubin. During its first 10 years, its sole goal is



▲ **BIG EYE** Seen from above in November 2023, the Rubin Observatory telescope mount waits for its primary mirror.

▼ **BUILD-OUT** Equipment fills the integration and maintenance hall during construction in 2021. At left is the commissioning camera, and at right is the surrogate mirror used during testing.



BIG EYE: RUBIN OBSERVATORY / NSF / AURA / A. ALEXOV; MAINTENANCE HALL: RUBIN OBSERVATORY / NSF / AURA to carry out the Legacy Survey of Space and Time, which will yield a humongous treasure-trove of data for other astronomers to explore and study (*S&T:* Sept. 2016, p. 14).

To that end, researchers have established eight Science Collaborations, bringing together more than 2,000 astronomers from over 30 countries who are planning the survey and preparing the data flow. “Everyone is excited about what we might find,” says cosmologist Catherine Heymans (University of Edinburgh). No one doubts that keeping a vigilant and sensitive eye on the whole sky for a decade is bound to uncover myriads of new objects and exciting phenomena.

In our own solar system alone, Rubin is expected to find some 5 million new objects, most of them in the asteroid belt between the orbits of Mars and Jupiter but others elsewhere, such as in the Kuiper Belt beyond the orbit of Neptune. It should also find thousands of new comets. Collecting 10 years’ worth of data on these small bodies will “transform everything,” says Megan Schwamb (Queen’s University Belfast, UK), who is the co-chair of Rubin’s Solar System Science Collaboration. “Usually we find them, and that’s it,” she says. “But now we will also monitor their brightness variations, rotational properties, color change, and potential activity.”

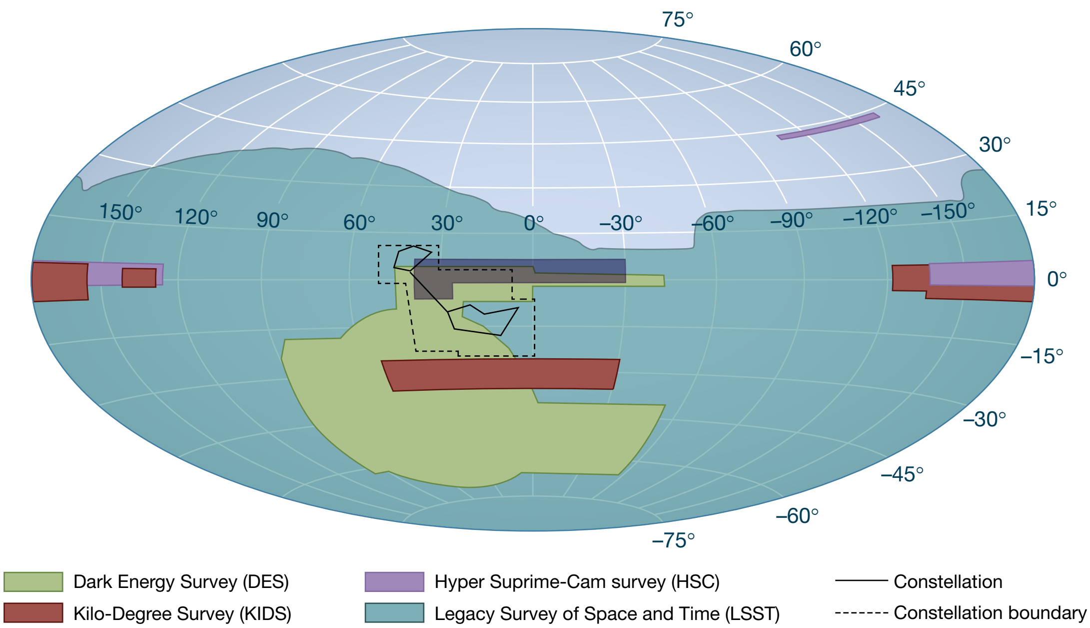
Thanks to its huge sensitivity, the survey will also find many more near-Earth objects and *potentially hazardous asteroids* (PHAs), helping to deliver on the Congressional mandate of finding 90% of the Earth-threatening bodies larger than 140 meters in diameter, says Schwamb. Rubin may even uncover Planet Nine, a proposed large planet beyond the Kuiper Belt that might be the cause of an observed “alignment” of the orbits of a number of small objects in the solar system’s outermost regions — if the planet exists, that is. “I’m sure many groups will dive into the data to look for it,” says Schwamb. “It’s very exciting.” Finally, she expects Rubin to find additional temporary visitors from beyond the solar system, comparable to the mysterious object 1I/‘Oumuamua that flew by in 2017 and Comet 2I/Borisov in 2019.

Beyond the solar system, the LSST survey’s repeated images of the same area of sky will reveal a multitude of variable sources, explosive events, and other astronomical transients, bolstering *time-domain astronomy*, a.k.a. “whoosh-flash-bang astronomy.” “With current facilities, we already discover some 20,000 transients per year,” says Craig Pellegrino (University of Virginia), “compared to a few hundred back in 2013. Rubin will exponentially accelerate this growth.” These phenomena include quasar activity in distant galaxies, feasting black holes, the aftermath of merging neutron stars (so-called *kilonovae*), optical counterparts to gamma-ray bursts, and, of course, supernovae. According to Willman, Rubin should discover a new remote supernova every two minutes or so, corresponding to some 3 million finds in 10 years.

Tyson has high expectations for Rubin’s transient program. “I’m convinced that a hundred years from now, this observatory will be remembered for discovering mind-blowing, unexpected things,” he says. “Like some new class of object that explodes in a completely novel way. That’s almost guaranteed.”

Constraining Cosmological Models

As for cosmology, the expected wealth of supernova discoveries in distant galaxies will help cosmologists like Tyson to better understand the expansion history of the universe. After studying the relationship between the distances of Type Ia supernovae and the *redshifts* of their spectra (which reveal how quickly the universe’s expansion is carrying the supernova’s host galaxy away from us), scientists announced in 1998 that cosmic expansion is currently accelerating (*S&T:* Feb. 2024, p. 26). Adding so many new data should reveal further details about the puzzling dark energy in empty space that is



▶ **SKY COVERAGE** LSST will dwarf other major cosmological surveys. The Hyper Suprime-Cam (HSC) survey covers 1,400 square degrees, the Kilo-Degree Survey (KIDS) covers 1,500 square degrees, and the Dark Energy Survey (DES) covers 5,000 square degrees. LSST, in comparison, will cover some 18,000 square degrees, surpassing even the Sloan Digital Sky Survey’s latest data release (14,555 square degrees). The Cetus stick figure and constellation boundary lines are included for comparison: Cetus covers just over 1,230 square degrees.

GREGG DINDERMAN AND BEATRIZ INGLESSIS / S&T

thought to be responsible for this expansion boost.

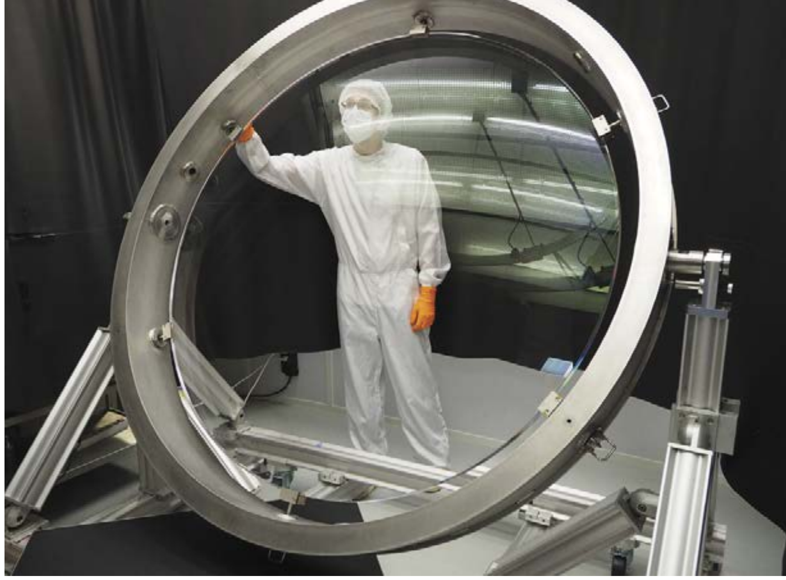
"Cosmology is one of the main pillars for the LSST survey," says cosmologist and Rubin Operations Scientist Andrés Plazas Malagón (SLAC). "By comparing our huge data sets with computer simulations of cosmic evolution, we can constrain our cosmological models" of the content and evolution of the universe.

According to Plazas Malagón, four other analysis techniques, in addition to the supernova technique, will be applied to the survey data in order to get a better grip on the fundamental properties of our universe. These four methods will all be based on Rubin's observations of galaxies, some 20 billion of which are expected to show up in the survey data.

First, as a result of *weak lensing* (see sidebar, page 40), the apparent shapes of galaxies are slightly distorted by gravitating matter along our line of sight to each galaxy. Most of this matter is dark, so statistically studying this effect will shed light on the 3D distribution of dark matter.

Second, astronomers will follow the growth of the large-scale structure of the universe through cosmic time. This growth is essentially the result of the tug of war between dark matter and dark energy. Researchers can study it by measuring the number and masses of galaxy clusters at different distances, corresponding to different look-back times.

Finally, the expansion history of the universe leaves two telltale fingerprints. One is a change in the size of *baryon acoustic oscillations* (BAOs), the imprint of sound waves in the newly born universe. BAOs have been frozen into the distribution of matter at a specific scale, and they are still recognizable in the 3D distribution of galaxies, their size growing over time as everything expands (*S&T:* Feb. 2024, p. 20). The other fingerprint is time delays between brightness fluctuations in multiple images of the same remote quasar. These images result when the gravity of a foreground, massive galaxy or galaxy cluster strongly lenses the distant quasar's light. The light of each image travels along a different path, each with its own length and duration and, therefore, amount of expansion.



▲ **READY FOR A CLOSE-UP** A team member inspects the largest of the three lenses in Rubin's LSST camera.

Eventually, says Plazas Malagón, astronomers will refine the measurements so much that they'll be able to distinguish between various theoretical frameworks for how the universe behaves. "For instance, we hope to discover whether or not dark energy is changing with time," he says — something that might alleviate a number of nagging cosmological issues. These include discrepancies between measurements and predictions for both the expansion rate of today's universe and the "clumpiness" of cosmic structure.

Data Deluge

Right now, the various science collaborations are preparing for a true avalanche of data, says Schwamb. "With so many

▲ **TIGHT SQUEEZE** After arriving at the port of Coquimbo in Chile in 2018, the telescope's coating chamber was divided into two parts like an Oreo and transported to the summit of Cerro Pachón. Along the way, hanging signs, utility cables, and lights had to be removed to make room. Here, the chamber makes its way through the narrowest tunnel along the route. (Planners decided the telescope's size with this tunnel in mind.)

LENS: SAFRAN; TELESCOPE TRANSPORT: MANUEL PAREDES / NSF / AURA / GEMINI (2)

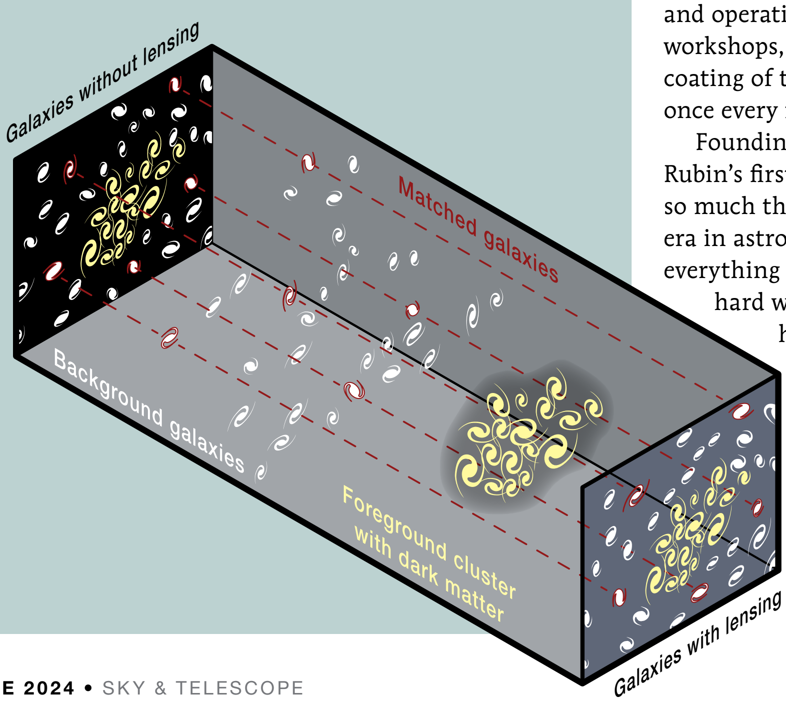
Weak Lensing

Light is bent by gravity. We see this phenomenon often enough in the Hubble and Webb photos of gravitationally lensed galaxies, their images magnified, multiplied, and/or stretched into light arcs by the gravity of a foreground cluster.

But apart from this *strong lensing* effect, there's also *weak lensing*: the slight distortion in the shape of each and every distant galaxy's image that's produced by the accumulating gravitational effect of all matter between the galaxy and Earth (*S&T:* Sept. 2016, p. 34). If remote galaxies were perfectly spherical, this effect would be easy to observe. Instead, since galaxies usually look elongated to start with from our point of view, astronomers need to study the appearances of thousands or millions of them in a particular area on the sky, to look for preferential distortions in a particular direction. From such a statistical analysis, they can map the distribution of intervening matter, both luminous and dark — a technique pioneered by the Vera C. Rubin Observatory's founding father, J. Anthony Tyson, in 1990.

Combining this approach with distance measurements, Rubin's detailed observations of billions of galaxies will be used to map the distribution of gravitating matter through space and time.

▼ **SUBTLE EFFECT** As the light from background galaxies skirts the outer edges of a large, foreground galaxy cluster, the distant galaxies' apparent shapes are slightly stretched. This *weak lensing* effect is too subtle to be visible in a single galaxy's image; rather, astronomers must combine a large sample of galaxies to see it. (The diagram below magnifies the effect in order to make it visible.)



science drivers, it's hard to optimize the survey strategy — how often do we want to return to a particular part of the sky, what filters do we want to use, et cetera. Everybody wants something else. But we're getting ready for it."

To collect all these data, the telescope will be working like mad. The camera will capture a 6-gigabyte image in just 15 seconds. Reading out the CCDs takes some 2 seconds. Next, the 62-ton telescope, which rests on a hollow, 16-meter-wide concrete pier, will slew to a new sky position in a mere 5 seconds, to start another 15-second exposure just half a minute after the first. This will go on night after night, for 10 years in a row. "It's an awesome sight to see this huge, massive instrument move so fast and quiet," Krabbendam says.

During the survey, a 1.2-meter Auxiliary Telescope, erected close to the 8.4-meter giant, will continuously monitor *atmospheric transmission*. Always pointing at the same part of the sky as the main instrument, the small telescope will measure the precise way in which certain wavelengths of light are affected or absorbed by Earth's atmosphere, dependent on weather conditions, altitude on the sky, and so on. Astronomers will use this information to calibrate and correct Rubin's observations before they end up in the survey catalog.

Rubin will collect some 20 terabytes of raw data per night, for a total of 60 petabytes (i.e., 60 million gigabytes) at the end of the survey — three times the total digital content of the Library of Congress. By then, the project will have amassed millions of individual images. These will become available to the wider astronomical community after two years.

The only interruptions to the constant grind of the observing cycle will be when the massive primary/tertiary mirror has to be recoated with a thin layer of aluminum, about once every two years. On those occasions, a giant 80-ton-capacity elevator will transport the mirror to the coating plant, which lies four levels below the telescope floor in the service and operations building. (This building also houses offices, workshops, computer rooms, and a control room.) The silver coating of the smaller secondary mirror needs to be renewed once every five years.

Founding father Tyson, for one, is looking forward to Rubin's first-light ceremony in early 2025. To him, this is not so much the completion of a project but the start of a new era in astronomy. "Of course it's very gratifying to see how everything has come together after more than 25 years of hard work, thanks to a very strong and dedicated team," he says. "But to any scientist, and in particular to the young astronomers who weren't even born when I first came up with the idea, the start of something new is always much more exciting."

■ Contributing Editor **GOVERT SCHILLING** last visited Cerro Pachón in 2017, when the Vera C. Rubin Observatory was still very much a construction site. He looks forward to visiting the completed observatory in early 2025.

OBSERVING
June 2024

1 **DAWN:** Kick the month off with the sight of the waning crescent Moon, Mars, and Saturn in a tidy line stretching some 35° above the east-southeastern horizon before sunrise.

2 **MORNING:** The lunar crescent leads Mars by about 6½° as the pair rises in the east.

8 **DUSK:** Face west-northwest as twilight deepens to see the waxing crescent Moon in a neat isosceles triangle with Castor and Pollux, the bright star pair of Gemini. Catch them before they dip out of view. Turn to page 46 to read more on this event and others listed here.

11 **DUSK:** The Moon, two days shy of first quarter, hangs a bit more than 3° above right of Regulus, Leo's brightest star. Follow the duo as they sink toward the western horizon.

16 **EVENING:** The waxing gibbous Moon visits Virgo, where it gleams 3½° left of Spica in the south-southwest.

19 **EVENING:** Look toward the south to see the almost-full Moon 3½° right of Antares, the red supergiant that marks the Scorpion's heart. The gap between the pair shrinks as the night wears on.

20 **THE LONGEST DAY OF THE YEAR** in the Northern Hemisphere. Summer begins at the solstice, at 4:51 p.m. EDT.

27 **MORNING:** The waning gibbous Moon and Saturn, with about 3° separating them, grace the southeastern sky.

—DIANA HANNIKAINEN

▲ Ursa Major, the Great Bear, fills the sky above the dome housing the 4-meter telescope at Kitt Peak National Observatory in Arizona. The constellation is brimming with star pairs (see the article starting on page 20). Mizar and its fainter companion, Alcor, form the second star in the Big Dipper's handle.
KPNO / NOIRLAB / NSF / AURA / T. SLOVINSKÝ

JUNE 2024 OBSERVING
Lunar Almanac
Northern Hemisphere Sky Chart

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

MOON PHASES

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

NEW MOON
June 6
12:38 UT

FIRST QUARTER
June 14
05:18 UT

FULL MOON
June 22
01:08 UT

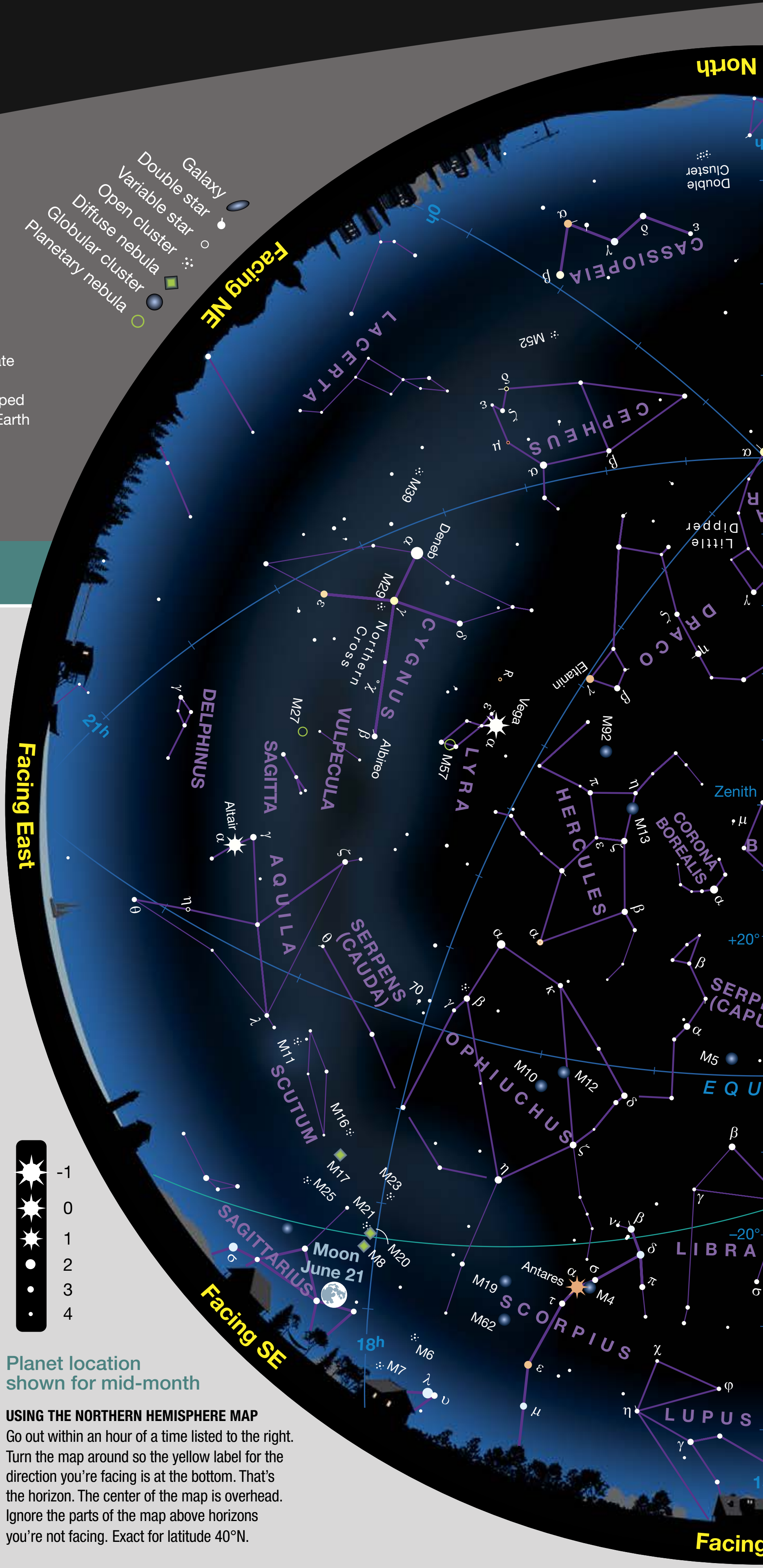
LAST QUARTER
June 28
21:53 UT

DISTANCES

Perigee	June 2, 07^h UT
368,103 km	Diameter 32′ 28″
Apogee	June 14, 14^h UT
404,076 km	Diameter 29′ 34″
Perigee	June 27, 12^h UT
369,286 km	Diameter 32′ 22″

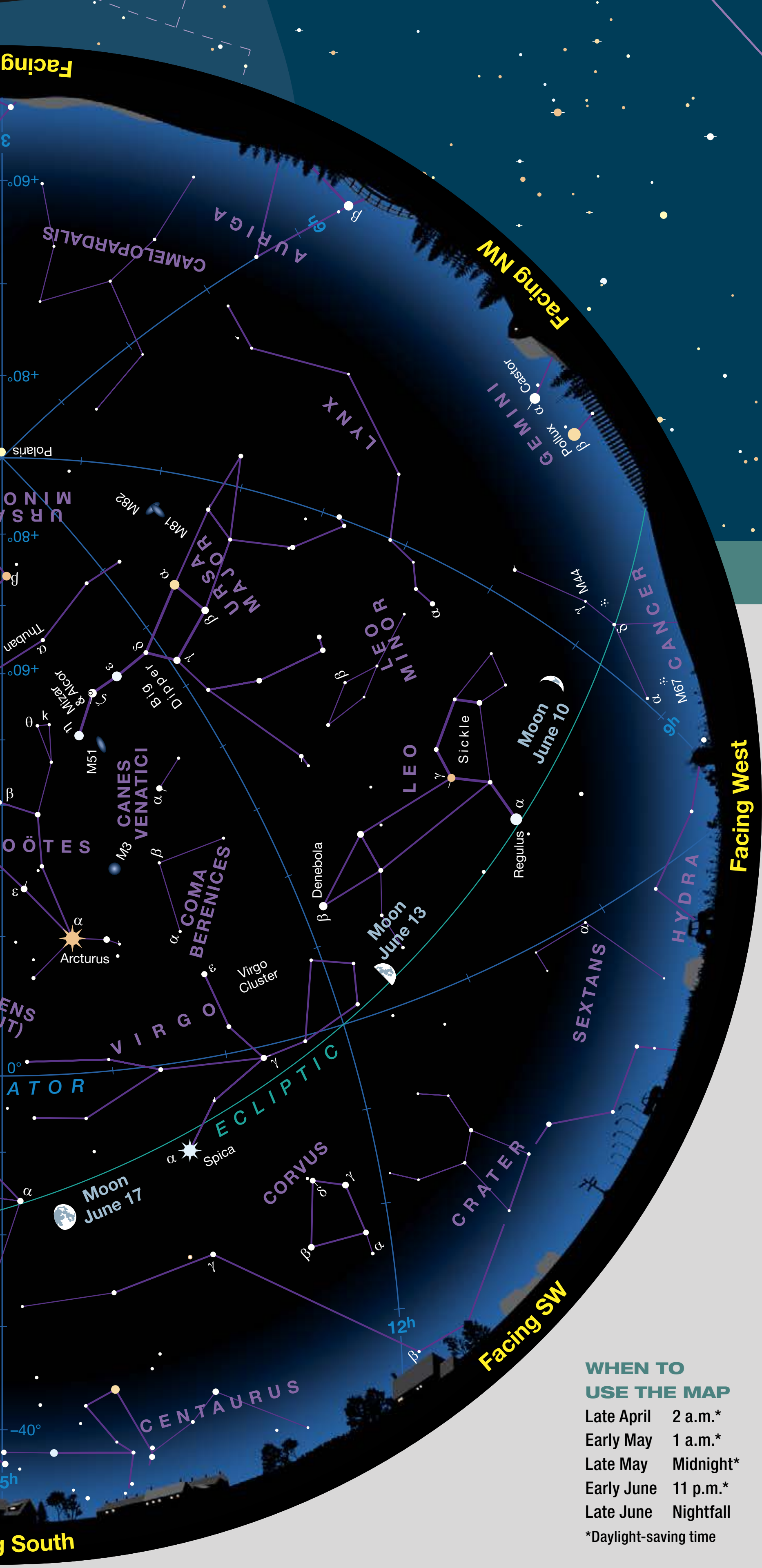
FAVORABLE LIBRATIONS

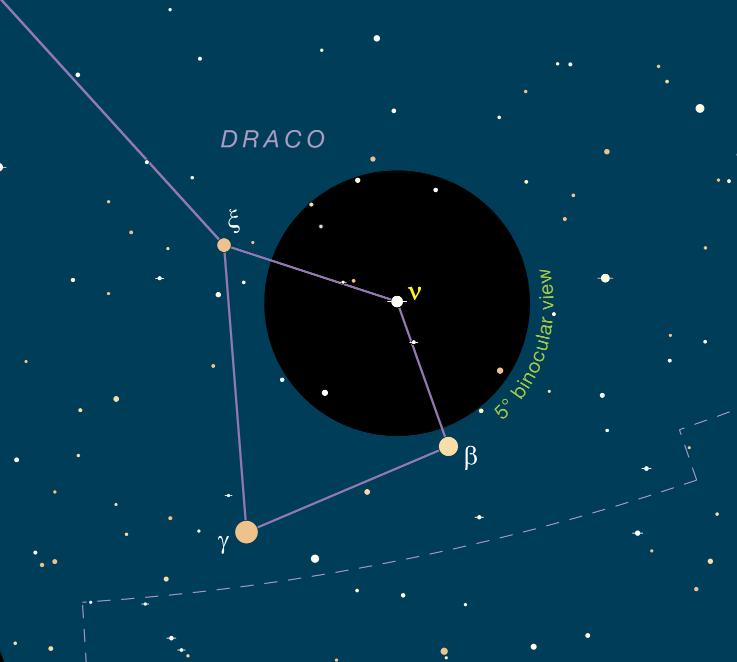
- Brisbane Crater June 9
- Galvani Crater June 22
- Cleostratus Crater June 24
- Desargues Crater June 26



Planet location shown for mid-month

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





Binocular Highlight by Mathew Wedel

In the Mouth of the Dragon

You've likely admired the double star Albireo in Cygnus, the Swan, and marveled at the striking color difference between the duo, one a mellow orange, the other a steely blue. (If you haven't already, you should.) In fact, for many observers it's mainly the color difference between the components in a binary pair that they find attractive. But double stars need not exhibit color differences to be worthy of your attention.

Take **Nu (ν) Draconis**. The faintest of the four stars that mark the celestial Dragon's head, Nu Draconis's two suns are remarkably similar: They're both white, *A*-type dwarfs, and each shines at magnitude 4.9. Their combined light produces a 4.1-magnitude, naked-eye spark. But point your binoculars at this target and you should behold evenly matched gems.

Unlike the majority of the star pairs described in the article starting on page 20, Nu Draconis is a true double — its components orbit a common center of mass, forever locked in a celestial dance. The stars that comprise the system are currently a bit more than 1′ apart — 62″ to be exact. You'll need at least 10× to fully enjoy the sight of the sparkling pair, but you may just about split them with 7×. You can use Nu Draconis to test the resolving power of your binoculars — and the steadiness of your grip.

The stars are physically about 1,900 a.u. apart, and it takes them 44,000 years to complete one full orbit. When you next check in on Draco, bear in mind that one orbit ago, members of the *Homo sapiens* and Neanderthal tribes may have been standing side by side looking up into the sky, and Nu Draconis would have been in the same configuration as today.

■ **MATT WEDEL** likes to alternate between studying mouths of dinosaurs and mouths of dragons.

WHEN TO USE THE MAP

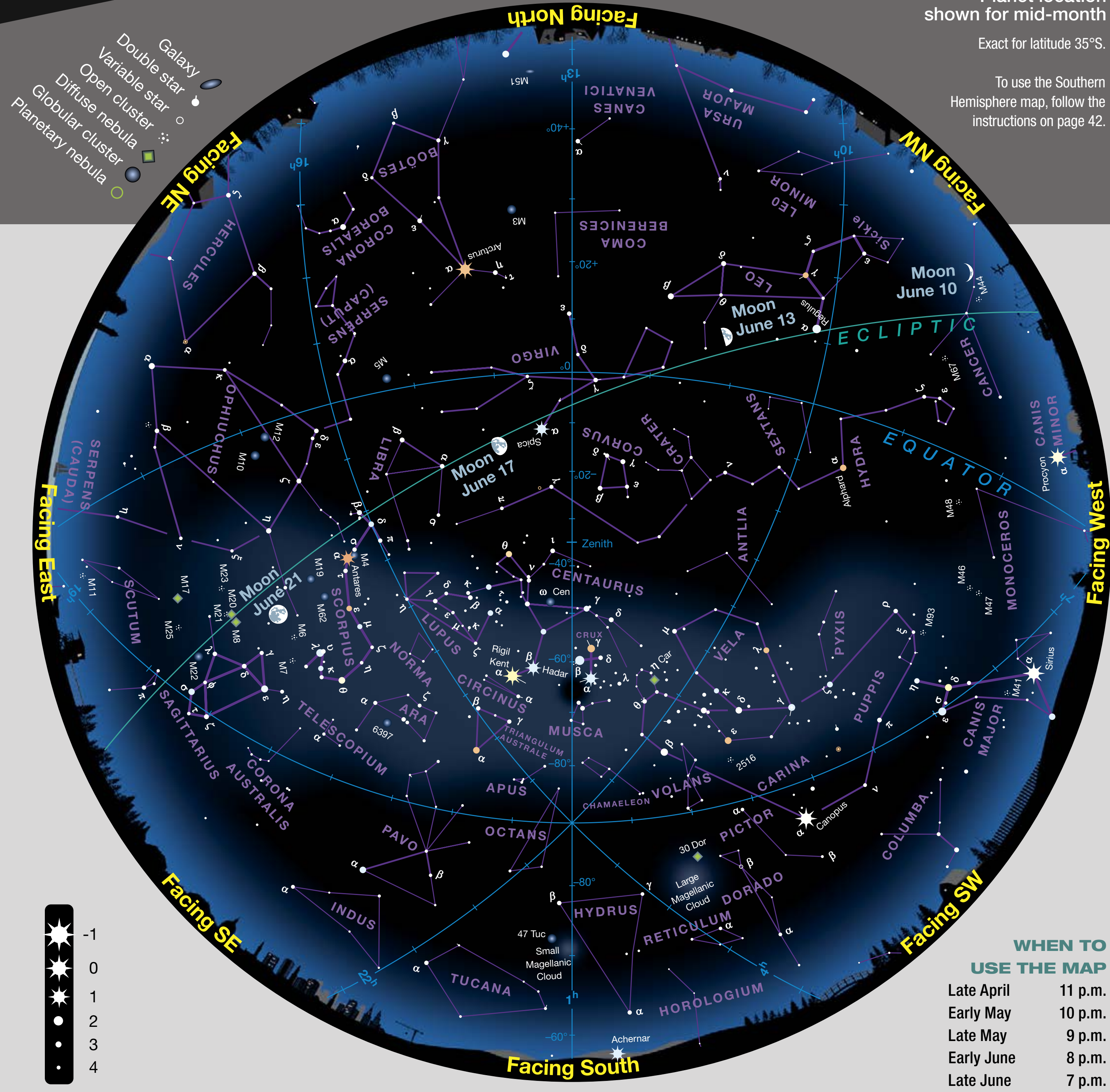
Late April	2 a.m.*
Early May	1 a.m.*
Late May	Midnight*
Early June	11 p.m.*
Late June	Nightfall

*Daylight-saving time

JUNE 2024 OBSERVING

Southern Hemisphere Sky Chart

by Jonathan Nally



WHEN TO USE THE MAP

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

WHAT'S BIG, BRIGHT, AND BOLD and inhabits the southern sky? The fabulous globular star cluster **Omega Centauri** (NGC 5139). Scottish astronomer James Dunlop, observing from Sydney in the mid-1820s, described it as "the largest bright nebula in the southern hemisphere." Undeniably the finest globular in the entire sky, it's readily visible to the naked eye as a fuzzy ball and looks like a comet without a tail. When viewed under pristine conditions, it occupies an area almost as large as the full Moon.

Some astronomers think Omega Centauri is the remnant core of a dwarf galaxy that was long ago disrupted by an encounter with our Milky Way. That would certainly explain its enormous size (roughly 150 light-years across) and mass (about 4 million Suns). ■

The Tragic Tale of Thisbe's Veil

A mist of delicate starlight lends an air of mystique to the June night sky.

Go out on any clear, moonless night in June and look high overhead for Coma Berenices, the constellation of Berenice's Hair. Don't be fooled by the paucity of Coma stars plotted on our Northern Hemisphere star chart on pages 42–43. In addition to the three dots shown, under dark, rural skies your eyes will be greeted by a 5°-wide maze of glittering starlight. The collection's most conspicuous stars form a pattern resembling the Greek letter lambda, λ. With averted vision, numerous fainter suns flow down from it like long tresses.

The constellation glitters like dew on a moonlit cobweb blown by a breeze. In his 1888 book *Astronomy with an Opera-glass*, Garrett P. Serviss wrote of the starlit haze that "One might think the old woman of the nursery rhyme who went to sweep the cobwebs out of the sky had skipped this corner . . ."

Indeed, few constellations have as many guises as Coma Berenices. Its stars were recognized by the earliest skygazers, including those of ancient Mesopotamia, who recorded "the dusky stars which stand in the tail of the Lion." German cartographer Caspar Vopel then humanized the group by including the stars on his 1536 celestial globe as Coma Berenices.

The constellation honors Queen Berenice II of Egypt, whose amber tresses, say the classical poets, flowed in an erotic state of disarray to the wonder of all. When the Queen honored a vow to cut off her hair and sacrifice it to the temple of Venus upon her husband's safe return from war, it miraculously reappeared as a constellation in the heavens.

But these stars have not always belonged to Queen Berenice. An old Babylonian love story, related by another Roman poet, Ovid, offers a different, tragic take. The tale centers around two star-crossed lovers, Pyramus and Thisbe, who decide to meet in secret one evening in a forest. First to arrive, Thisbe hears the roar of a lioness and flees. In her haste, she drops her veil. The lioness, whose jaws are dripping with the blood of a recent kill, attacks the veil, ripping it to shreds, before disappearing into the woods. When Pyramus arrives, he finds only Thisbe's bloody veil and the mauled carcass. Fearing the worst, he draws his knife and stabs himself. When Thisbe returns to the scene and sees Pyramus mortally wounded, she takes her own life. To honor the pair for their devotion, Jupiter puts Thisbe's veil among the stars, where, as Julius D. W. Staal so eloquently writes in his 1988 book, *The New Patterns in the Sky*, it still "flutters today in the stars of Coma Berenices, wafted by an eternal cosmic breeze."

British astronomer Philibert J. Melotte identified the stars streaming south from Gamma (γ) Comae Berenices as a star cluster, listing it as the 111th object in his 1915 catalog of star clusters. Now popularly known as Melotte 111, the Coma Berenices star cluster is extraordinarily close, at a distance of 280 light-years. In fact, next to the Hyades star cluster in Taurus, the Bull, the Coma star cluster is the nearest major star cluster to our Sun.

On the next clear evening, try to piece together the legend of Pyramus and Thisbe using several of the season's main constellations. You can see Coma Berenices as Thisbe's blood-stained veil; Leo as the lion that stained it and frightened Thisbe away; Virgo as the fallen Thisbe; and Boötes performing the role of the aggrieved Pyramus.

▲ **WRITTEN IN THE STARS** This 1606 etching by Italian artist Antonio Tempesta shows Thisbe taking her own life. Note the lioness in the background and Thisbe's veil in the foreground.

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

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

Mighty Jupiter Returns

The giant planet reappears at dawn while Mercury ascends at dusk.

FRIDAY, JUNE 7

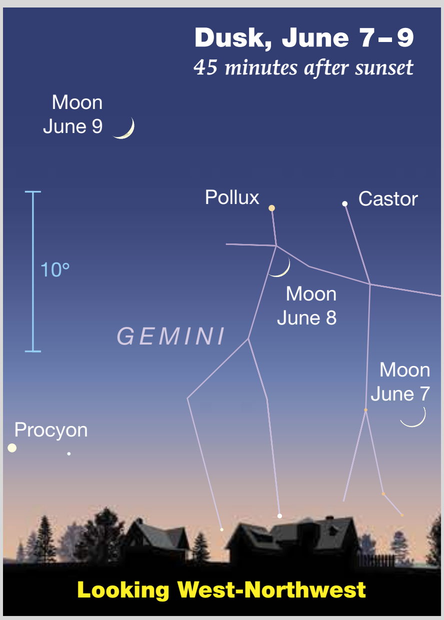
Just how good is your east-northeastern horizon? Is it flat and unobstructed? If so, face that direction a little before 5 a.m. local daylight-saving time and see if you can spot **Jupiter** with your naked eye. This morning presents your first reasonable chance at sighting the planet as it emerges from its May 18th solar conjunction. Jupiter shines brightly at magnitude –2.0 and rises roughly 45 minutes before the Sun, so it'll be a race between the planet's increasing altitude and brightening twilight. If your horizon isn't very flat, you may have to wait until Jupiter is higher and in a brighter sky, which means you'll likely have to resort to binoculars to fish it out. Still, it's worth the effort — there's something rewarding and reassuring about claiming Jupiter at the very beginning of a new apparition. And if you don't succeed this morning, try again tomorrow or the day after as the planet gradually climbs higher on the way to its December 7th opposition.

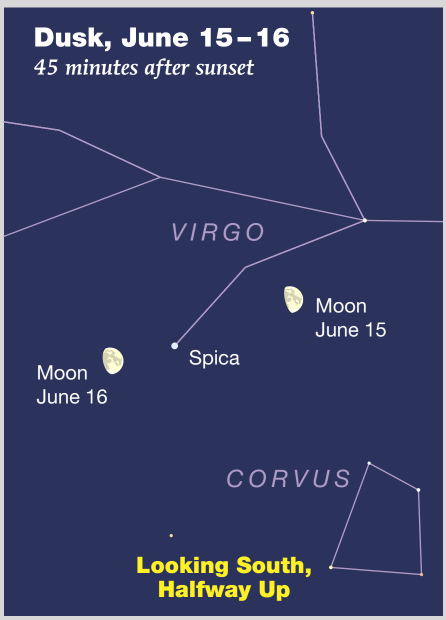
SATURDAY, JUNE 8

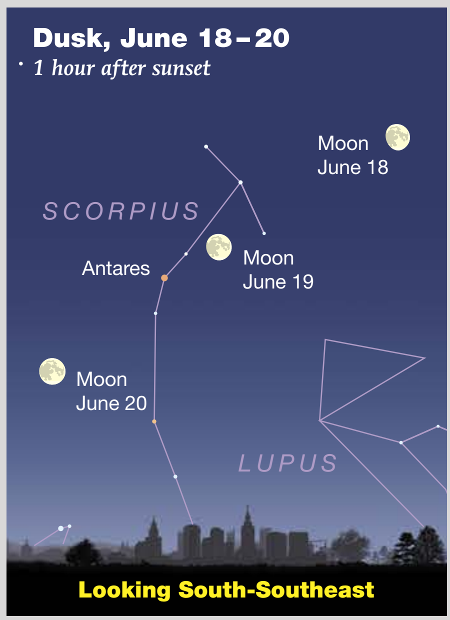
Here's one for those who prefer to do their sky-watching at dusk rather than at dawn. It's also for fans of celestial geometry. Cast your gaze to the west-northwest as darkness falls to catch the waxing crescent **Moon** in a tidy triangle with Gemini's two brightest lights, **Castor** and **Pollux**. The stars are separated by about 4½° — the same as the gap between Pollux and the Moon. But that tidiness is temporary. As we've noted here before, the Moon moves roughly its own diameter every hour, so the triangle might look a little less neat if you check in an hour or so before or after 9:30 p.m. EDT, the time when the alignment is most nearly symmetrical. The gathering will remain attractive (and a triangle) throughout the evening, though.

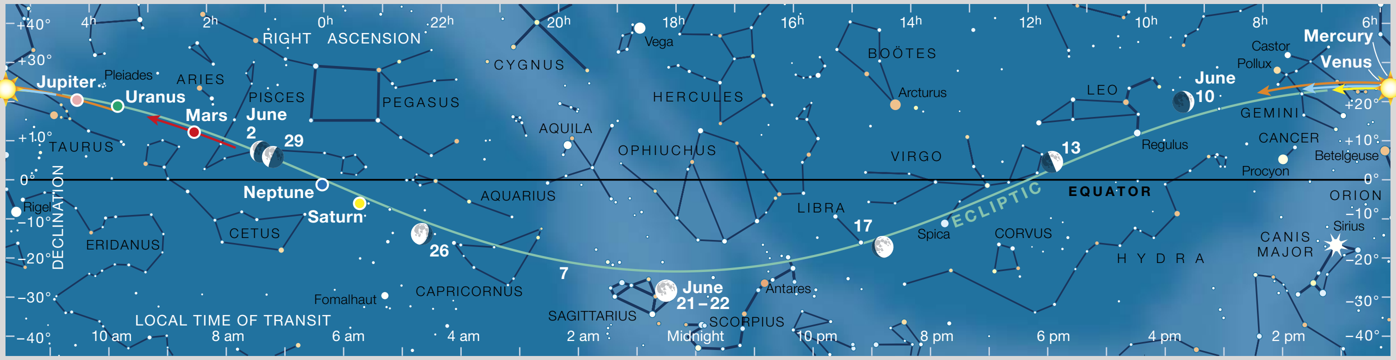
This is also a good time to appreciate *earthshine* — sunlight reflecting off our planet and illuminating the "unlit" portion of the lunar disk. A thin crescent is when the effect is most striking. The Moon is only about 7½% illuminated this evening, which means Earth as seen from the Moon is 92½% lit, thus reflecting lots of sunlight back onto the lunar surface.

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





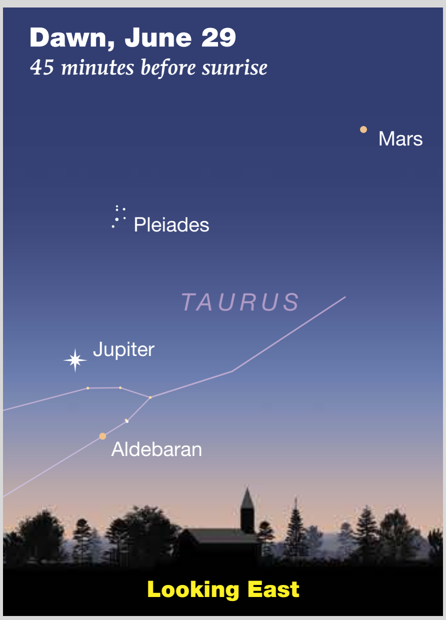




▲ The Sun and planets are positioned for mid-June; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

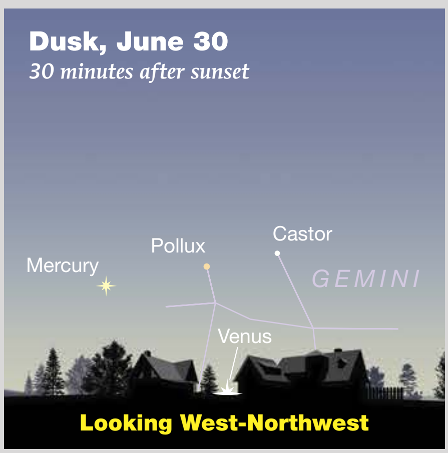
THURSDAY, JUNE 20

As the **Moon** makes its way along the ecliptic this month, it encounters three more bright stars. On the 11th, it's roughly 2½° upper right of **Regulus**, in Leo, and on the 16th it sits less than 4° left of **Spica**, in Virgo. However, the Moon's closest and best stellar conjunction occurs in the predawn hours of the 20th, when it sinks toward the southwestern horizon paired with **Antares**, in Scorpius. Of course, "best" is largely subjective, but I think the case here is strong. Not only does the waxing gibbous Moon get within 2° of the red giant (the exact amount depends on where you are and when you look), but Antares is also the brightest of the trio the Moon approaches in this sequence, albeit besting Spica by the tiniest of fractions. The Moon was much closer to Antares in May and will be again in August, but that doesn't diminish the visual appeal of tonight's pairing. Seeing the ruddy, 1st-magnitude gem twinkling away next to the gray Moon is always a delight.



THURSDAY, JUNE 27

One week after its best stellar encounter of the month, the **Moon** has its best planetary pairing when it closes in on **Saturn** before dawn today. Since its Antares meet-up, the Moon has gone from being nearly full to a 67%-lit waning gibbous and has traversed more than 90° of sky. When the Moon and Saturn rise in the hour after local midnight, they're separated by roughly 5°. However, by the time they approach the meridian and the sky really starts to brighten with the arrival of morning twilight, the gap between them has closed to less than 3°. That's for locations near the middle of the U.S., but for those on the West Coast the Moon gets even closer to the planet — a bit more than 1½° away. Saturn currently shines at magnitude 1.1 and is at the beginning stages of an apparition that began back in March.



SUNDAY, JUNE 30

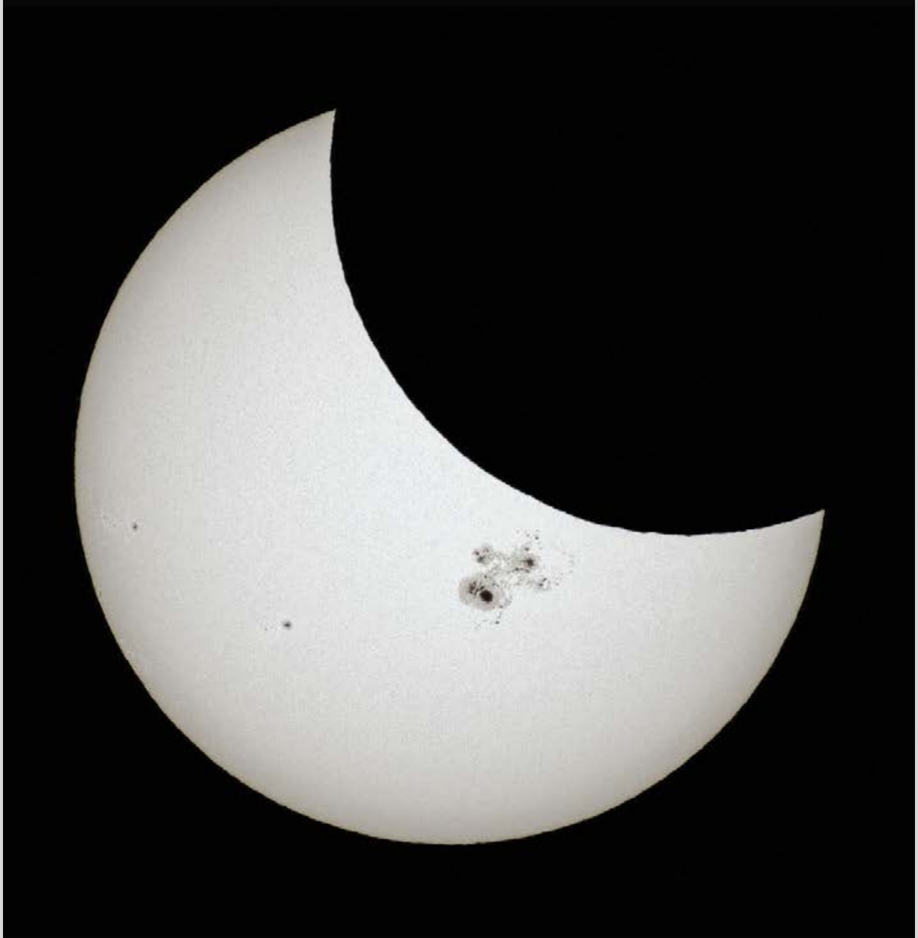
Mercury is a fast-moving planet. For proof you need only consider that on the 4th of this month it was having a very close (but difficult to observe) conjunction with **Jupiter** at dawn, as described on page 50. And now, less than four weeks later, it has popped up at dusk. Mercury has three evening appearances this year, and this one is neither the worst nor the best. As this month concludes, the swift little world is still on its way up and reaches its greatest altitude on July 12th. However, on this particular evening, it sits just 6½° above the west-northwestern horizon 30 minutes after sunset.

As it happens, Mercury forms a nice three-in-a-row line with the departing winter duo, Castor and Pollux. Mercury shines at magnitude –0.5 and sits a bit more than 6° left of 1.1-magnitude Pollux. To take in this sight, you'll once again need an unobstructed horizon and probably binoculars, though all three glints won't fit into a single bino view.

■ Consulting Editor **GARY SERONIK** keeps tabs on the Moon and planets from his home in British Columbia.

Solar Cycle 25 Update

Get your solar filters and scopes ready as activity on the Sun ramps up to maximum.



A giant sunspot was crossing the face of the Sun during the October 23, 2014, partial solar eclipse. That event occurred just months after Solar Cycle 24's April peak, when sunspot activity remained very high. The current solar cycle (number 25) is expected to produce even more sunspots when it climaxes, likely before February 2025.

GARY SERONIK

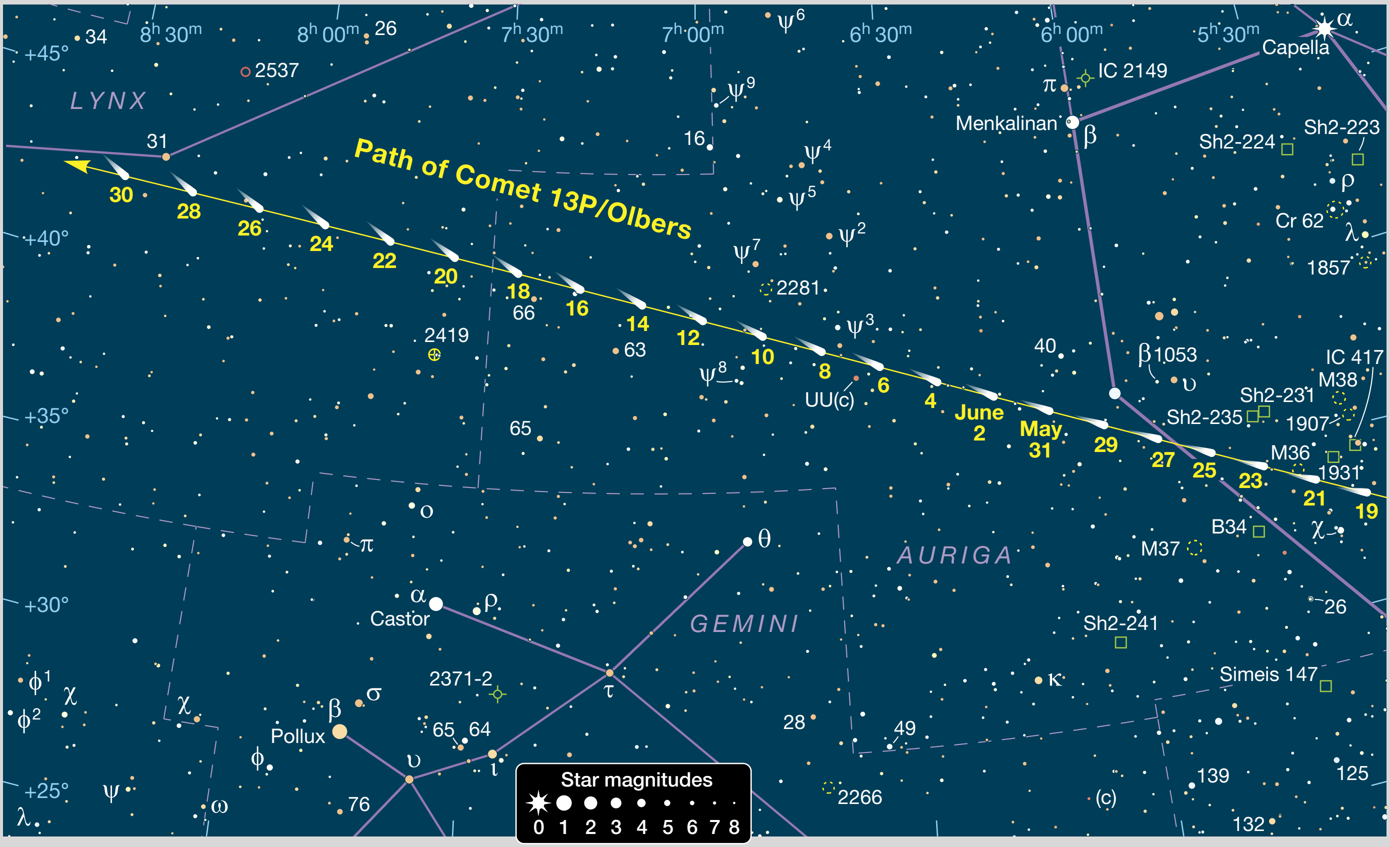
Forecasting the moment of solar maximum is trickier than you might think. The Sun goes through a cycle of activity that lasts on average about 11 years, starting at minimum, reaching maximum, and then declining to a new minimum. Around "solar max," large, magnetically complex sunspot groups are common and give rise to solar flares and coronal mass ejections capable of disrupting radio communications and sparking shockingly beautiful aurorae. Some cycles have strong maxima, others less so. Presently, we're in the thick of Solar Cycle 25 — the 25th since meticulous record-keeping of sunspot activity began in 1749. (Solar Cycle 1 began in February 1755.)

The most recent minimum occurred in December 2019, when Solar Cycle 24 concluded and the current one began. That year, researchers at the National Oceanic and Atmospheric Administration's Space Weather Prediction Center expected the next maximum would occur in July 2025, with an average monthly sunspot count of 115. Allowing room for uncertainty, the group noted that the peak could occur between November 2024 and March 2026, with a monthly sunspot count ranging from 105 to 125. For context, the average cycle peak hovers around a sunspot count of 178.

Once Cycle 25 got underway, it soon became apparent that the original estimate was too low — something obvious to amateur astronomers who routinely monitor the Sun. An updated projection issued in February 2024 now projects a peak occurring between then and February 2025, with a monthly sunspot number in the range of 136 to 139. In other words, though the lead-up to solar maximum will be swifter and the peak more intense than originally expected, it will be below average.

Take a look at the graph presented at the Space Weather Prediction Testbed website (**https://is.gd/testbed**) and note the gentle slope of the curve's decay phase. It hovers close to the originally forecasted solar max all the way into early 2027 before falling off. This could mean that enhanced Sun-related activity may continue at a modest pace even as we slide back toward minimum.

Given that the Sun's wily ways don't always lend themselves to crisp predictions, astronomers are cautious about forecasting a cycle's peak. And occasionally the Sun displays a double-peaked maximum separated by a temporary lull in activity called a *Gnevishev's gap*. In fact, the only way to know when maximum occurs is to wait and watch for a decline in sunspot numbers. Solar astronomers do this by calculating the 13-month smoothed sunspot number. By averaging monthly mean values over 13 months — from six months before to six months after a base month — they arrive at the time of maximum. If Cycle 25 were to peak this August, for instance, we wouldn't know it until early March 2025.



Comet 13P/Olbers Sticks to Twilight

IN A GAME OF poker, you might be dealt a good hand or get stuck with a bad one. Periodic comets are like that. One apparition might be highly favorable, with the comet making an especially close approach to Earth at the same time it reaches perihelion. Or, at its next appearance many years later, it might pass far from Earth after approaching the Sun or cling fast to twilight after perihelion.

When German astronomer Heinrich Olbers discovered this particular comet in March of 1815, it had reached 5th magnitude during a favorable apparition. This year, Comet 13P/Olbers arrives at perihelion on June 30th and zooms closest to Earth on July 20th at a relatively distant 284 million kilometers (176 million miles). Predicted to peak at around magnitude 7.5 in late June, the comet should be an easy binocular object under reasonably dark skies. So, while this appearance isn't exactly a royal flush, it's at least a full house.

Comet 13P/Olbers has an orbital period of 69.4 years and last passed through the inner solar system in 1955–56. I got my first look at it on February 4th this year when I swept up the 13.5-magnitude tuft of comet-candy in Eridanus with a 15-inch Dobsonian. In early June we should see it shine between magnitude 8 and 8.5, low in the northwestern sky at nightfall. By the end of the month, it should brighten perhaps another magnitude and remain brighter than 8.5 in July. Binoculars and telescopes may show a short, eastward-pointing tail throughout early summer.

Keep in mind that during the best part of its run, 13P/Olbers will hover low in the northwestern sky at the end of evening twilight. To make the most of its window of peak brightness, observe from a spot with an unobstructed horizon. Set up your scope during early twilight so that by the time the sky is fully dark, you're ready to spring into action.

For observers at mid-northern latitudes, on June 1st the comet hovers about 7° high in the northwest in Auriga at the end of astronomical twilight. Its altitude doubles by month's end as it tracks eastward past Gemini and into Lynx. In mid-June, a line extending from Pollux through Castor will take you straight to the comet. Then on night of the 19th, the fuzzy flyer passes 2.8° north of the 10th-magnitude globular cluster NGC 2419 in Lynx — an object better known as the Intergalactic Wanderer. (Use our chart above to locate the comet from late May through June. Its position is plotted for 0h UT on the dates indicated.)

I hope you'll take the opportunity to cash in your comet chips this month and tip your scope toward this infrequent icy visitor.

◀ This simulated view shows the waning gibbous Moon slowly occulting Saturn in daylight on June 27th at around 10:10 a.m. MDT, as seen from Denver, Colorado. The farther west you are, the higher up the Moon will be.

Saturn by Daylight

LIKE YOUR ASTRONOMY garnished with a little sunlight? On June 27th the waning gibbous Moon occults Saturn in daylight as seen from the central U.S. to California (except the northwestern states) and across Mexico. You'll need a telescope to see the ringed planet disappear from view. Fortunate skywatchers in Polynesia, northern New Zealand, and far eastern Australia can observe the occultation as it unfolds in a dark sky.

Saturn disappears along the Moon's bright limb in the morning hours for U.S. skywatchers. From Denver, Colorado, the Moon takes 41 seconds to completely hide the ringed planet, starting at 10:10 a.m. MDT. Saturn reappears on the Moon's trailing, "dark" limb 44 minutes later.

Only the western third of the U.S. will see Saturn reemerge before moonset. The view could be memorable as the narrow rings emerge as a razor-like line before the planet's globe begins its exit. I wonder how visible the rings will be, given they're currently tilted just 1.9° from edge-on?

For more details, including a list of cities and occultation times, see the International Occultation Timing Association's website: **https://is.gd/junesaturn**.

A Daylight Occultation and Conjunction

ON THE MORNING OF June 4th, Mercury and Jupiter will meet in a close conjunction, separated by just 7′. However, seeing this tight pairing will be a challenge, as the duo lie just 12° west of the Sun and are up just 38 minutes before sunrise, as seen from mid-northern latitudes. The planets are about 6° above the east-northeastern horizon at sunrise. From equatorial regions and mid-southern latitudes, the situation is better, and the pair should be easily visible in binoculars about 40 minutes before sunrise.

Another approach to observing the event is to wait until after sunrise to catch the twosome when they're higher in the sky. Although the planets slowly separate, they'll still be about 9′ apart around 8 a.m. EDT and 17′ by 10 a.m. Both objects should be plainly visible in telescopes at low to medium magnifications, provided the atmosphere is transparent. Mercury shines at magnitude −1.1 just southeast of Jupiter, which is at magnitude −2.0. Jupiter's ghostly, 32.8″-diameter disk contrasts with the 5.4″ pinhead of Mercury, but which will be easier to see?

To track down this pairing in daylight, use an equatorial or Go To mount. If you're manually aiming, dial in Jupiter's position by offsetting from the Sun's right ascension and declination — data any stargazing app will provide for the specific time you're viewing. Be sure to use a safe solar filter as you aim at the Sun and focus. Once you've made your shift to the planetary pair, remove the filter and enjoy the view.

Action at Jupiter

JUPITER WAS IN CONJUNCTION with the Sun on May 18th and effectively out of view until the beginning of June. Although the planet's low altitude makes it a poor telescopic target at the start of a new apparition, the situation improves with each passing week as Jupiter climbs higher and higher at dawn. By the end of June, it rises two hours ahead of the Sun and achieves an altitude of 20° at sunrise. On the 30th, the planet shines at magnitude −2.0 and presents a disk 33.6″ across. Jupiter spends the remainder of 2024 slowly drifting eastward in Taurus, where it's favorably placed for Northern Hemisphere observers. When the planet finally reaches opposition on December 7th, it will have brightened to magnitude −2.8 and increased in diameter to 48.2″.

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

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

Associate Editor Sean Walker recorded this view of Jupiter and its Great Red Spot on January 3rd, 2024.

OCCULTATION SIMULATION: STELLARIUM

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

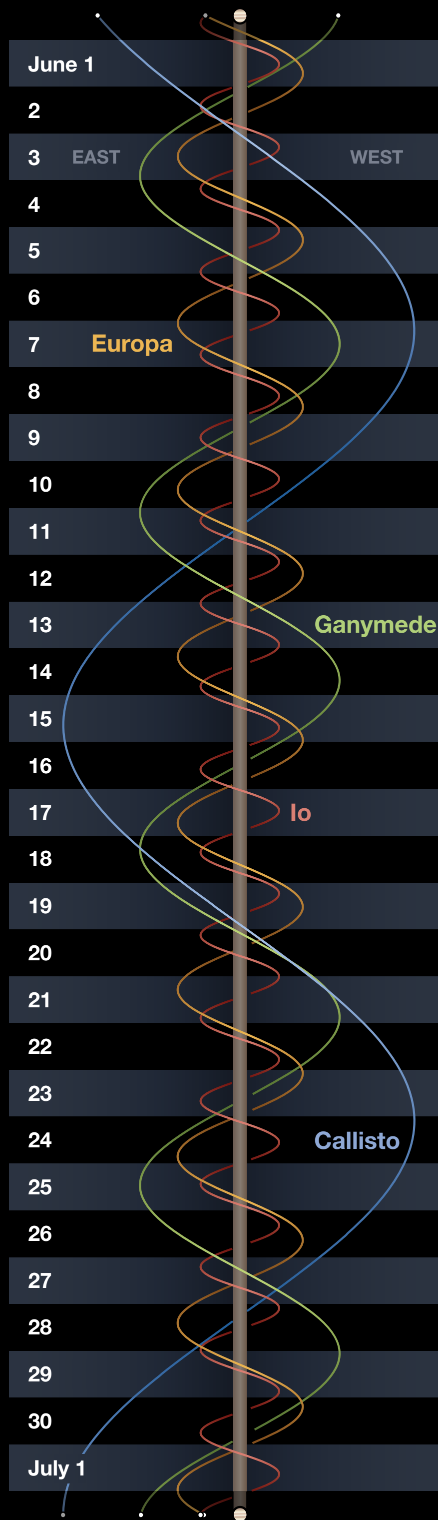
These times assume that the spot will be centered at System II longitude 59° on June 1st. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 59° and $1\frac{2}{3}$ minutes later for each degree more than 59°.

Phenomena of Jupiter's Moons, June 2024

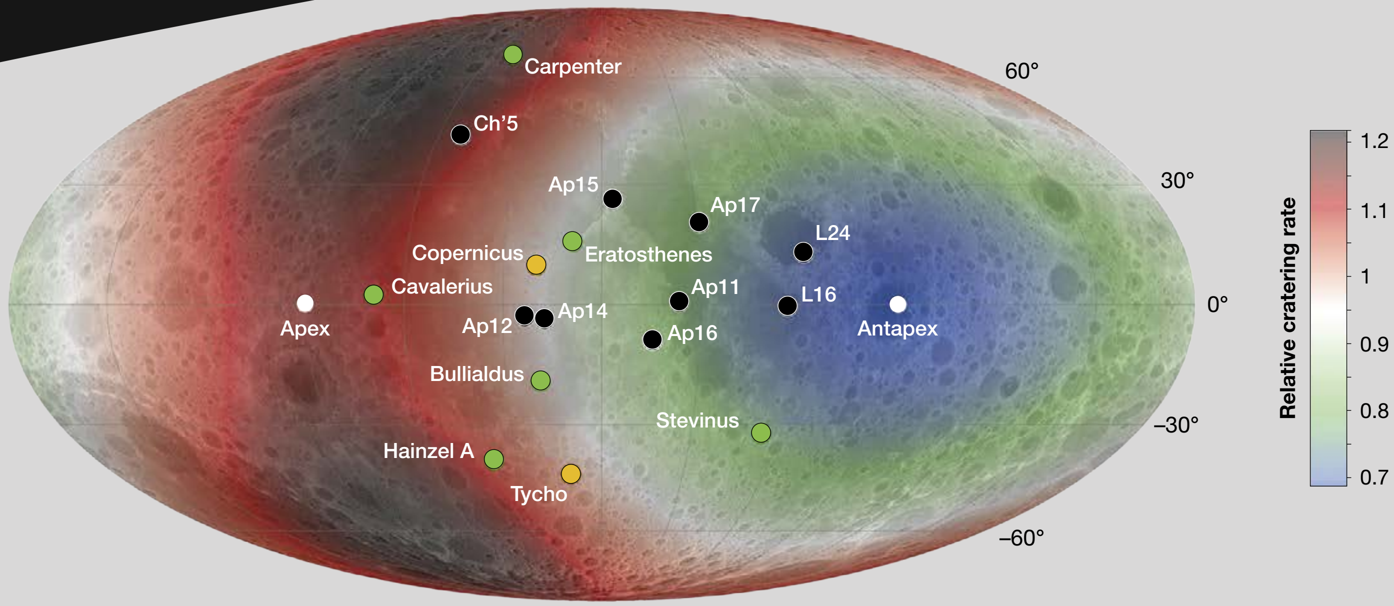
June 1	0:44	I.Sh.I
	0:57	I.Tr.I
	2:54	I.Sh.E
	3:08	I.Tr.E
	21:53	I.Ec.D
June 2	0:19	I.Oc.R
	0:35	III.Ec.D
	3:27	III.Oc.R
	13:04	II.Ec.D
	16:01	II.Oc.R
	19:13	I.Sh.I
	19:28	I.Tr.I
	21:23	I.Sh.E
	21:39	I.Tr.E
June 3	16:22	I.Ec.D
	18:49	I.Oc.R
June 4	7:20	II.Sh.I
	7:53	II.Tr.I
	9:45	II.Sh.E
	10:21	II.Tr.E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



Craters Younger Than We Thought

New crater counts help to revise our understanding of lunar chronology.

Among the most critical data required to understand lunar history are the approximate times that major lunar features formed. The most accurate ages come from radiometric analyses of lunar samples. Unfortunately, samples from only 11 sites have been returned to Earth by the lunar programs of the U.S., the Soviet Union, and China.

For the rest of the Moon, the standard method used to estimate crater ages and other formations is to count the number of impact craters in an area of interest. This technique assumes that craters form all the time, and therefore older surfaces have more craters and younger regions have fewer. Impact craters have formed throughout the last 4.5 billion years, though not at a constant rate.

To determine how the crater production rate (CPR) changed over time, scientists count the number of impact craters with diameters larger than 1 kilometer that are present per square km. This is called the N(1) value. For the areas where lunar samples were returned to Earth, their absolute ages were measured in laboratories. A graph of N(1) and age data shows how the CPR decreased over lunar history, with a very high cratering rate about 4 billion years ago and a much lower, near-constant rate for roughly the last 3 billion years.

Astronomers establish an estimated age (called the *model age*) for any feature lacking radiometrically dated samples by counting craters to derive their N(1) values, then plotting them on a graph. Having done so, scientists determined hundreds of model ages for features. For instance, the east side of **Sinus Iridum** is about 3.35 billion years old, while the west side is 350 million years younger. Both values match that of adjacent **Mare Imbrium** lavas, which flowed downhill into Iridum.

▲ This map illustrates the asymmetry of lunar cratering rates, with red colors showing higher-than-average rates and blues for lower-than-average ones. The two white circles mark the *apex* or leading edge (left) and *antapex* or trailing face (right) of lunar motion. Black and yellow circles indicate 11 age-dated samples used for chronology calibration; green circles are craters listed in the table below.

Revised Crater Ages (billions of years)

Crater	Neukum age	Lagain age
Carpenter	3.1	2.4
Cavalerius	3.1	2.5
Hainzel A	3	2.5
Bullialdus	3.7	3.6
Eratosthenes	3.3	3.3
Stevinus	0.9	1.0

As marvelous as the ability to ascertain a model age is, there are uncertainties that sometimes lead to disparate estimates. For example, researchers often count different numbers of craters in the same area. This can be due to the difficulties in deciding if a feature is a crater, a degraded crater, or random topography. They also sometimes disagree if a crater is a primary impact or a secondary crater that formed from the fallback of materials ejected from a primary impact and thus should be ignored. Another variable arises when researchers develop different mathematical fits to N(1) values and absolute-age data. In extreme cases, this can result in a billion years of difference in the model age! The late Gerhard Neukum (Free University of Berlin) and colleagues established a standardized fit in 2001 that has been widely used since.

But now, Anthony Lagain (Aix-Marseille University in France) and a team of colleagues have reevaluated orbital and projectile factors that affect the diameter and number of impact craters that formed in different lunar regions. In their paper (**https://is.gd/cratercounts**) they found that a given N(1) value yields different model ages depending on the location. Simply put, any chart that plots N(1) versus age is only correct for places on the Moon with the same cratering rate. Complex equations must be solved to estimate model ages for each feature.

Here are three major corrective factors proposed by Lagain and his team:

1: More impacts occur close to the lunar poles than near the equator.

2: The approach angle of impactors varies across lunar latitudes.

3: The number of impacts and their velocities vary according to the distance from the Moon's apex of movement around Earth (the point on our tidally locked Moon that always faces the direction of its orbit).

Both factors 1 and 2 are due to the orbital characteristics of near-Earth objects (NEOs) that are the main contributors to inner-solar-system cratering over the last 3.5 billion years. NEOs are typically collisional fragments of main-belt asteroids with orbits that bring them into the inner solar system. Although many NEOs have low-inclination orbits that favor collisions near the lunar equator, the dynamics of high-inclination NEOs lead to cratering at the poles being 1.13× greater than near the equator. And steeper impact angles increase the polar cratering rate to 1.26× the equatorial rate.

With regards to factor 3, the near match between the periods of the Moon's orbit and its axial rotation causes one side of the lunar surface to constantly lead as the satellite orbits Earth. As a consequence, the leading face (or *apex*) collides with more NEOs, and at higher velocity, than the trailing side. The lunar apex of motion at 0°N, 90°W (just north of **Mare Orientale**) receives 28% more impacts and produces slightly larger craters than the antapex side (0°N, 90°E, at **Mare Smythii** on the eastern limb).

Combining all three factors shifts the location of the maximum cratering intensity to ±60°N, 90°W, with the minimum cratering rate at the eastern equatorial limb. Overall, the cratering rate at maximum-intensity locations

◀ Carpenter crater (left) is 700 million years younger than previously thought. Stevinus (lower left) turns out to be 100 million years older because it formed in terrain with a lower-than-average cratering rate.

is 1.77× greater than at the area with the minimum rate.

Adjusting for these three factors leads to corrections of N(1) and thus model ages for craters at different locations on the Moon. The table on the facing page lists the model ages in billions of years of several familiar nearside features using the 2001 Neukum cratering curve and the new relation by Lagain and colleagues.

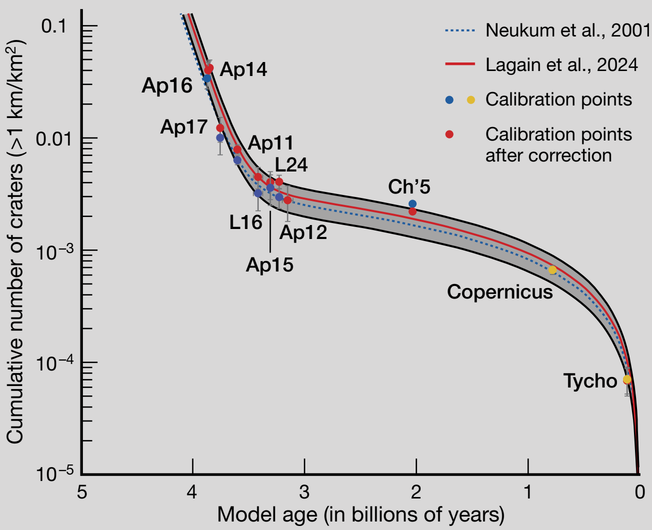
A few notable differences arise with this new approach. Craters such as **Carpenter**, **Cavalerius**, and **Hainzel A** are in a zone where the impact rate is predicted to be higher than normal, yielding corrected Lagain ages that are 500 to 600 million years younger than the Neukum-derived ages.

The ages for **Bullialdus** and **Eratosthenes** are essentially unchanged, because these craters are in the annular zone where the corrected cratering rate is the same as the old rate.

Stevinus is in a zone where the cratering rate is lower than average, and its corrected age is 1 billion years old, slightly older than the previous Neukum value of 0.9 billion years.

The new Lagain model will soon be tested with samples from never-before-visited lunar regions. The upcoming Artemis landing near the Moon's South Pole is in an area predicted to have high impact rates, and thus samples should be younger than expected from the traditional N(1)-age relationship. I bet they will be.

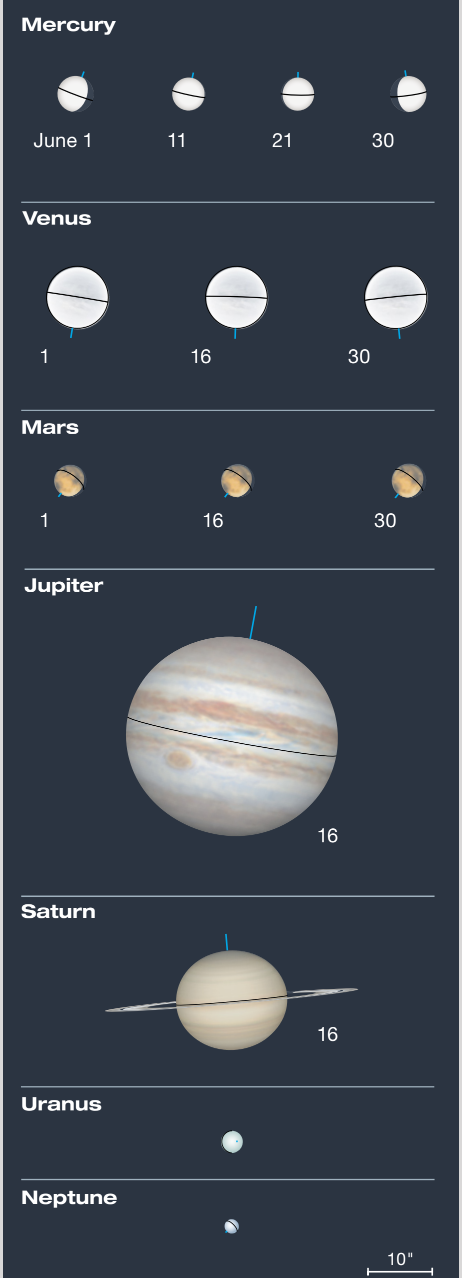
▶ This graph updates the absolute lunar chronology, plotting the ages of measured lunar samples (blue circles) on the *x*-axis against the cumulative number of craters larger than 1-km diameter per square kilometer of lunar surface along the *y*-axis. The gray area shows extremes of corrected fits for high-cratering-rate areas (top black line) and low-cratering-rate areas (bottom black line). Gray bars represent the margin of error.



GRAPH: ANTHONY LAGAIN; CRATERS: NASA / GSFC / ARIZONA STATE UNIVERSITY

■ Contributing Editor **CHUCK WOOD**'s lunar columns have appeared in *Sky & Telescope* for 25 years.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dusk starting on the 24th • **Venus** is lost in the Sun's glare all month • **Mars** visible at dawn all month • **Jupiter** visible at dawn starting on the 7th • **Saturn** is visible at dawn and climbs to an altitude of 40° by sunrise at mid-month.



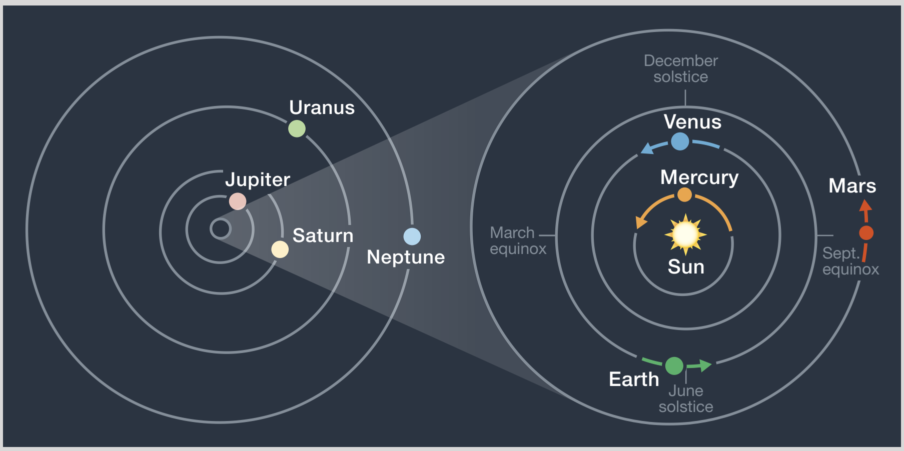
▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

▶ **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.

June Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$4^h\ 36.3^m$	+22° 03′	—	–26.8	31′ 33″	—	1.014
	30	$6^h\ 36.4^m$	+23° 10′	—	–26.8	31′ 28″	—	1.017
Mercury	1	$3^h\ 32.9^m$	+17° 41′	16° Mo	–0.8	5.6″	82%	1.198
	11	$4^h\ 57.6^m$	+23° 01′	5° Mo	–1.9	5.1″	98%	1.311
	21	$6^h\ 32.8^m$	+24° 54′	8° Ev	–1.5	5.2″	95%	1.299
	30	$7^h\ 49.9^m$	+22° 57′	17° Ev	–0.6	5.6″	80%	1.197
Venus	1	$4^h\ 32.2^m$	+21° 42′	1° Mo	—	9.6″	100%	1.735
	11	$5^h\ 25.0^m$	+23° 23′	2° Ev	–4.0	9.6″	100%	1.734
	21	$6^h\ 18.6^m$	+23° 57′	5° Ev	–3.9	9.7″	100%	1.728
	30	$7^h\ 06.9^m$	+23° 26′	7° Ev	–3.9	9.7″	99%	1.717
Mars	1	$1^h\ 28.9^m$	+8° 03′	47° Mo	+1.1	5.0″	92%	1.859
	16	$2^h\ 11.2^m$	+12° 04′	50° Mo	+1.0	5.2″	91%	1.800
	30	$2^h\ 50.9^m$	+15° 23′	53° Mo	+1.0	5.4″	91%	1.743
Jupiter	1	$3^h\ 56.4^m$	+19° 40′	10° Mo	–2.0	32.8″	100%	6.016
	30	$4^h\ 24.0^m$	+20° 54′	31° Mo	–2.0	33.6″	100%	5.874
Saturn	1	$23^h\ 20.3^m$	–6° 18′	82° Mo	+1.2	17.0″	100%	9.778
	30	$23^h\ 23.0^m$	–6° 08′	109° Mo	+1.1	17.9″	100%	9.302
Uranus	16	$3^h\ 29.4^m$	+18° 41′	30° Mo	+5.8	3.4″	100%	20.456
Neptune	16	$0^h\ 00.2^m$	–1° 21′	85° Mo	+7.9	2.3″	100%	29.962

The table above gives each object's right ascension and declination (equinox 2000.0) at 0h 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**.



Mod Your Camera for Astrophotography

Here's how you can get more out of the camera you already have.

One common path into the universe of astrophotography is to start with regular, daytime photography. Many a photography enthusiast who first started shooting birds, landscapes, or family events eventually decides to mount the camera they already have on a tripod and aim it at the night sky. Nightscape photography is an entire art and passion all its own. Indeed, it's so rewarding that some astrophotographers stop right there and never bother to get a telescope, equatorial mount, and all the accessories that seem vital to the more involved craft of deep-sky imaging. Even if they eventually get a telescope, often they will simply use it as a very long telephoto lens, still using the camera they already have.

Let's talk about that "camera you already have." It's likely a DSLR or a mirrorless camera, with an interchangeable lens system. And it's possibly the only one you own. But should it be? Consider that almost no one who starts taking pictures of the night sky remains satisfied with just one lens for very long. While the included "kit lens" may be versatile and capable of producing good results, eventually other options become more appealing (*S&T:* Oct. 2022, p. 54). Wide, fast lenses are great for nightscapes and Milky Way shots, and long lenses on a star-tracker mount can serve as short-focal-length telescopes, capturing expansive regions of the sky, including star clusters and other large deep-sky targets. Similarly, a different camera can help open the door to new photographic possibilities.

"Seeing" the Light

A modern digital camera is a powerful photographic tool, especially for capturing the night sky. Its sensor is much more sensitive to light than the human eye — and this sensitivity not only extends to very low light levels, but also to wavelengths that our eyes can't see at all. Take your garden-variety security camera system, for example. At night it produces a black-and-white image rich with detail. Somehow, it can "see in the dark." How is that possible? The device typically floods the area in front of the camera with infrared (IR) light. IR light is invisible to the human eye, but not to the camera's sensor.

As it happens, there are wavelengths of light that we want to be able to capture to produce impressive astrophotos, including hydrogen alpha (Hα). Although it's only faintly visible to the human eye, hydrogen alpha comes in buckets full when you're capturing emission nebulae such as the Lagoon Nebula (M8) in Sagittarius or the North America Nebula (NGC 7000) in Cygnus. It's also visible in nightscapes

▲ **GALACTIC DETAILS** This panoramic photo shows the summer Milky Way spanning from Sagittarius into Scorpius, dotted with pink hydrogen-alpha highlights. The author made this 20-second exposure with his Canon EOS Ra DSLR and a 35-mm Tamron f/1.4 lens (working at f/2) riding on a motorized Sky-Watcher Star Adventurer AZ-GTI tracking mount.

▲ **HORSEHEAD PORTRAITS** This pair of identical, 30-second frames illustrates the difference between the results produced by a regular Canon EOS R (left frame) and an astronomy-friendly Ra camera (right). While the reddish hydrogen region surrounding Orion's dark Horsehead Nebula appears in both shots, it's far more pronounced in the Ra camera's image.

as tiny pinkish knots of nebulosity in the Milky Way.

While a regular camera will certainly record bright nebulae as faint pink highlights, a camera that has been modified to be more sensitive to hydrogen-alpha wavelengths will pick up these details far more readily.

Filtering Fun

A dedicated astronomy camera is rarely used without adding at least one filter in front of its sensor. As it happens, your camera already has a filter built in to reduce IR and ultraviolet (UV) light. If it didn't, your daytime images would include a lot more red than you can see and even allow some UV to intrude into the photo. Aside from producing flat and blown-out images, it's also likely your camera's lenses wouldn't be able to cope with such a wide range of wavelengths, resulting in pictures that appear a little out of focus as well.

So, the presence of a UV/IR filter is great for daytime photography, but it's not ideal for shooting certain objects in the night sky. That's why your camera will only barely register nebulosity in many astronomical targets. Thankfully, you're not stuck with the stock sensor filter — you can replace it with one that still blocks UV and IR light but lets the valuable hydrogen-alpha wavelength pass through. Milky Way images or even portraits of constellations such as Orion or Cygnus really pop when regions of glowing hydrogen gas are also captured.

Plenty of YouTube videos and online instructions will show you how to disassemble your camera and replace the standard built-in sensor filter with one more suited to astrophotography. But it's tricky work. In fact, I'll confess that the very idea of messing with my camera's delicate sensor terrifies me. (If you ever saw me with a screwdriver or power tool, it would terrify you, too!) And I'm not alone in having this fear. Thankfully, a few people gifted with steady hands and experience will modify your camera for a reasonable fee. Two firms that offer this service are **astrogear.net** and **kolarivision.com**. A Google search will turn up several more.

I took advantage of this approach myself with my original Canon EOS Rebel. I was nervous about surrendering my DSLR, but once I got it back and started shooting, I wondered why I'd waited so long! I even purchased a brand-new Canon 5D Mark II and nervously sent it to a gentleman by the name of Hap Griffin, in South Carolina, for a warranty-voiding modification. I have no regrets.

You can find plenty of mod-ready cameras on the used market, or maybe you've recently upgraded and already have a second camera that doesn't see much use anymore. Another option is to turn to a company such as **nightskycamera.com** or **hutech.com**, which sell new, pre-modified "spectrum-enhanced" cameras and include warrantees.

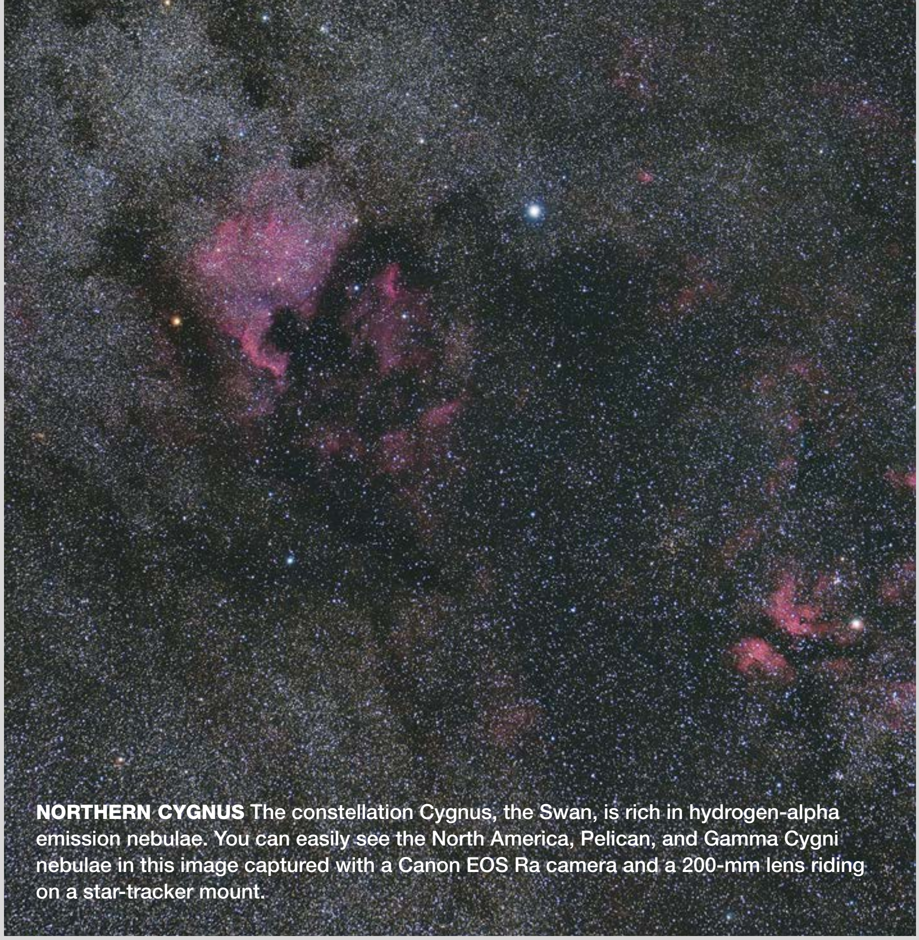
What's the Catch?

Shooting the night sky with a modified camera is an amazing experience, but there are a few things you should know

▲ **IN THE PINK** Shooting daytime photos with a modified camera requires a manual white-balance adjustment to avoid a pink color cast to your images. The difference is obvious in this pair of images shot with a modified Canon EOS Rebel DSLR.

before you pack up your camera for modification. First, the autofocus may no longer work. Some cameras may have an internal adjustment that may restore this capability, however. Another catch is that unlike a multi-billion-dollar company with vast resources to spare for clean-room environments, when you send your camera to a smaller, specialty firm (or individual) for modification, it may acquire some dust between the sensor and the new filter. The effects are usually very slight, but the pixel peepers among you will notice. When this occurs, you'll need to resort to flat-field techniques or some post-processing, cosmetic corrections. (As always, it's best practice to shoot in RAW format for easier post-corrections.) Finally, when shooting with a modified camera your daytime images will have a strong reddish or pink tint to them. You can easily correct this with a custom white-balance setting, either in camera or applied during post processing.

The fact that the natural colors can be restored for daytime photography is important because it means your camera will be able to do double-duty — astrophotography *and* whatever else you want to shoot during the day. There are also numerous clip-in filters available that restore your camera's original UV/IR performance. These let you do daytime photography without the need for post-processing heroics to fix the color balance.



NORTHERN CYGNUS The constellation Cygnus, the Swan, is rich in hydrogen-alpha emission nebulae. You can easily see the North America, Pelican, and Gamma Cygni nebulae in this image captured with a Canon EOS Ra camera and a 200-mm lens riding on a star-tracker mount.

Soaking Up the Full Spectrum

So far, I've been describing modifications that are something of a compromise — procedures that enhance nighttime performance while retaining daytime capabilities. But you can go all-in if you want with a "full-spectrum" modification. This means replacing the camera's original filter with clear glass so that *all* wavelengths of light reach the sensor. However, you'll be sacrificing autofocus capabilities for sure, which you're not likely to miss at night anyway. With a full-spectrum modification, you have the option of adding clip-in filters that emphasize specific parts of the spectrum. For example, you can get a filter that passes only UV or IR light. You can even get a filter that restores the normal UV/IR balance! A great source for many types of clip-in filters is **astronomik.com**.

I took this route myself with a Canon EOS Rebel T3i and use a clip-in IR filter to turn the camera into an infrared DSLR. Looking through the viewfinder I can't see anything at all, so I have to use the LCD screen to frame my shots. Daytime IR photography is a fantastic artistic pursuit in itself, and different IR filters can be used to create altered-color images that are simply otherworldly. You can also shoot the Moon with an IR filter — a strategy that helps mitigate the blurring effects of atmospheric seeing. IR also lets your camera peer through dusty regions to better show stars and structures not apparent in normal, visible light.

I've saved the very best option for last. Both Canon and Nikon have produced cameras with modified internal filters specifically designed for astrophotography. Canon was first out of the gate when it released the EOS 20Da in 2005 (the lowercase "a" denotes "astro," of course). It followed up with the EOS 60Da in 2012 and finally the EOS Ra in 2019. Nikon also got in the act and released the D810A in 2015. I've used all of these cameras except the D20Da. With the exception of the EOS Ra and D810A, the rest required manually setting a custom white balance to correct an excessive red cast in daylight photographs.

Unfortunately, these cameras are no longer in production. The good news is they're not difficult to find used and in excellent condition. Fingers crossed, Canon or Nikon will release new astro cameras in the near future.

Thankfully, there are several places to purchase a suitably modified camera and services that will perform the filter surgery for you. And if you're good with tools, you can even try it yourself. If you want to extend your astrophotographic reach, there are plenty of options.

■ Contributing Editor **RICHARD S. WRIGHT, JR.** loves traveling to dark skies to turn his Canon EOS Ra loose on the Milky Way and bright emission nebulae.

Abell's Galaxy Clusters

Snagging distant objects is a whale of a task, but it's a way to peer into the universe's past.

Modern astronomical imaging has revealed galaxy clusters out to a distance of more than 10 billion light-years (beyond a redshift of 1). Since the start of its operations, the James Webb Space Telescope has been shattering those records, recently unveiling a cluster at a whopping distance of 13 billion light-years (redshift of 7.9) — this translates to a mere few hundred million years after the Big Bang. In fact, this is so far back in time that astronomers classify the object a *protocluster*.

The earliest systematic study of galaxy clusters, however, occurred when George Abell tackled them as part of his PhD thesis work in the 1950s. He scoured the then ongoing *National Geographic Society – Palomar Observatory Sky Survey* (*POSS*) plates for faint groupings of galaxies, classifying these clusters by density, redshift, type, and magnitude. Abell published his results in a seminal 1958 article that's still referred to today. An update to his original catalog was published posthumously in 1989 (curated by Harold Corwin and Ronald Olowin) and extended coverage to southern clusters, as well as offering improvements to the accuracy of magnitudes and distances. That article also listed redshifts for approximately 25% of the clusters, which at the time provided insight into the three-dimensional nature of the universe.

Cluster Cataloger

George Ogden Abell was born in Los Angeles, California, in 1927, earned his undergraduate and postgraduate degrees from the California Institute of Technology in the 1950s, and died in his hometown of a heart attack in 1983

▲ **ONE OF MANY ABELLS** Listed as number 2065 in George Abell's seminal catalog, the Corona Borealis Cluster is framed by a pretty smattering of 9th- and 10th-magnitude stars. Astronomer Ron Buta noted that detecting anything besides the cluster's brightest galaxies was a challenge.

RON BRECHER

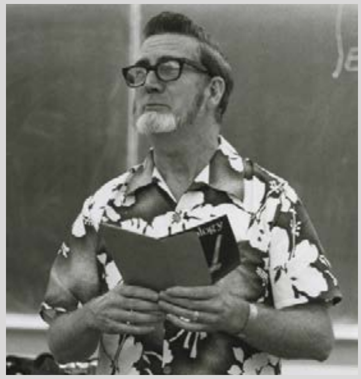
at the young age of 56. He taught at the University of California Los Angeles and at a summer school in Ojai, California, and he also mentored amateur and professional astronomers researching galaxy clusters and the large-scale structure of the universe. Abell's most celebrated student may have been Ed Krupp, the director of Griffith Observatory in Los Angeles since 1974, where he continues to inspire generations.

Although I never got the chance to meet Abell, galaxies have held a fascination for me since I first started using a telescope in the 1980s. Each galaxy's beauty and subtle variations reflect its history, environment, and interactions. The unseen, attractive hand of dark matter affects membership of groups and clusters, shaping their courses in ways we are still discovering. Knowledge about our targets enhances our experience when viewing them in a telescope. Let's dip into Abell's catalogs and take a look at several clusters, some of whose light has been traveling since the time of Earth's formation.

Faraway Clusters

The nearest cluster to Earth — at a distance of approximately 54 million light-years — is the Virgo Cluster, which is anchored by the giant elliptical galaxy M87. However, Abell didn't include it in his catalog as it's too spread out. Somewhat farther out, at a distance of 340 million light-years, **Abell 1656**, or the Coma Cluster, is the nearest *rich* cluster in the catalog. (Clusters are classified as rich or poor depending on the number of galaxies they contain.) The Coma Cluster, with its proximity and density of objects, is the best galactic hunting ground for amateur telescopes, with a population estimated at perhaps up to 3,000 galaxies. The core of the cluster lies 2⅔° west of 4.3-magnitude Beta (β) Comae Berenices.

I have a project underway to view galaxies in the cluster's central square degree — so far I've detected about 700 galaxies within two-thirds of that area. My 32-inch reflector allows me to see as faint as magnitude 20, and I estimate more than 1,000 galaxies will be visible in that central square degree. The whole cluster spans 25 square degrees in the sky. To search it at this level of detail would entail more than 1,000 hours of eyepiece time — and yield many more galaxies. (Based on my examinations of a *POSS* plate, I estimate there may be as many as 5,000 galaxies in the area!)



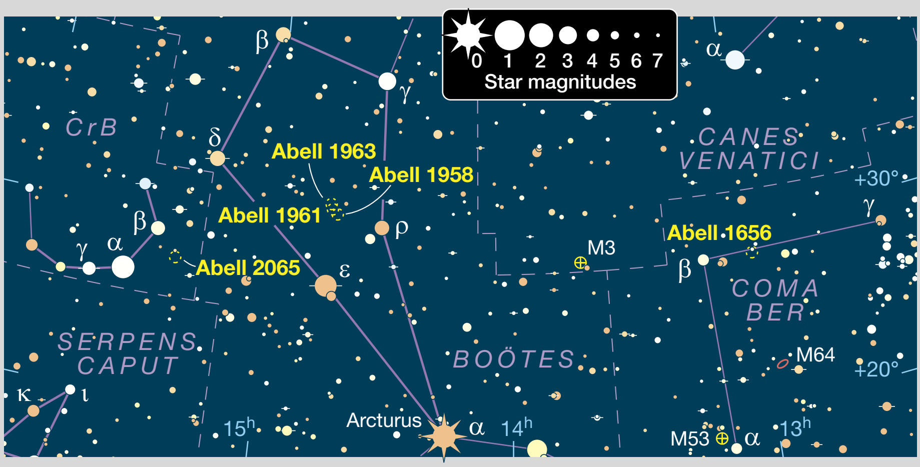
SKY & TELESCOPE ARCHIVES

◀ **CLUSTER COLLECTOR** George Ogden Abell only lived to 56 years old, but he left behind a rich legacy. Although best known for his monumental work on galaxy clusters, he also turned his attention to other objects, such as planetary nebulae.

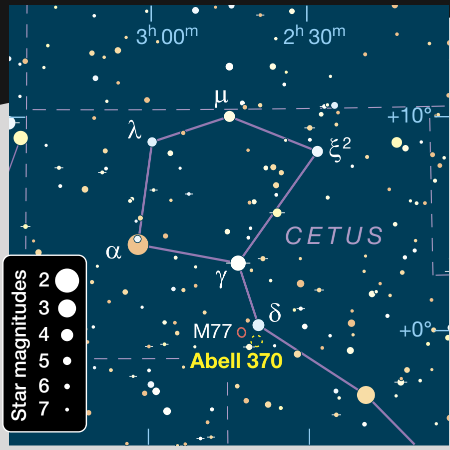
Abell 2065, the Corona Borealis Cluster, has long been held as a benchmark for visual observers. The distance to Abell 2065 is a little less than one billion light-years, and its brightest galaxies are at 16th magnitude. The cluster lies 1¾° southwest of 3.7-magnitude Beta Coronae Borealis.

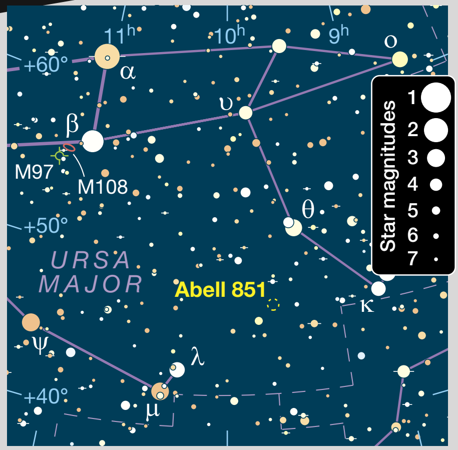
The classic series of the *Webb Society Deep-Sky Observer's Handbook* from the 1970s to 1980s included in its volume on clusters of galaxies, the fifth in the series, Ron Buta's (University of Alabama) description of Abell 2065 as seen through the 36-inch reflector at McDonald Observatory. Buta described the group as "very difficult" and, except for the "three brightest members, the cluster was a challenge." Few amateurs in 1982 had access to a 36-inch telescope, but about 10 years later I was able to purchase a 25-inch reflector and start hunting for some of these challenging objects. Experienced amateurs Barbara Wilson and Larry Mitchell included Abell 2065 on their infamous AINTNO (the Association of Invisible Nebulae and Things Nobody Observes) list — to win the AINTNO award, an observer would have to snag 45 of the cluster's galaxies. In 2004 I spent four and a half hours over two nights hand-guiding my scope, and I observed 51 galaxies in Abell 2065. This was the most technically challenging viewing I have done thus far, as the high-power fields of many galaxies lacked reference stars.

But this is just the beginning of our explorations, as it's one of the nearest galaxy clusters. For those with an everlasting itch to explore the deepest reaches of space, we can go farther afield. The "moderate distance" objects are represented by a group of three clusters: **Abell 1958**, **Abell 1961**, and **Abell 1963**, all around 2.8 billion light-years away. They're very close to each other in the sky, lying only about 15′ to 20′ from one another in central Boötes — all three fit into the same wide-field



▲ **CLUSTERING OF CLUSTERS** A handful of Abell objects populate three adjacent constellations. On late spring nights you can "cluster-hop" among them.





▲ **FAR, FAR AWAY** *Left:* You'll have to wait until late autumn to snag the second-most distant cluster covered here, Abell 370. Enjoy the sight of the barred spiral galaxy M77 while you're in the vicinity. *Right:* The most remote galaxy cluster described in this article is Abell 851, located below the Great Bear's front paw. When you view this collection of galaxies, you're looking back to the epoch of Earth's formation.

▲ **COSMIC ARC** Abell 370 acts as a gravitational lens for more distant galaxies — their light is bent into the arcs seen in this image. The most prominent arc is lower left of the cluster's core.

NASA / ESA / HUBBLE / HST FRONTIER FIELDS

eyepiece view. Abell 1963 includes a 17th-magnitude galaxy; otherwise the brightest objects within these three clusters are 18th to 19th magnitude. In my 32-inch scope from my home in Minnesota, on an average night I could only detect three galaxies in Abell 1961, the faintest of the three clusters.

Stretching Back in Time

If one sifts through all the redshifts in the 1989 Abell catalog there are two clusters that stand out as more distant than the rest: **Abell 370** and **Abell 851**, 4.2 and 4.5 billion light-years away, respectively. With my 32-inch f/4 reflector in 2006 from pristine western Oklahoma skies at an elevation of 4,500 feet, I searched the 6′-wide area of Abell 370, which you'll find just a smidgen less than 2° south of 4th-magnitude Delta (δ) Ceti, in the neck of Cetus. With an Ahab-like obsession, I struggled with this whale of a cluster, which fought against being captured. Atmospheric blurring and wind disrupted my quest for things remote, and I had to temporarily abandon my hunt when 20–30 mph gusts weathervaned my scope. In the end, my effort was partially redeemed when the two main large elliptical galaxies of Abell 370, along with six of their pod, were caught in my instrument, as I strained against the elements at nearly 1000×. However, try as I might, I was unable to detect the gravitationally lensed arc on the southern end of the cluster.

Nestled between the feet of the Great Bear, about 5° south-southeast of 3rd-magnitude Theta (θ) Ursae Majoris, is the most distant of Abell's galaxy clusters, Abell 851 — its light has traveled between 4 and 5 billion light-years to reach us. Nevertheless, deep photographs still show many hundreds of galaxies, which are much smaller than our Milky Way, and dozens would fit between our galaxy and the Andromeda Galaxy (lying at a distance of around 2.5 million light-years). Using my 25-inch scope at the Texas Star Party in 2004, I was able to spot Abell 851's four brightest galaxies as one, indistinguishable mass. I like to consider what that cluster would look like today, with the inexorable merging and evolution of its smaller members having altered its appearance.

Beyond Abell, the literature is replete with clusters dating back to within a few billion years of the Big Bang. I have spotted some approaching 6 billion light-years away using my 32-inch instrument, and close to 8 billion using a 48-inch telescope. The magnifying power of gravitational lensing has even allowed me a glimpse of a galaxy at a redshift greater than 3. Captain Ahab would approve.

Abell's Clusters

Object	Redshift	Distance (M l-y)	RA	Dec.
Abell 1656	0.023	328	12^h 59.8^m	+27° 59′
Abell 2065	0.072	991	15^h 22.7^m	+27° 43′
Abell 1958	0.227	2,810	14^h 43.2^m	+30° 58′
Abell 1961	0.232	2,860	14^h 44.4^m	+31° 14′
Abell 1963	0.221	2,750	14^h 44.8^m	+31° 28′
Abell 370	0.375	4,220	02^h 39.8^m	–01° 35′
Abell 851	0.406	4,480	09^h 43.0^m	+46° 59′

Right ascension and declination are for equinox 2000.0.

■ **DAVE TOSTESON** enjoys catching very old photons from his backyard in Minnesota and other dark-sky sites.

You and the Universe

WAVES IN AN IMPOSSIBLE SEA: *How Everyday Life Emerges from the Cosmic Ocean*

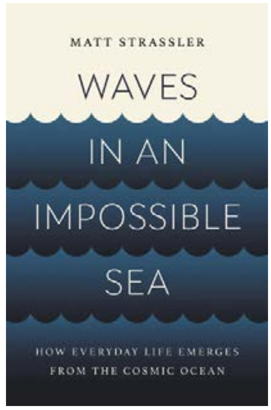
Matt Strassler
Basic Books, 2024
384 pages, ISBN 9781541603295
US$32.00, hardcover

"I HOPE TO OFFER you a clearer sense of how we fit into the cosmos and of how the ordinary emerges from the inconceivable," writes Matt Strassler early on in *Waves in an Impossible Sea*. Just what he means by that unfolds slowly, and by the end of the book, you might look at the universe and our place in it in ways you never have before.

Strassler is a theoretical physicist at Harvard who has worked with the Large Hadron Collider and written about string theory and particle physics. Unsurprisingly, he focuses whole chapters of this book on the quantum realm and on fields such as the Higgs, but there's much here of interest to astronomers. In particular, stargazers may be fascinated by his deep explorations into two phenomena they spend a lot of time contemplating: light and space. These two aspects of our universe play key roles in Strassler's grand conception of his book's titular "waves" and "impossible sea," respectively.

With light, Strassler starts with some fundamentals. A photon, he explains, is the dimmest possible flash, or *quantum*, of light. It has the most minimal vibration, with the smallest possible amplitude. Because light can have both a frequency and an amplitude, physicists consider it a wave. But it also behaves like a particle. Strasser, for one, prefers the term *wavicle*, denoting that it's somehow in between particle and wave.

"Almost by definition, it has extraordinarily strange properties," Strassler continues. Like any sound or water wave, a photon can spread out, even across a room. Yet if it's absorbed into the room's wall, a single atom swallows it whole. "First the photon is widely dispersed, and then, somehow, it isn't," he writes. Even more curiously, light waves — unlike sound or water waves — don't require a medium to travel through. Or at least scientists have never identified one for light (nor, for that matter, for electric and magnetic fields).



Perhaps the strangest thing of all about light waves, as Einstein taught us with special relativity, is that no matter how fast you move, photons will always approach you at the speed of light (or *c*, as physicists abbreviate it). Even if you somehow traveled at 99% of *c*, any light waves you encountered would reach you not at 1% of *c* but at 100%.

For astronomers, even more compelling might be Strassler's investigation into the nature of empty space, which he considers on both the largest scale (the universe) and the smallest (atoms). He asks, "Why is it that we've never been able to detect empty space?" It's not just that we humans can't sense it; no scientific instrument has ever detected a "somethingness," as Strassler puts it, to empty space. It seems like nothingness.

But then, Strassler asks of intergalactic space, how could it expand, as we know it has done vastly since the Big Bang? How could it warp, creating gravity, as Einstein demonstrated it does? How could it ripple with gravitational waves? "It's hard to imagine that nothingness could do these things, which seem more characteristic of materials such as fabric or rubber," he writes.

All of Strassler's explorations into the nature of light and space, along with everything else he explores in this book, lead to his "long-awaited secret" — that we and everything else around us are made from vibrations. He's not clear on whether he's referring here to string theory, a term that appears surprisingly rarely in this book. But he argues that we comprise quanta of waves (the aforementioned wavicles) — mainly electrons and quarks. We aren't made from ingredients that exist *within* the cosmos, he stresses, but from waves *of* it: "We are aspects of the universe, as seismic waves are aspects of rock and as sound waves are aspects of the air."

As a reader, I felt like I was taking a course on basic physics principles and much more from a patient and highly engaging professor. Often I wondered, *Did I actually know that? And if I didn't, why am I only learning it now?* He throws out zingers, such as: "Abandoning space and perhaps even time might someday help us understand why the cosmos is so fantastically, mind-bogglingly odd." *Abandon space and time?*

If you want a mental challenge and, like me, have only a rudimentary understanding of particle physics and how it might relate to us and to the universe as a whole, read this book. You may find it riveting, as I did, and it may well illuminate some of the things you spend so much of your nighttime hours either looking at or through.

■ **PETER TYSON** often reads books rapidly when reviewing them, but not this one — too rich with provocative ideas.

In Search of *the*

HIDDEN IN PLAIN SIGHT Messier 31 is one of the most popular targets for astrophotographers, yet it took a creative approach (and hundreds of hours of exposure time) by European amateurs Yann Sainty, Marcel Drechsler, and Xavier Strottner to reveal a previously unknown nebula residing to its east. Today the object is named for the discoverers with the designation SDSO 1.

NEW

Intrepid amateurs have found hundreds of uncataloged nebulae.
You can get in on the action, too.

Perhaps the biggest dream of most amateur astronomers is to discover something. After all, the sky isn't an unchanging firmament of stars and galaxies: Giant stars live relatively short lives then end their time in spectacular supernova explosions visible far across the universe. Nearby, hundreds of thousands (maybe even millions) of minor planets and comets orbit our Sun. An unknown number of comets regularly drift sunward from the cold outer reaches of the solar system. Being the first to sight a bright one of these and enjoying a lifetime of modest astronomical fame awaits.

These days, robotic sky surveys make the majority (though not all) of these discoveries. But there's one area where amateurs can still make significant finds in the night sky. That region lies between our solar system and the edge of our galaxy, where faint nebulae glow dimly just above the brightness of the background sky.

The Not-So-Unchanging Firmament

Discovering a nebula is significantly different than, say, finding a new comet, because comets — or at least the brighter ones — swoop into the inner solar system then race back out just as quickly, perhaps never to be seen again. For example, Comet C/2020 F3 (NEOWISE), which graced the northern skies throughout most of July 2020, won't return to the inner solar system for 6,800 years. Even short-period comets like Halley are essentially once-in-a-lifetime visitors. By contrast, a nebula remains fixed in its position in the sky and is visible every year, just like the stars. So a century from now an astronomer can sort through lists of objects to study and target your find.

But all the bright nebulae have been found already and are often popular objects for observers and astro imagers alike. Until recently, cataloging fainter, previously unknown clumps of gas and dust was the realm of professional astronomers conducting comprehensive sky surveys. Often the objects they reveal have unfamiliar names like PK 329-02.2 or G70.0-21.5.

Early Finds

That all changed in the mid-2000s as large, sensitive CCD detectors became more affordable and grew in popularity among amateur astrophotographers. Following the lead of pioneer imagers like Rob Gendler, astrophotographers began taking very deep and detailed images of familiar objects, revealing them as never before. And they then began to look closer at what those images revealed.

In January 2004, while comparing his recently processed image of M78 to other amateurs' work, deep-sky imager Jay McNeil noticed "something funky-looking in the field." A stationary, comet-like nebula appeared next to a pair of stars in each of his exposures where no nebula appeared in other contemporary images. This discovery led to the announcement in the *International Astronomical Union Circular* the next month of the object that today is known as **McNeil's Nebula**. It's a variable object similar to NGC 2261, Hubble's Variable Nebula, though McNeil's Nebula seems to have faded in recent years. It was the first amateur nebula discovery in recent memory, perhaps going back to 1939 when the father-and-son team of Harold and Charles Lower discovered their namesake nebula (today designated Sh2-261).

Not long after McNeil's success, an online group formed as a way to keep track of potential amateur discoveries (and to avoid duplicating efforts). Known as the Deep Sky Hunters (**groups.io/g/deepskyhunters**), this community gathered finds of all types: planetary nebulae, supernova remnants, reflection nebulae, dark nebulae, and even asterisms, open

▲ **PEEKABOO NEBULA** While examining his CCD photo of M78 taken with a 3-inch refractor in early 2004, Kentucky amateur Jay McNeil spotted a new feature in the nebula not visible in contemporary images. The nebula has appeared and faded twice since 1966.

MCNEIL'S NEBULA: MASIL IMAGING TEAM

clusters, and uncataloged galaxies. Members began slowly cataloging these finds.

Other nebulae caught the attention of amateurs outside of the Hunters group. In 2008, California amateur David Jurasevich noticed a faint ring in a hydrogen-alpha (Hα) photo he took the previous year while imaging the Crescent Nebula, NGC 6888, in Cygnus. After targeting it again, he reported his find to the International Astronomical Union (IAU). About the same time, amateurs Keith Quattrocchi and Mel Helm noticed the same object and sent their report into the IAU. All three imagers are credited with the discovery of **PN G075.5+01.7**, commonly known as the Soap Bubble Nebula.

The same year, French amateurs formed a group dedicated to the discovery of new planetary nebulae (PNe). The site **planetarynebulae.net** began as a community of French amateurs and later opened up to any observers with PN candidates to report. The group, led by Pascal Le Dû, rigorously follows up on potential discoveries with spectroscopic observations to confirm or disprove each find. However, candidate nebulae confirmed by this group aren't considered official until they are published in the astronomical data center (CDS) of the University of Strasbourg and included in the VizieR catalog at **https://is.gd/VizieR**. To date, the group has amassed 1,202 finds, with 143 officially accepted as PNe.

One member of the French group, Nicholas Outters, was returning to a project he had begun earlier of imaging objects in the Sharpless Catalog using narrowband filters. After targeting Sh2-129 in May 2011, he was amazed to see a large, elongated shape in images taken with a 5-nanometer Astrodon O III filter. This shape was radically different than the nebulae as seen in Hα wavelengths. He began shooting more images with a narrower O III filter in order to better isolate the signal. The object, today well-known to amateurs as the Squid Nebula, bears the official designation **Ou4**.

While these nebulae were found adjacent to (and sometimes overlapping) other well-known and often-imaged objects, they were only noticed by those who looked beyond the beauty of their photos to investigate all the details within the field. Yet, far more treasures await seekers who venture far from the well-trodden path to popular targets.

A Discovery Dynamo

These astronomical hunters slowly accumulated potential finds over the years. In late 2018, astro-imager Marcel Drechsler stumbled upon a faint orange-yellow reflection nebula surrounding variable star BE Camelopardalis while searching for new targets to shoot from his backyard observatory in Bärenstein, Germany. Marcel's intriguing find consumed his attention for the next several weeks, culminating in his drafting a semi-scientific paper describing the object. He named his discovery **Finn's Nebula** as a birthday gift to his nephew.

Though reflection nebulae aren't of much scientific interest, the excitement of tracking down his find and scouring

▼ **DEEP DIVIDENDS** Reddish emission nebula Sharpless 2-129 yielded a surprise when Nicholas Outters targeted the nebula with an ionized oxygen (O III) filter. His bluish discovery, dubbed Ou4, is now a popular challenge for deep-sky imagers.

Amateur Nebula Discoveries

Object	Type	Constellation	Size	RA	Dec.
McNeil's Nebula	Variable Nebula	Orion	1.3′ × 1′	5^h 46.1^m	-0° 06′
PN G075.5+01.7	Planetary Nebula	Cygnus	4′	20^h 15.1^m	+38° 03′
Ou4	Emission Nebula	Cepheus	68′ × 23′	21^h 11.8^m	+59° 59′
Finn's Nebula	Reflection Nebula	Camelopardalis	30′ × 40′	3^h 49.5^m	+65° 39′
Dr1	Planetary Nebula	Puppis	1.8′	7^h 59.5^m	-46° 31′
β Gruis	Emission Nebula	Gruis	38.2′	22^h 42.6^m	-46° 53′
StDr Object 4	Supernova Remnant	Monoceros	25′	6^h 51.7^m	+2° 46′
G107.5-5.2	Supernova Remnant	Cassiopeia	3°	23^h 04.1^m	+54° 32′
YY Hya	Emission Nebula	Hydra	0.5°× 1°	9^h 26.13^m	-22° 23′
SDSO 1	Emission Nebula	Andromeda	1.5°	0^h 47.5^m	+40° 43′

Angular sizes and separations are from recent image measurements. Right ascension and declination are for equinox 2000.0.

SQUID NEBULA: MASIL IMAGING TEAM; SOAP BUBBLE: T. A. RECTOR (U. ALASKA ANCHORAGE) AND H. SCHWEIKER (WIYN / NOIRLAB / NSF / AURA); STDR4: MARKUS BLAUENSTEINER / MARCEL DRECHSLER online sources for information about it changed the course of Drechsler's astronomical pursuits. He began searching out other like-minded amateurs hunting for uncataloged objects to learn their methods and strategies.

Drechsler joined the Deep Sky Hunters, where he met members Matthias Kronberger and Dana Patchick, who have each made major finds. The pair patiently answered all his eager questions. He regularly presented Patchick with lists of dozens of objects that the more experienced hunter would analyze. Patchick taught him the basic techniques Drechsler uses today in his hunts for nebulae, especially PNe and supernova remnants (SNR), as they are of particular interest to astronomers.

Over many months, Drechsler spent hundreds of hours carefully examining images from digital surveys, including the Digitized Sky Survey (**https://is.gd/possII**), Pan-STARRS (**https://is.gd/panSTARRS**), SLOAN (**sdss.org**), and many others, trying to spot previously unnoticed treasures. Finally he spotted an inconspicuous bubble in Puppis. After it was verified, the likely PN **Drechsler 1** (PNG 260.9-08.5) was added to the official Hong Kong/AAO/Strasbourg H-alpha planetary nebula database (HASH) for galactic PNe. It was the first object to officially bear his name.

After just a year of his searching, Drechsler's catalog of nebulae grew to more than a dozen entries, with many other potential finds awaiting confirmation. In 2019, another mem-

INTERSTELLAR BUBBLE Planetary nebula PN G075.5+01.7 in Cygnus was discovered independently by amateurs David Jurasevich, Keith Quattrocchi, and Mel Helm in 2008. The nebula lies less than one degree from the popular Crescent Nebula, NGC 6888, in Cygnus.

▼ **FINN'S NEBULA** *Top:* Discovering this rare orange reflection nebula surrounding the variable star BE Camelopardalis set Marcel Drechsler on a path of discovery that continues to this day.

▼ **DISTANT REMNANT** *Bottom:* After they teamed up, Marcel Dreschler and French imager Xavier Strottner became a power team of discovery, uncovering hundreds of potential finds in a relatively short time. This image shows StDr Object 4, a faint supernova remnant in Monoceros that the duo discovered in 2019.

▲ **BIG SUPERNOVA REMNANT** California amateur Bray Falls, along with Marcel Drechsler, discovered this supernova remnant while examining an image that Falls recorded over a year and a half earlier. The object, now known as G107.5-5.2, lies in Cassiopeia and spans some 3°.

▲ **HIDDEN IN THE GLARE** Some discoveries are found in surprising locations. This strange ultraviolet shell surrounds the star Beta (β) Gruis and evaded detection until recently because of light scatter due to the brightness of its magnitude-1.7 progenitor.

ber of the French group, Xavier Strottner, contacted him. The two quickly joined forces and combined their efforts to become more efficient in their searches. To date, the pair have chalked up no less than 350 scientifically relevant discoveries, with many of their PNe confirmed by independent spectroscopic observations and included in the HASH database.

A Good Strategy

The search for previously undiscovered celestial objects can be an emotional roller coaster. The brain lurches from moments of ecstasy, because you spot an interesting object in survey images, to deep dejection when after days of research your object turns out to be already cataloged.

Although many amateurs hunt for new finds on their own images, others focus their attention on the massive archive of pre-existing survey images available online.

This search for cosmic treasure often consists of examining field after field on a survey website, such as the Digitized Sky Survey, which contains all of the Palomar Observatory Sky Survey I and II plates. When you notice a fuzzy spot or non-stellar object, note its approximate coordinates and begin searching for known objects around its location in the large and small databases. Compared to computers and artificial intelligence, the human brain is still the most effective tool for identifying these subtle patterns.

A few primary resources are the SIMBAD Astronomical Database (**simbad.cds.unistra.fr/simbad**) and the HASH database (**hashpn.space**). SIMBAD is a continually updated database that provides information on known objects and is searchable by identifier or coordinates. It also contains links to the VizieR database.

Don't discount surveys focused on wavelengths beyond the visible spectrum, either. Often objects discovered at radio wavelengths have an optical component, too. Still, hydrogen-alpha surveys tend to bear the most fruit. Based on Drechsler's experience, only one out of every 100 of his potential finds turns out to be new.

If a thorough search of online databases at your suspected find's location comes up empty, you should enlist the help of a fellow hunter or imager who can confirm the discovery. It's only when the candidate object clears this hurdle that you should attempt the next, most important step: submitting your object for publication. The first port of call for previously undiscovered PNe is with Pascal Le Dû at **planetarynebulae.net**. He's responsible for the registration of PN candidates that are transferred to the HASH database.

For every discovery of a new PN, a detailed report is sent to Le Dû. It should include the object's coordinates, at least two independent photographic references, a description of its characteristics, and a brief scientific analysis. For example, is the object most prominent in O III or Hα? What are its angular dimensions?

If you intend on performing a search with your own equipment or do follow-up observations of a potential find yourself, the most effective tools for the task are a sensitive digital camera equipped with a set of narrowband filters. Such filters

SUPERNOVA REMNANT IN CASSIOPEIA: MARCEL DRECHSLER / YANN SAINTY / BRAY FALLS / NICOLAS MARTINO / RICHARD GALLI; BETA GRUIS: MARCEL DRECHSLER

NEW CLASS OF NEBULAE This nebula, called a common-envelope system, surrounds the binary star YY Hydrae. The nebula's discovery was announced in the journal *Astrophysics and Astronomy*. Also seen in the field at left is planetary nebula StDr 47, another discovery by the prolific Strottner-Drechsler team.

highlight ionized gas, making nebulae stand out from the background stars better. Additionally, plan on taking *a lot* of exposures of each target. Undiscovered nebulae tend to be extremely faint, which is often a big part of the reason why they haven't been discovered. This is where amateurs have a leg up over professionals — while the pros must vie for the limited time available on instruments at large observatories, amateurs are hindered only by their night-sky conditions.

Collaborative Effort

As noted earlier, combining your efforts with others in the search for the undiscovered can lead to great results. Having a team in which each member specializes in different aspects of the research can speed up the process greatly, especially if you enlist the help of a professional astronomer who can draft the paper that announces your team's discovery in a peer-reviewed journal.

For example, French astrophotographer Yann Sainty shared some data with Drechsler, who then discovered an exceedingly faint swath of O III next to M31. Drechsler brought the find to the attention of Sainty and Strottner, and the three reached out to astronomer Robert A. Fesen of Dartmouth College, in New Hampshire, who then asked other amateurs (including the author) to target M31 through O III filters to verify or disprove the tenuous nebula. The object was announced in the *Research Notes of the American Astronomical Society* at the start of 2023, with nine amateurs listed as co-authors, and today it bears the designation **SDSO 1**.

▶ **DYNAMIC DUO** Nebula hunters and close friends Xavier Strottner (left) and Marcel Drechsler

MARCEL DRECHSLER (2)

Organizing a large team like this requires assigning specific duties to each participant. One member might organize observations, while another specializes in image processing. Yet another might research the professional literature to ensure the target isn't already known. And still another member might draft the paper to be submitted to a journal.

Understand, though, that verification and acceptance of your nebula is a long process, sometimes taking a year or more. It can be difficult resisting the urge to announce your find prematurely. You also must remain open to questions about your methods and findings. It's a scientific process, so expect frequent setbacks. But when all the steps are completed, you can finally go public with your discovery.

The Galaxy Awaits

Discovering new deep-sky objects is difficult and challenging work but extremely rewarding. It comes with many moments of both intense excitement and stinging disappointment. But your efforts can provide valuable information that helps paint a more complete picture of the universe we live in. And not many things are more satisfying than watching amateurs and professionals alike imaging and studying an object *you* had a hand in finding.

■ Associate Editor **SEAN WALKER** has participated in groups that have discovered several large supernova remnants through his collaboration in the MDW Sky Survey (**mdwskysurvey.org**).

Celestron's StarSense Autoguider

This smart device does much more than simply guide your Celestron telescope.

◀ The StarSense Autoguider is a camera with an on-board computer that does much more than simply guide astrophotos captured using Celestron telescopes and mounts.

StarSense Autoguider

U.S. Price: $799.95

celestron.com

What We Like

Excellent centering of targets

Good guiding performance

What We Don't Like

Only works with newer Celestron mounts

Limited control of guiding parameters

WHEN I HEARD ABOUT Celestron's StarSense Autoguider, I was intrigued. This new device takes the functions of its StarSense AutoAlign accessory and adds the ability to autoguide long-exposure astrophotos, like a small guidescope and camera combination wrapped up in one convenient package.

For years, the StarSense AutoAlign has been a real labor saver for me, performing Go To alignments for my Celestron mounts as well as I can. Autoguiding, however, had been a complex and often frustrating experience for me in the past. The new device promises to simplify the process and make autoguiding automatic, requiring little or no user input.

Compact Package

I was excited when *S&T* contacted me about reviewing the StarSense Autoguider, but first I had to make sure my mount was compatible with it. Celestron's website warned that my mount, an Advanced VX German equatorial with a NexStar hand control, would need the latest firmware to function properly with the updated StarSense. While waiting for the camera to arrive, I performed the firmware upgrade on both the mount and hand control, and thought I was set. Only cloudy skies would prevent me from running the StarSense through its paces, or so I thought.

The camera, which is 17.4 centimeters (7¼ inches) long by 5.3 cm in diameter, is attractive and solidly built. It includes mounting brackets for both Celestron's wide, EdgeHD finder brackets and the older, Synta-standard finder brackets to allow the device to be used in place of the telescope's finderscope. Weighing in at just about 1 kilogram (2 pounds), the StarSense didn't cause balance problems for my mount.

Also in the box was a fairly comprehensive set of instructions and an auxiliary cable for connecting the RJ-11 receptacle on the rear of the StarSense with the mount's auxiliary (Aux) port.

▶ The StarSense includes an RJ-11 cable for connecting the device to Celestron mounts and a mounting bracket to attach the device to EdgeHD optical tubes. Also included is a mounting bracket (seen at left in image) that fits into most universal finder saddles.

The StarSense Autoguider uses the mount's hand paddle.

The device has a 31-mm objective lens with a clear aperture of 28 mm and a focal length of 120 mm, producing a focal ratio of f/5.6 and a wide field of view. The guider's sensor is a Sony IMX290LLR back-illuminated, monochrome CMOS chip with a 2.13-megapixel array of 2.9-micron-square pixels. This isn't much different from the AutoAlign's sensor, but what *is* different is the inclusion of more on-board memory: 4GB of ROM and 512MB of RAM.

Compatiblility

Setting up the autoguider is simple. With the camera mounted to the telescope in place of the finderscope, plug the included cable into the Aux port on the mount and the other end into the Aux port of the camera. There's a USB-C port on the StarSense as well, but it's only used for upgrading the camera's firmware or viewing a live feed of the camera's images on a computer. It can also communicate with your computer via Wi-Fi.

Unfortunately, as soon as I powered on the mount with the StarSense connected, I received "No Response" errors on my NexStar hand control, indicating it couldn't communicate with the mount. When I unplugged the Star-

Sense, the mount operated normally. I checked cables and connections but was unable to resolve the problem, so I contacted Celestron's tech support for help.

Celestron said the problem was simply my old mount. My Advanced VX is one of the first produced more than 10 years ago, and there'd been plenty of hardware and firmware revisions in the interim. The company loaned me an Advanced VX mount of more recent vintage, and as soon as I powered it on with the StarSense connected, everything functioned as it should. So, if you own an older Celestron mount, it would be wise to contact the company before purchasing the StarSense Autoguider to ensure it will indeed work with your equipment.

In addition to performing automatic Go To alignment as well as autoguiding long-exposure images, the new StarSense offers a high-precision pointing mode that uses *plate solving*, in which the camera images a star field and matches star patterns to charts in its on-board memory for high-accuracy pointing. There's also a new and improved polar-alignment routine that also takes advantage of this plate-solving upgrade.

Sensing the Stars

My first night with the StarSense paired with my C8 Schmidt Cassegrain telescope went well. The mount's hand control asked if I wanted to do a polar alignment. I selected ***Yes***, and the controller instructed me to slew the telescope to an unobstructed area of the sky.

After confirming I had performed that step by pressing the ***Enter*** button, the mount began slewing east in increments of 10° until it was pointing about 50° from its original position. When it stopped, the hand control displayed the message "Adjust AZM" for a few moments, then the screen displayed both axes' error numbers and a caret indicating the azimuth error. I began moving the mount's azimuth adjustment knobs slowly. The guider continued to take images and update the error numbers in near real-time. After I got the error value as low as I could, I pressed ***Enter***, and the hand

▲ The rear of the StarSense has two ports: a USB-C receptacle for interfacing with a PC (left) and an RJ-11 port (right) for the auxiliary cable used to connect to your Celestron mount. The device also includes built-in Wi-Fi.

control moved on to altitude, showing the message "Adjust AZ" with the caret now next to the altitude value. Following those adjustments and hitting ***Enter*** when I was ready, I was then offered the opportunity to perform fine adjustments on both axes. The manual advises not to worry about getting under two arcminutes from the pole, since the difficulty of doing so won't produce additional accuracy.

It was a welcome surprise to find that the StarSense Autoguider doesn't need to be aimed in the direction of the celestial pole to achieve polar alignment, which can be a real boon if you don't have a clear view to the north. With the hand controller there's no graphic display to help during adjustment, but I didn't find that to be a problem. It was easy to align by watching the error numbers decrease. The entire procedure took me about 10 minutes.

With polar alignment achieved, the NexStar hand control next prompted me to perform a Go To alignment. The camera took a shot of a star field, plate-solved the image, and moved the mount to three additional positions. If enough stars aren't visible in a field, the StarSense automatically slews to another one. I didn't encounter any problems despite a fat gibbous Moon hanging in the east. The StarSense zipped the mount to four calibration fields, told me it was done, and then asked if I wanted to do a "Center Calibration" to improve its pointing accuracy even more.

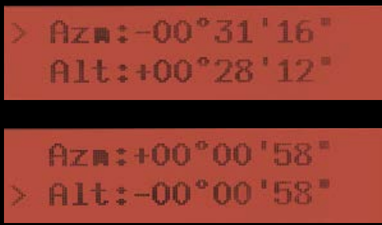
Because this was the first time I'd used the new StarSense, I selected ***Yes***. I was asked to select a star and chose Vega from the device's list of named stars. When the slew stopped, Vega was on the edge of my eyepiece field. I centered it with the paddle's arrow buttons, pressed the ***Enter*** and then ***Align*** buttons on the hand control, and calibration was complete. According to the manual, you should do another Center Calibration if you swap the StarSense Autoguider onto a new telescope tube, even if it's on the same mount.

How accurate is the Go To pointing with the new StarSense? I selected the globular cluster Messier 15, inserted a

▲ The StarSense Autoguider has a 28-mm effective-aperture objective lens with a focal length of 120 millimeters. This produces a plate scale of 4.98 arcseconds per pixel.

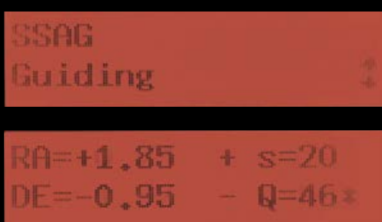
▲ The mounting bracket that comes with the unit replaces the finder bracket on your Celestron SCT or EdgeHD OTA and secures in place with two knurled thumbscrews.

ALL IMAGES COURTESY OF THE AUTHOR



▲ Polar alignment with the StarSense and a Celestron NexStar hand control is an easy process. First, select ***Polar Align*** in the menu. The scope then slews to several locations around the sky (not directly towards the pole) and in a few moments displays how far your alignment is off in azimuth and altitude. As you adjust the azimuth knob on the mount base, the device continues imaging the sky and updating the numbers until you're within 2 arcminutes of the celestial pole. Repeat the process for altitude, then you're done.

▲ After polar alignment is complete, it's time to begin the automatic Go To alignment. All that's necessary is to activate the AutoAlign feature and the Starsense does the rest. After completion, there is an option to further refine its centering of targets.



▲ *Top:* Activating the autoguiding feature in the hand controller simply requires selecting SSAG Guiding and hitting the Enter button. The device automatically chooses multiple guide stars and begins its work without additional user input. *Bottom:* After each guiding exposure, the hand control displays the movement of the guide star measured in arcseconds. The Q value indicates the guiding quality.

13-mm eyepiece in the diagonal, and hit the ***Enter*** button. The slew stopped with the scope pointing in the correct direction. But the hand control indicated we weren't done yet — it was plate-solving to improve accuracy. In 10 seconds, the mount moved slightly a few times, and when it finished, M15 was dead-center at 110×. No doubt I could have inserted a higher-power eyepiece, and the story would have been the same. While I've used plate-solving for polar alignment before, I hadn't used it as a Go To aid. For me, the accuracy was frankly uncanny.

On night two, I planned to test the StarSense with the company's free Windows-only *Celestron PlaneWave Instruments Telescope Control Software* (*CPWI*). This is a full-featured program that displays a planetarium sky chart indicating the telescope's position and interfaces with many of Celestron's accessories, including the StarSense Autoguider.

There were no surprises when I set up the camera to work with the software. With *CPWI* connected to the telescope via a USB-C cable, clicking ***Alignment*** near the top of the screen offered a menu with the choice ***StarSense Alignment***. Selecting that option resulted in the software asking — as the hand control had — whether I wanted to perform a polar alignment. The mount hadn't been moved, but I chose ***Yes*** anyway.

The polar-alignment routine with the *CPWI* software is similar to that with the hand control but with one big difference. Instead of numbers on the hand control's dim red display, I could watch the software's graphic altitude and azimuth indicators showing the current alignment errors.

In every other respect, the *CPWI* program functioned just like the hand control. When I finished the automatic alignment, it enquired as to whether I would like to do a Center Calibration. When using the software, it bypasses the hand control, and calibration values are stored on my computer. Out of curiosity, I selected ***No***. Despite skipping the Center Calibration routine, anything I requested was centered in the eyepiece after each slew was completed.

I wondered, though, what would happen if the plate-solve couldn't be completed satisfactorily due to a passing cloud or some other obstruction? I sent the telescope to Jupiter, which was low in the east and partially obscured by tree branches. When the scope slewed to the planet, it stopped, started its plate-solve, and then *CPWI* reported "Failed to plate-solve for the target." But that wasn't the end of the story. The program then announced it was falling back to the pointing model that the hand control contained. After completing this slew, Jupiter wasn't quite centered but easily in the ½° field with the same good accuracy as the original StarSense.

Autoguiding Performance

Before calling it a night, I wanted to get an idea of how autoguiding worked even though I hadn't attached a camera to the scope. Activating ***Guiding Enabled*** in the software immediately opened a guiding error graph. The plot showed an average error of between 1 and 2 arcseconds on this night of poor seeing, which was consistent with the performance with my own Advanced VX mount under similar seeing conditions. However, what was surprising was that I had simply activated the guiding — the device had already picked a guide star and immediately went to work.

I didn't have to do any of the things typical when starting other autoguiding systems. There were no movement calibrations or any backlash settings to adjust. You can set the guide rate for each axis, though its default settings worked as expected. With *CPWI* you can also have the computer move the scope a small amount between each exposure, a technique known as *dithering* that helps to reduce noise in the stacked result. Dithering is not an option available in the hand controller menus.

The following evening was clear, so I attempted a rather stringent test while imaging through my 8-inch SCT. The seeing hadn't improved since the previous night, so I used a focal reducer to bring the focal length of the scope down to 1,400 mm from its native 2,000 mm. Even so, this meant the device was guiding an instrument with more than 10× its focal length. Getting round stars with such a large image scale and a short, fast guidescope like the StarSense would be a tall order. I slewed over to NGC 884 and NGC 889, the Double Cluster in Perseus, for my test. I began by firing off 2-minute exposures, which would be enough to reveal any guiding problems. I chose to use the *CPWI* software since the graph was much easier to interpret than numbers on the hand control. The error was again around 1 to 2 arcseconds.

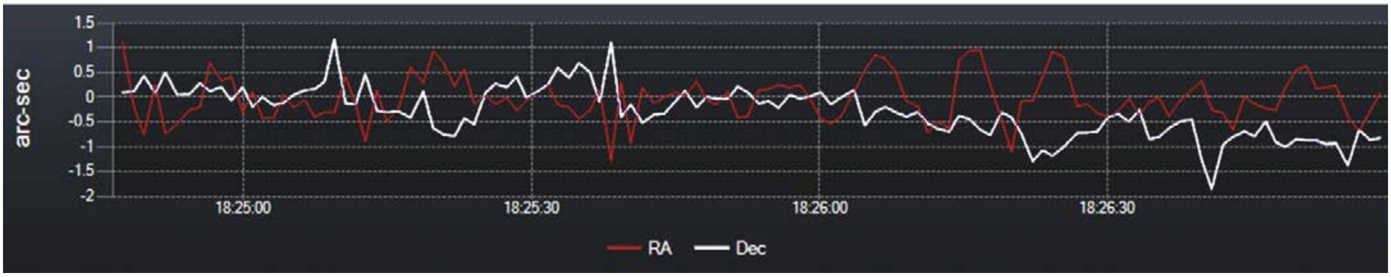
Like most current autoguiders, the StarSense uses multiple stars. One night it indicated it was monitoring 20 stars in the field for guiding corrections!

One thing I really appreciated was how the StarSense put my targets right in the middle of my Canon DSLR's field of view. Absolutely no additional centering was required. So, what were the results of my imaging runs? They were similar to what could be expected with an off-axis guider and more complex guiding software. Most frames were well-tracked.

Summing It Up

The StarSense Autoguider is impressive. It combines highly accurate Go To assistance, alignment aids, and autoguiding in one sleek, compact package. Furthermore, it allows camera-assisted, plate-solving Go To — a process that one might think too difficult or complicated for such a compact device. It did a good job of polar alignment, and it auto-guided my scope as well as any autoguiding systems I've used, but with practically no input at all. Even if you're primarily a visual observer, the device is worth considering because it improves the Go To accuracy of your Celestron mount. Every time this little gadget put objects dead-center in a high-power eyepiece or on my camera's detector, I was amazed all over again.

■ Contributing Editor **ROD MOLLISE** happily dodges clouds and mosquitoes to observe the sky from his backyard along the Gulf of Mexico.



▲ The autoguiding feedback is more informative in Celestron's optional *CPWI* program than when using a NexStar hand paddle. The program displays a continuously updated graph showing the errors in both axes after each correction.

▲ Users can control the StarSense Autoguider with Celestron's free *CPWI* PC software. The polar-alignment routine displays a sky map with a green target showing the precise rotational axis of the mount.

◀ DEEP-SKY CAMERA

Camera manufacturer Player One Astronomy announces a new full-frame camera for deep-sky imaging. The Zeus 455M PRO (IMX455) USB 3.0 Mono Cooled Camera ($3,699) is designed around the Sony IMX455 BSI CMOS Sensor, which has a 9,576 × 6,388 array of 3.76-micron-square pixels measuring 36 × 24 mm. This 61-megapixel, back-illuminated sensor provides native 16-bit A-to-D conversion on chip. The camera uses dual-stage thermoelectric cooling to –35°C as well as proprietary hardware to control dark-current noise. The camera body includes a built-in dew heater around the optical window that prevents condensation. Its 512 megabytes of DDR3 memory allows for stable downloads even when connected to USB 2.0 ports. Each camera comes with an AC power adapter, 2-inch nosepiece adapter, a bulb air blower, and a 2-meter USB-C cable. A one-shot-color version of the camera is also available at the same cost.

Player One Astronomy
168 Yuxin Rd., Bldg. 1, Rm. 522, Suzhou, China 215027
player-one-astronomy.com

◀ SMART SCOPE

Unistellar Optics unveils a new addition to its line of observing stations. The Odyssey ($2,499) is a system that combines an 85-mm f/3.9 reflector with a permanently mounted, color CMOS detector and a powerful alt-azimuth Go To mount controlled by your smartphone or tablet. The system's patented Autonomous Field Detection feature automatically recognizes star fields, self-aligns, and is ready to observe within 10 seconds of powering up. Its track-and-accumulate imaging with automated intelligent image processing produces colorful "live" images of more than 5,000 deep-sky targets from its internal database within minutes of pointing at a subject. Images are recorded to 64 gigabytes of internal storage and sent directly to your smartphone. An internal, rechargeable battery powers the unit for up to 10 hours. The Odyssey weighs 4 kilograms (8.8 lbs) when fully assembled. It is controlled via a free app requiring iOS 12 or Android 6 systems and comes with a collapsible tripod, a charging cable, and a set of adjustment tools.

Unistellar
unistellaroptics.com

◀ STURDY MOUNT

Orion Telescopes & Binoculars adds the EQ-26 to its line of portable equatorial telescope mounts. The Orion EQ-26 Motorized Equatorial Telescope Mount and Tripod ($749.99) is an affordable, no-frills motorized mount designed to hold telescopes weighing as much as 12 kilograms (26 pounds). Each axis is equipped with stepper motors that are controlled by an included hand paddle with several tracking speeds and is capable of slewing rates of up to 800x sidereal rate. The mount's dovetail saddle accepts optical tubes equipped with Vixen-style dovetail mounting bars. Its steel tripod legs extend the saddle height from 91.5 to 124.5 centimeters (36 to 49 inches). A built-in polar finderscope allows for quick and accurate alignment. A pair of 2.6-kilogram counterweights are included with purchase. A DC power cable is provided, though the mount requires an external 12-volt, 5-amp power supply (sold separately).

Orion Telescopes & Binoculars
89 Hangar Way, Watsonville, CA 95076
831-763-7000; telescope.com

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

Make a Little Magic

Catch field-of-view fever with this beautiful binocular scope.

◀ Robert Asumendi's Magic binoculars are compact and versatile, and they will knock your socks off with their wide field of view.

ROBERT ASUMENDI IS arguably the most vocal proponent of binocular astronomy these days. I've written about his 8-inch (200-mm) "Drifter" binoscope (*S&T:* June 2019, p. 74) and his 80-mm "Heart" (*S&T:* Aug. 2022, p. 72), but Robert hasn't been resting on his laurels. For the last couple of years he's been working on yet another design, this one a 50-mm f/3.6 version that he calls "Magic."

You'll notice that the aperture keeps going down. That's contrary to most people's experience when they get into amateur astronomy. The most common affliction among us is "aperture fever," wherein we seek out larger and larger optics, but that comes at a price: The field of view shrinks. Robert went the other way, pushing the limits of how wide he could go with the view rather than with the aperture.

That limit is surprisingly wide. No, it's astonishingly wide. Looking through Magic is like nothing I've experienced before. At its lowest power, with a pair of 36-mm eyepieces, Magic delivers 14° of glorious cosmos. That's enough to see entire constellations at once.

If you do the math, you'll see that the exit pupil with those eyepieces is 10 mm, way bigger than the 7 mm that most people's eyes will accommodate. Are you wasting light? One look through the Magic will show you that you're getting plenty of photons. A 14° field of view is nothing short of spectacular even if you're not using all of the light that enters the objective. As Robert points out, "Using eyepieces with an oversized exit pupil gives you a free pair of 42-mm binoculars, a pair of 35s, 30s, and even 24s inside Magic."

Going the other way, Magic will easily handle 75× if you use high-quality lenses and diagonal mirrors. That's enough to see a ton of detail on the Moon, Saturn's rings, and Jupiter's bands as well as bust open star clusters all the way to their cores.

As with Robert's Heart design, the Magic binos are designed to look downward into, so you can use them comfortably while they're aimed up into the sky. They're great for hand-held exploration, but they can also be tripod mounted, which becomes essential beyond 15× or so.

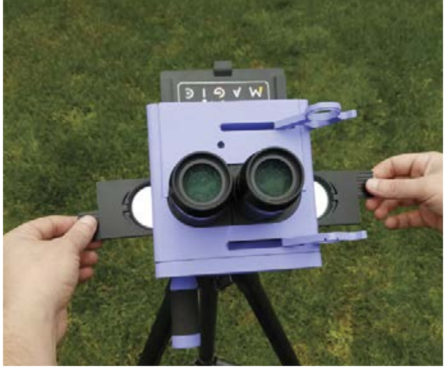
Almost all the components are 3D printed. One advantage of this is the flexibility it allows ATMs to tweak the design to their own liking. Robert has even experimented with longer-focal-ratio objectives, simply extending the body to accommodate the increased light path.

The real attraction, though, in my opinion, is the extra-wide view of the night sky with the short-focal-ratio lenses. I go out observing with Robert fairly often, and night after night he'll call me over to his scope with a "Hey, cool, look at this!" I'll take a peek and see the Double Cluster with the Muscle Man (Stock 2) in the same field, or the entire Cygnus Loop (the Veil Nebula) with room to spare all around it.

The Cygnus Loop in 50-mm binoculars? You'd better believe it. Because Magic can also use regular eyepiece filters in cartridges that slide in directly below the eyepieces. With a pair of O III filters in place, practically every nebula in the sky looks as glorious in Magic as it would in a 10-inch Dob. It's just smaller, which means more context. The Cocoon Nebula (IC 5146) is one of my favorites: You can see not only the emission nebula, but the long trail of dark nebula (Barnard 168) stretching out behind it. The entire thing, with room to spare. I've never

▼ Reverse aperture fever: Robert's 8-inch (200-mm) Drifter, his 80-mm Heart, and his 50-mm Magic binoculars progress smaller in aperture but wider in field of view.

ALL IMAEGS COURTESY OF THE AUTHOR



▲ Filter cartridges slide in below the eyepieces for viewing nebulae.

seen that in my 10-inch scope.

Probably the most sublime view I've seen yet through the Magic was M45, the Pleiades, rising up out of the trees on a ridgeline a mile or so away. With a 14° field of view, we watched for nearly an hour as the cluster drifted slowly free of the trees and climbed, twinkling hypnotically, into the sky. We didn't have to keep nudging the scope along; we just watched in silent awe as the universe put on its show for us.

How to build your own Magic binoculars? Robert has put all the print files and a video series on how to assemble them on his website, **analogsky.co/magic**. He's charging a modest fee for them, but it is indeed modest, and he's also created an online community for Magic builders. There are already over 100 of them, and the number keeps growing — and the builders keep coming up with new innovations every day. There's even a solar-filtered version Robert calls "Sunny," perfect for keeping an eye on our closest star.

■ Contributing Editor **JERRY OLTION** eagerly anticipates nights out with Robert and his Magic binoculars.

▲ The Magic and its accessories, including three sets of eyepieces, all fit comfortably in a modest-sized case.

What Is the Messier Catalog?

IF YOU'VE PERUSED the star chart on pages 42 and 43 of this magazine, you've likely noticed different symbols accompanied by the letter "M" and a number. These denote "Messier" objects, and they're named for the 18th-century French astronomer Charles Messier.

Systematically organizing information is one of the hallmarks of the scientific method, as it provides scientists of all stripes with the framework for understanding how new discoveries fit into the existing body of knowledge. The earliest compilers of knowledge likely were, in fact, astronomers. Several thousand years ago, Babylonian stargazers collated what they knew of the skies in a compendium known as the MUL.APIN. In it, they listed the names and relative positions of stars as well as the appearances and disappearances of the five naked-eye planets.

Sometime in the 2nd century AD, the great Alexandrian polymath Claudius Ptolemaeus, better known as Ptolemy, aggregated seven centuries' worth of Greek astronomy into an opus. The *Almagest* (from the Arabic meaning "the greatest") contains information on more than 1,000 stars' magnitudes and their coordinates.

Today, these works (and others) are largely relegated to the pages of history. However, a catalog that modern astronomers still refer to is Messier's. But who was Messier and what prompted him to compile his famous list?

Messier, Comet Hunter

As a teenager, Charles Messier (who was born on June 26, 1730, in southern France) was one of many to witness the Great Comet of 1744. He was so captivated by the experience that he decided to make comet-hunting his life's pursuit. And so, at the age of 21 he moved to Paris, where he was soon clerking for famed astronomer Joseph-Nicolas Delisle. In the late 1750s, much of the astronomical world was in a tizzy anticipating the predicted return of Halley's Comet. Delisle, in the hopes that Messier would be the first to spot the comet, had calculated and plotted its orbit on star charts for the young comet-hunter.

Messier did indeed recover Halley's Comet — on January 21, 1759 — but he was pipped by German farmer and astronomer Johann Georg Palitzsch, who had sighted it on the night of December 25, 1758. Messier's excitement at having proven that comets could — and did — return in their orbits around the Sun somewhat dampened. Nevertheless, he persisted at his chosen profession, and by the end of his career he'd independently discovered 13 comets and co-discovered many more.

Along the way, Messier realized that in order to hunt comets efficiently, he needed to systematize his efforts.

Messier's Objects

While searching the skies, on the night of August 28, 1758, Messier stumbled upon a smudge near the tip of the southernmost horn of Taurus, the Bull. He initially thought he might have discovered a new comet, but on subsequent nights he noticed that the fuzzy patch hadn't moved against the backdrop of stars, like a comet would. He realized he'd wasted valuable observing time on this stationary impostor — and he set out to rectify his procedures.

In the 18th century, star charts were few and far between and certainly did not have the accuracy of the ones we're used to today. Historic star atlases showed the constellations but generally not the "faint fuzzies" that are the clusters, nebulae, and galaxies that pepper the celestial vault. So as to avoid wasting time and getting fooled again, Messier marked the position of his Taurus smudge on a star chart and started cataloging similar fuzzy patches as he became aware of them — thus ushering in the era of the modern astronomical catalog. That target is known today as Messier 1, or M1, and is the remnant of a star that went supernova in AD 1054. (You might know it as the Crab Nebula.)

In the final version of his catalog, published in 1781, Messier listed 103 objects. Of those, he discovered some 40 himself. He always acknowledged that others, including his colleague Pierre Méchain, had either recorded or found the rest. In the 20th century, several astronomers (including Canadian Helen Sawyer Hogg and historian Owen Gingerich among them) added targets to the catalog that they suspected Messier had identified but that for some reason or another hadn't included in his original list, bringing the tally to 110.

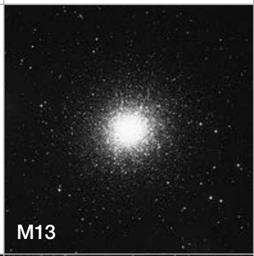
As with all things scientific, working with data can get messy. So, too, it is with Messier's catalog. Some targets in the list weren't what they were originally thought to be, some were misplaced, and others were just confused. Historians of astronomy have devoted much of their time deciphering scrawls in logbooks of yore, unraveling some of the objects' true identities.

Messier's list holds its place in history as the first modern catalog still in regular use today. Amateurs learning their way around the night sky will refer to Messier's opus for guidance. Next time you look at a star chart and see the letter M followed by a number, cast your mind back to the 18th-century French astronomer eager to instill some order and method into the night skies in his quest for new comets. ■

ALL MESSIER OBJECTS: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY; CHARLES MESSIER: ANTOINE ANSIAUX / STOYAN R. ET AL. *ATLAS OF THE MESSIER OBJECTS: HIGHLIGHTS OF THE DEEP SKY* / PUBLIC DOMAIN

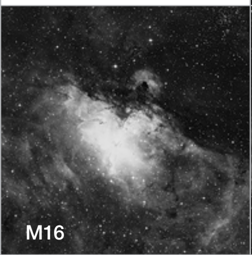

M5


M7


M13

Messier Marathon

From certain latitudes, all 110 Messier objects can be observed in one night during late March or early April (depending on the phase of the Moon). The Messier Marathon, as this is known, is a popular pursuit among amateur astronomers.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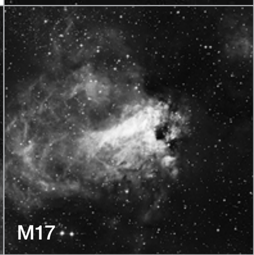
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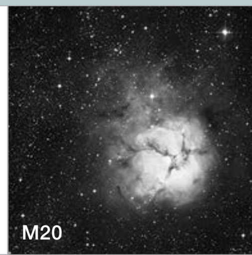
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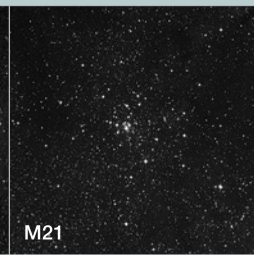
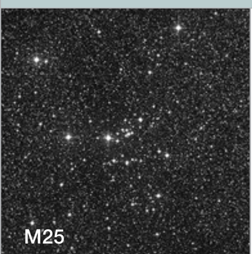
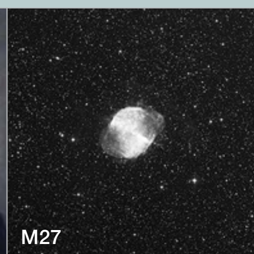
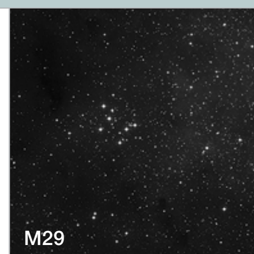

M21

Systematically organizing information is one of the hallmarks of the scientific method . . .


M25


Charles Messier


M27


M29

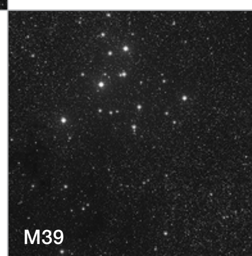
Categories of Messier Objects

Star clusters
Open
Globular

Nebulae
Diffuse
Planetary

Galaxies
Spiral
Elliptical
Irregular

A few Messier objects don't fit neatly into any of the categories noted above, e.g., M40, which is, in fact, a double star.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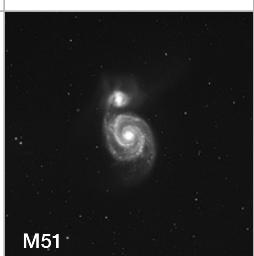
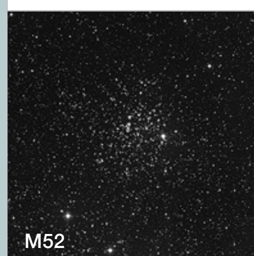
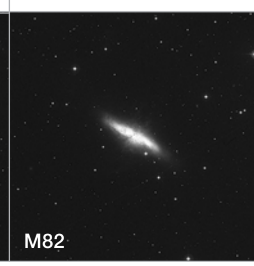

M51


M52


M81


M82

ORION'S DUSTY SHOULDER
Vikas Chander
Barnard 35 was discovered at the end of the 19th century as a dark nebula blocking starlight. These days, sensitive digital detectors reveal that it also contains reddish emission nebulosity and yellowish dust. North is to the left.
DETAILS: *Takahashi Epsilon E-130 astrograph and ZWO ASI6200MM Pro camera. Total exposure: 29½ hours through Hα and RGB filters.*

◁ COLORFUL MOON

Oleg Bouevitch

This enhanced-color image of the full Moon seen last February 24th reveals the subtle hues of various minerals contained within the mare lavas. Reddish-brown areas have a higher iron content than the surrounding regions, while bluish zones are rich in titanium.

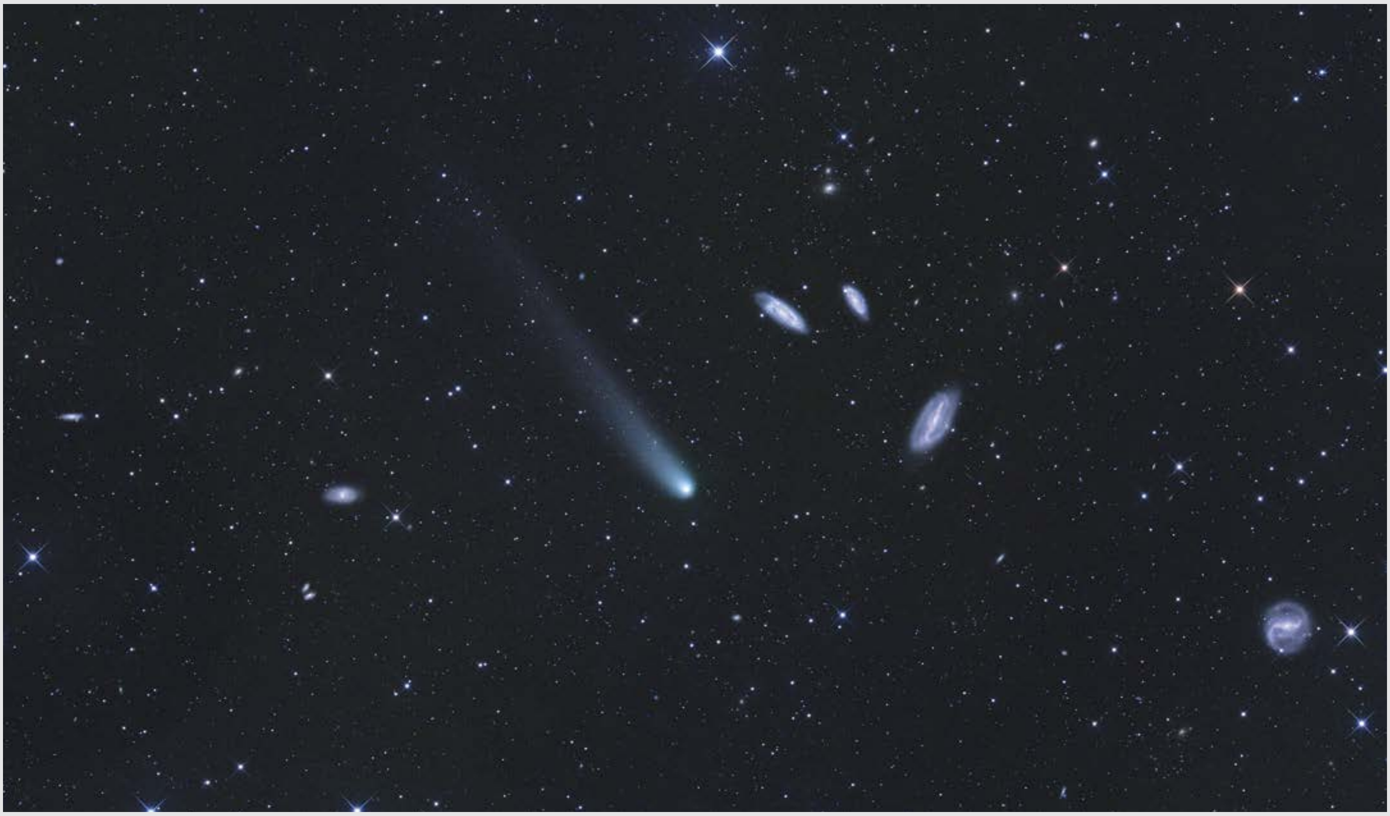
DETAILS: *8-inch Schmidt-Cassegrain and Sony α7 III camera. Stack of 4,300 frames, each 1⁄160 second at f/10, ISO 125.*

▽ GALACTIC QUINTET

Gerald Rhemann

Comet ZTF (C/2020 V2) was captured as it "passed by" the Grus Quartet of galaxies on October 12, 2023. From left to right, the galaxies in the image are PGC 71309, NGC 7632, and the quartet containing NGC 7599, NGC 7590, NGC 7582, and NGC 7552.

DETAILS: *AstroSysteme Austria 12-inch astrograph and ZWO ASI6200MM Pro camera. Total exposure: 1 hour through LRGB filters.*



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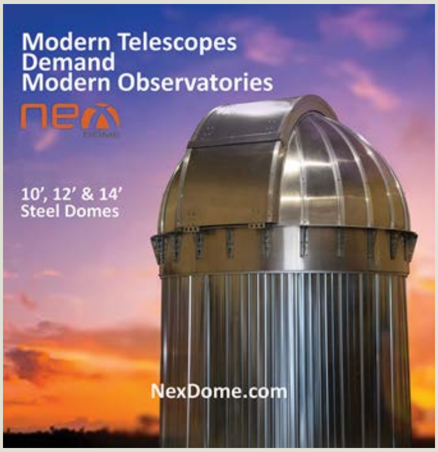
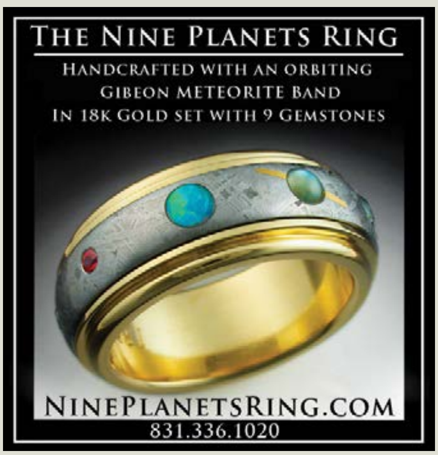


MISCELLANEOUS



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F-Bombs in the Night

A spectacular view of M31 through the author's binoscope gives rise to a big no-no.

THE VIEW THROUGH a telescope can sometimes be so awe-inspiring that it takes your breath away. Other times it evokes spontaneous language your mother wouldn't approve of. I can't remember a star party where someone hasn't said "Holy sh—!" upon seeing Saturn or M13 for the first time. I've said it myself on a number of occasions. People usually apologize for their language, but I smile when I hear it because I know the appreciation is sincere.

There was one time, though . . .

I was at the Oregon Star Party with my freshly built 12.5-inch binocular scope. OSP is a haven of home-built optics, and people love to go around from camp to camp to check out the new scopes in action. My binoscope was a popular item that year, and I had a steady run of people coming by for a look through it. The stereo view of open clusters and nebulae elicited plenty of "Holy sh—"s and F-bombs, along with many softer apologies. After a while, it became kind of a running joke.

At about 2 o'clock in the morning the line finally dwindled, and it was just me and a friend at the scope. I needed a break, so I told my friend to feel free to keep observing — I was going to take a nap. I crawled into my tent, lay back on my sleeping bag, and was just drifting off into the blissful rest of a day well spent when I heard my friend shout, "F-bomb!" (He didn't actually say "F-bomb." He said the real thing. At top volume.)

And again, and again, and again, very loud: "F-bomb! F-bomb! F-bomb!"

I scrambled out of my tent, certain that he had dropped an eyepiece onto one of the primary mirrors or something equally disastrous. By then people in tents around us were shouting as well: "Tone it down!" and "There are children present!"

Rushing up to my friend, I said, "Calm down! Calm down! Whatever happened, it's okay."

"Nothing happened," he replied excitedly. "I just turned the scope to the Andromeda Galaxy with a pair of 9-mm Naglers in the focusers, and *Holy F-bomb*! Have a look for yourself!"

I did, and I sympathized. That was the most glorious view of M31 I have ever seen, to this day. It filled the field of view and then some, with its dark lanes and bright star-forming regions in high contrast. The angled disk looked so three-dimensional I felt as if I could reach out and touch it. I nearly echoed my friend's sentiment at equal volume, but I restrained myself and said instead, "I totally understand how you feel, but you can't shout F-bombs over and over in the middle of the night with 400 people around."

My friend took a deep breath and let it out. "Yeah, you're right," he said. "Sorry." Then, softly, he said, "But *F-bomb*!"

I still regard that as one of the greatest compliments any of my telescopes has ever received.

■ Contributing Editor **JERRY OLTION** thinks "F-ratio" could become a new standard of measuring the impressiveness of a telescope's view.

LEAH TISCIONE / S&T


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