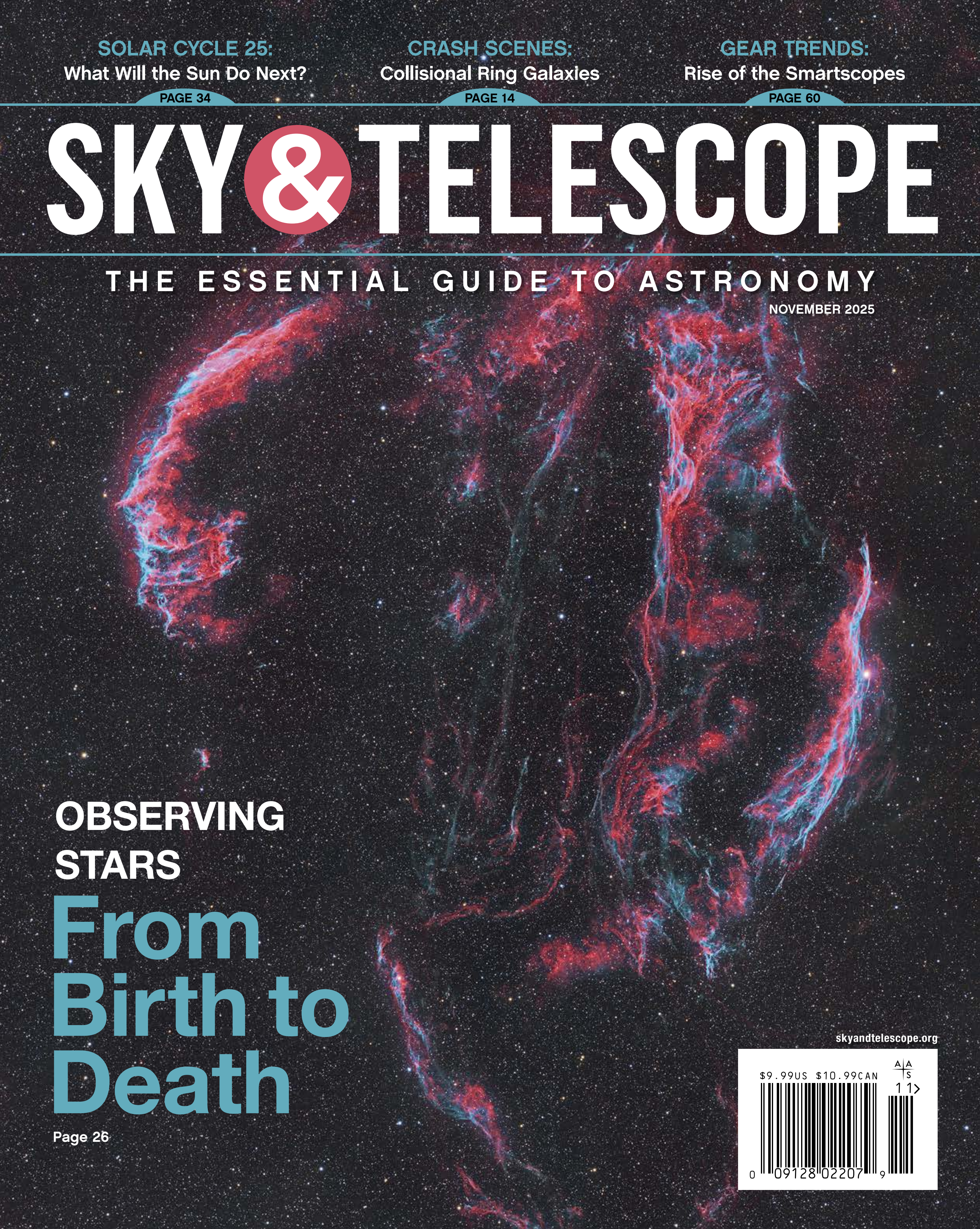

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THE ESSENTIAL GUIDE TO ASTRONOMY
NOVEMBER 2025

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Page 26

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Solar image by Simon Tang using the Heliostar 76H-a.
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The image on the right is the famous Pillars of Creation (M16) taken with the Wide Field Planetary Camera of the Hubble Space Telescope. The image on the left is taken with a QHY600M-PH Camera through a 7-inch refractor from the author's backyard in Buenos Aires. Courtesy Ignacio Diaz Bobillo. To see the original composition, resolution and acquisition details, visit the author's Astrobin gallery at https://www.astrobin.com/users/ignacio_db/

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THE ESSENTIAL GUIDE TO ASTRONOMY

November 2025 VOL. 150, NO. 5

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ON THE COVER

Intricate wisps of the Veil Nebula in Cygnus

PHOTO: RON BRECHER

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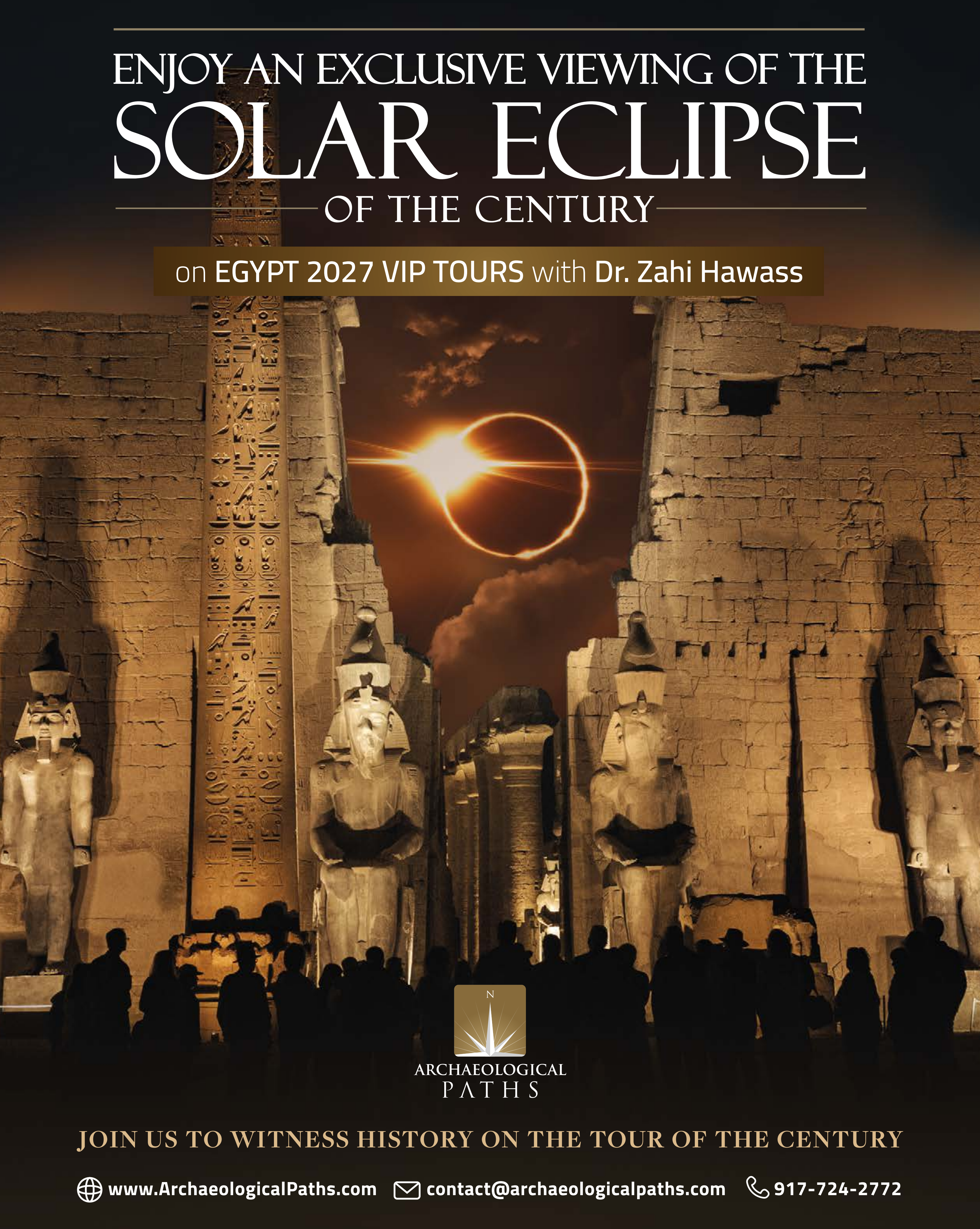
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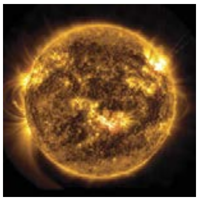
Our Unpredictable Sun

DID YOU WITNESS the aurorae in May 2024 and then again later in October that year? If you live anywhere poleward of latitude 20° and were awake under a clear sky, chances are that you did. The multi-colored spectacle was seen as far south as Hawai‘i and Puerto Rico and, in the Southern Hemisphere, as far north as Queensland in Australia, enchanting millions of viewers who normally don't experience such a show overhead.

The culprit behind this bedazzlement was, of course, the Sun. Our Sun has been doing some zany things during the maximum of its current activity cycle, including pushing the aurora farther equatorward than it usually reaches. As Paul Sutter outlines in his article on page 34, in spite of the Sun's proximity and the wealth of existing data, we still don't have a proper handle on predicting our star's behavior. There may be a few surprises in store yet as the Sun transitions to its quieter phase.



▲ The Sun in X-rays in May 2024

NASA / SDO

Besides spewing stuff out into space and lighting up the skies (to our delight), the Sun cheerfully supplies us with the warmth and light that ensure we have a habitable home planet. But the Sun, a middle-aged star at around 4.6 billion years old, didn't appear out of nowhere fully formed — it, like all stars, was born and will eventually die. Contributing Editor Brian Ventrudo's cover story on page 26 follows the path of a star's life as it's coaxed into life in a molecular cloud, becomes a burning furnace, and ultimately either quietly puffs out as a planetary nebula or self-annihilates in a supernova explosion.

By now, you must've heard of smart telescopes — they've been taking the hobby by storm. They not only appeal to imagers but also serve as excellent outreach tools. (I consider myself a visual observer, but did I ever have fun tinkering around with a smartscope recently!) Don't miss Contributing Editor Richard Wright's excellent write-up on page 60 on the rise of the smartscope as well as his comprehensive roundup of the models currently out there.

I'm just back at my desk after attending the Nebraska Star Party in the stunning Sandhills. Alas, we didn't see many clear nighttime skies. But we did experience several exhilarating lightning shows, a spectacular rainbow, amazing cloud formations, and memorable sunsets. It was a beautiful reminder that, even without snatching star-forming nebulae in our eyepieces, open clusters in our binoculars, or aurorae in our backyards, the sky is always giving us something to contemplate, reminding us of the primeval forces of nature. Let's all keep looking up and rejoicing in what the sky has to offer.

Diana

Editor in Chief

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The Essential Guide to Astronomy

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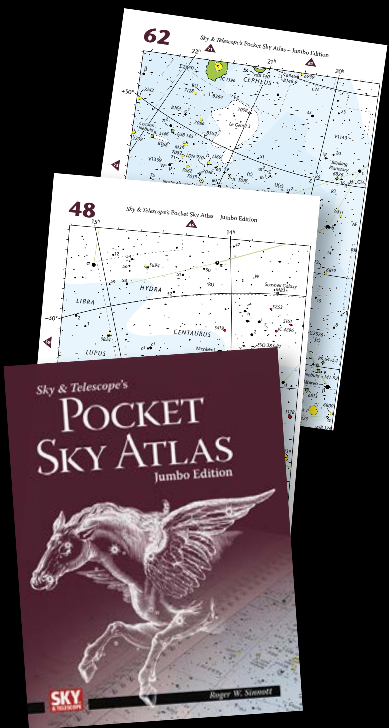

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▲ *Perfect (white) circle Photoshopped over totality, demonstrating the widening of the sun you'll see (without the white circle) on August 12, 2026.*

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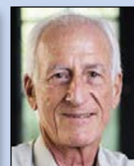
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Galaxies on Parade

I enjoyed Mario Motta's "Viewing Galaxies by the Bunch" (*S&T:* June 2025, p. 62). I'm fascinated with the many opportunities to see galaxy groups and would like to add a couple to the list. These are easily viewed from the Von Braun Astronomical Society site just outside of Huntsville, Alabama, but might not be quite so visible from Motta's observatory in New England: The Hydra Cluster (Abell 1060) at –27° 31′ centered around NGC 3311 and the Antlia Cluster (Abell S636) around NGC 3268 (–35° 19′) both made interesting targets in my ZWO Seestar S50.

Galaxy clusters seem to be great targets for smart telescopes from even moderately dark suburban skies.

Ed Faits
Owens Cross Roads, Alabama

◀ Ed Faits captured this image of NGC 3311 with his ZWO Seestar S50 smartscope.

Fun Little Experiment

Thanks, Bob King and *Sky & Telescope*, for the suggestion to measure shadows at the Moon's farthest south and the Sun's northernmost declinations in "The Moon and Sun Stand Apart" (*S&T:* June 2025, p. 50). I did the math on my 69-inch height and my shadow's lengths of 186 inches at high Moon on June 10–11 and 18 inches at high noon on June 19th. It works out to about a 20° elevation for the Moon and 75° for the Sun.

The *Multiyear Interactive Computer Almanac* by the U.S. Naval Observatory's Astronomical Applications Department calculated elevations of 20° and 72°. I figure the extra 3° for the Sun is from tilting my head down to see my shadow with the Sun nearly above me, thereby distorting my shadow in a way I didn't for the Moon. If I get to do it again, I'll be more scientific and use a stake like Bob King suggested.

That was a fun exercise.

Rick Wiegmann Koshko
Ottawa, Illinois

All the Colors of Aureoles

I enjoyed reading Stephen J. O'Meara's timely descriptions of atmospheric coronas of the Moon and planets in "Aureoles of Planetary Delight" (*S&T:* June 2025, p. 12). Just after sunrise on a cold January 9th, with the Sun just below my neighbor's roof line, I noticed several colored rings close to the Sun matching O'Meara's description of a blue ring on the inside and a red ring on the outside. The image I took with my cell phone (below) also shows many colored rings inside the blue one. Thank you for your enlightened explanation of this beautiful phenomenon.

STEPHEN BALLARON

Stephen Ballaron
Grass Valley, California

Ahead of His Time

In Tom Dobbins's interesting article "Feats of Planetary Observing" (*S&T:* May 2025, p. 52), the discovery of Titan's atmosphere is attributed to Josep Comas i Solà in the early 1900s.

But more than 100 years earlier, in a months-long study of Saturn's satellites, German-born British astronomer William Herschel made some remarkable observations, which he published in the *Philosophical Transactions of the Royal Society of London* for 1790.

On October 16, 1789, he notes, "The colour of the 4th satellite [Titan] is red, or inclining to red."

On December 16–17, 1789, "The 4th satellite, with a power of 500, shews a pretty considerable, visible disk." And in a footnote on that page he continues, "And from its ruddy colour (see Oct. 16) we may surmise it to have a considerable atmosphere."

As in so many fields of astronomical discovery, Herschel once again made an early, very suggestive, observation — though perhaps not sufficient to be actual proof of an atmosphere on Titan. And the fact that he was able to resolve Titan's tiny disk is more evidence of the excellence of both his eyes and his self-made telescope.

Thanks for continuing to include articles that emphasize visual observing!

Jack Koester
Charlottesville, Virginia

Lunar Exploration

Thanks so much for Charles Wood's Exploring the Solar System articles. They're one of my favorite features of the magazine!

Randy Trank
Winnebago, Illinois

Kuiper Belt Kudos

I liked the June issue of *Sky & Telescope*, and I've really enjoyed Emily Lakdawalla's writing. The two came together perfectly in "The Kuiper Belt, Revisited" (*S&T:* June 2025, p. 22).

Her piece is one of the best popular science articles I have read. The piece does more than just hand-wave the details, but not so much more as to baffle. And it was enhanced by all those great illustrations.

Many thanks! More articles like this, please.

Mark Olson
Framingham, Massachusetts

Retrograde Renegades

Thank you for Ken Croswell's "Long-Distance Partners" (*S&T:* June 2025, p. 30). It's great to hear about some of the research from European Space Agency's Gaia spacecraft.

I am, however, a little confused by something in the article: You mention that the binary stars HD 134439 and HD 134440 are located only 96 light-years from Earth and that said binary is a halo object. Wouldn't it be more probable that its retrograde motion is due to passing near a large molecular cloud or other massive body? Or are there other factors to consider that were not mentioned in the article?

Douglas Warshow
Ann Arbor, Michigan

Ken Croswell replies: *Although most halo stars lie above or below the Milky Way's disk, at any time some halo stars are passing through the disk, just as HD 134439 and HD 134440 are currently doing. We know that this binary belongs to the halo not only because of its extreme orbit around the galactic center but also because the binary has another halo hallmark: low metallicity. The binary's iron-to-hydrogen ratio is only 4% of the Sun's.*

In addition, though the gravitational pulls of giant molecular clouds can indeed alter a star's velocity through space, completely reversing a galactic orbit from prograde to retrograde is beyond their ability.

A Simple Setup

I enjoyed reading Sarah Mathews's "Making a Connection" (*S&T:* June 2025, p. 55). I have used afocal projection with my iPhone 13 coupled with a Celestron NexYZ smartphone adapter and Go To telescope to successfully capture hundreds of deep-sky astrophotos since 2022.

While the photos aren't as colorful or detailed as those from higher-end photography systems, I have gotten many images that show details of spiral arms, Markarian's Chain galaxies down to 13th magnitude, and numerous star clusters. I have also used this technique with groups during outreach events.

Bryan Schaaf
Hollister, Missouri

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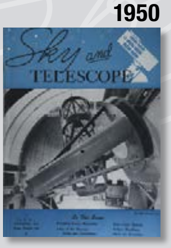
75, 50 & 25 YEARS AGO by Roger W. Sinnott

1950



1975

2000

◖ November 1950

Early Interferometry "In his address as retiring president of the Rittenhouse Astronomical Society, Dr. Raymond H. Wilson, Jr., of Temple University, [told how] last summer, [when] he turned his interferometer on 31 Cygni, the star was shown to be double with a separation of only 0.06 second of arc. This is much too close for the star to be directly observed as a double, even with the largest telescope. Later, Dr. Wilson discovered that the star was already known as a spectroscopic binary: Julie M. Vinter Hansen in 1944 had . . . predicted just about the separation found with the interferometer. This gratifying confirmation suggests that interferometer observations of many a spectroscopic binary may prove fruitful."

◖ November 1975

Observing in Comfort "Imagine living in Vermont and wanting to use your large amateur telescope on a bitterly cold winter night. If you were James Hartness in 1912, the temperature outside would hardly interfere with a long and pleasant evening of observing. This ingenious mechanical engineer could walk over to a central stairwell in his hilltop home, descend underground, and proceed through a 240-foot tunnel to a brow on the southwest edge of his lawn. Here were his subterranean library, a workshop, study, sitting room, and lavatory. . . . Climbing three short flights of stairs, Hartness was inside the heated turret of his fully automated 10-inch f/15 refractor. . . .

"On December 6, 1911, Hartness described his newly completed turret telescope before the American Society of Mechanical Engineers in New York City. . . . Sitting in the audience . . . were Worcester R. Warner and Ambrose Swasey, whose [firm produced mountings for the] Lick and Yerkes refractors. [Swasey noted that other refractors] with a warm observing room used at least one large optical flat to fold the light path. Such flats were always troublesome to manufacture."

Every year, scores of Stellafane conventioneers visit the Hartness House in Springfield to see this remarkable telescope.

◖ November 2000

Mind Boggler "The Voynich Manuscript is a handwritten parchment book that includes many beautiful astronomical diagrams. But the 234-page text, which lacks both a title and an author, was penned with a unique script in a language or cipher that remains unbroken despite vast efforts by the world's greatest codebreakers. . . .

"The manuscript came to light in 1912 when a rare-book dealer named Wilfred Voynich purchased it from a Jesuit school in Frascati, Italy. . . . The Voynich Manuscript definitely originated in Europe during the late Middle Ages, certainly between A.D. 1200 and 1600."

Despite Bradley E. Schaefer's challenge to readers, the text remains an enigma.

BLACK HOLES

A Candidate Direct-Collapse Black Hole in the Infinity Galaxy

RESEARCHERS HAVE DISCOVERED a rare ring-galaxy duo with a supermassive black hole in between them. The black hole might have formed via a process like what may have jump-started the growth of the first supermassive black holes in the universe.

Pieter van Dokkum (Yale) and collaborators found the system while searching for unusual objects in publicly available images of COSMOS-Web, a James Webb Space Telescope (JWST) program designed to capture key aspects of galactic evolution.

The galaxy duo features two bright, compact nuclei and two starry rings, overlapped from our perspective to make a figure eight. To learn more about this strange object, nicknamed the Infinity Galaxy for its shape, the team collected spectroscopy using the Keck I telescope as well as archival data from the Hubble Space Telescope, the Chandra X-ray Observatory, and the Very Large Array. The resulting multiwavelength portrait enabled the team to "weigh" the two galaxies' nuclei, showing them to be massive — containing 80 billion and 180 billion solar masses of stars, respectively. Each nucleus probably contains a supermassive black hole.

▲ A supermassive black hole sits in the green-colored patch of gas between two ring galaxies, dubbed Infinity for their figure-eight shape.

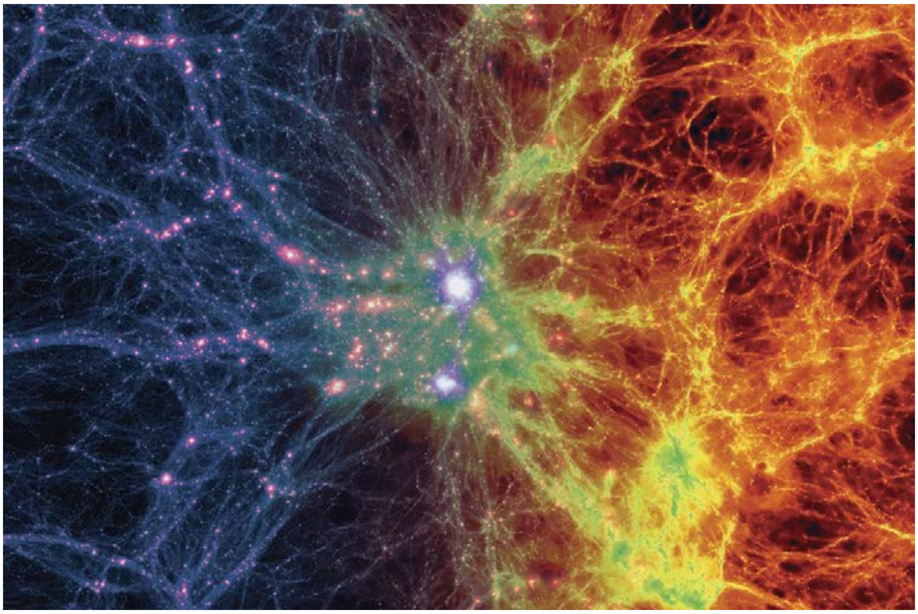
The new data also revealed a cloud of gas lying between the nuclei that contains its own 1-million-solar-mass black hole. Preliminary analysis of follow-up JWST observations shows that the black hole is indeed located in the Infinity system, instead of being a background or foreground object. The team reported the discovery in the July 20th *Astrophysical Journal Letters*.

The Infinity Galaxy appears to be the result of two disk galaxies that shot through each other face-on, forming a pair of collisional ring galaxies (see page 14) that we're seeing from an angle of about 40°. As the galaxies collided, some of their gas tore away, tangling together between the two nuclei. This is where the black hole resides.

But why does that tangle host a black hole? It's possible that it was ejected from one of the galaxies involved in the collision. But the researchers favor a different explanation: The colliding galaxies might have crushed a gas cloud between them so forcefully that some of the gas collapsed directly into a black hole. If the collision happened 50 million years ago, as the observations suggest, it could have created a 300,000-solar-mass black hole that subsequently grew to its current mass.

Astronomers have proposed direct collapse as a source of the seeds of supermassive black holes in the early universe (*S&T:* Jan. 2017, p. 24) and have even found a candidate (*S&T:* Jan. 2024, p. 8). However, that process and the one that might have happened in the Infinity Galaxy (when the universe was already 5 billion years old) are slightly different.

■ KERRY HENSLEY / AAS NOVA



◀ This image of the cosmic web comes from the Illustris simulation of galaxy formation.

COSMOLOGY

Filaments and Fast Radio Bursts: Mapping the Cosmic Web

WE CAN'T SEE MOST of the universe. Not only do dark matter and dark energy remain largely invisible, most "normal" particles (or *baryons*) evade detection, too.

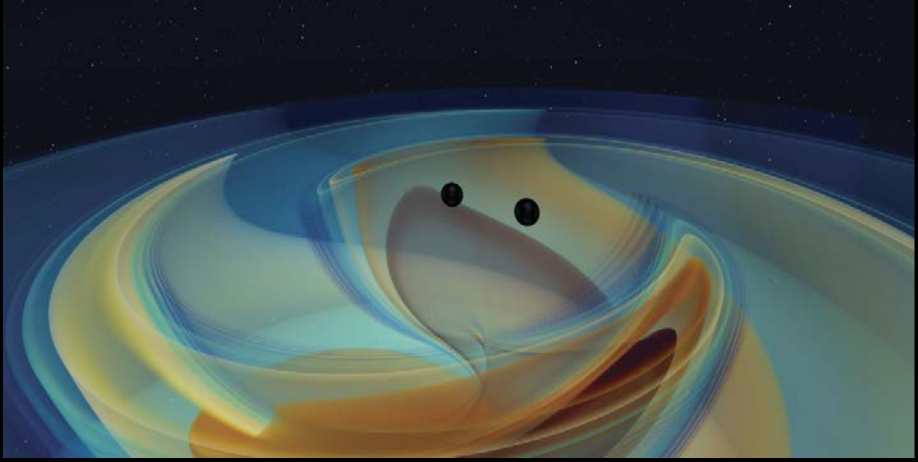
Now, two teams with opposite approaches have found that the vast majority of ordinary matter prefers to take up residence in the lonelier parts of the *cosmic web*, the latticework of filaments that crisscross the universe.

One of these filaments is a thick,

INFINITY GALAXY IMAGE: NASA / ESA / CSA / STSCI / PIETER VAN DOKKUM (YALE); COSMIC WEB SIMULATION: ESA

BLACK HOLES

New Black Hole Merger Breaks Record



▲ This image is a still from a video of a computer simulation of a heavy-black-hole merger similar to GW231123. As the black holes (black shapes) spiral together and merge, they emit gravitational waves, shown here in color.

GRAVITATIONAL-WAVE ASTRONOMERS have detected the collision of two beefy black holes, which created the most massive merger-made black hole found thus far.

The event, GW231123, rippled through the two detectors of the Laser Interferometer Gravitational-Wave Observatory (LIGO) on November 23, 2023, during the first part of the facility's fourth observing run. The signal was brief but loud, the cosmic equivalent of a thunderclap.

The event peaked around 60 Hz, near the lower end of LIGO's reach. Lower frequencies correspond to higher masses — in this case, between 120 and 159 Suns for the larger black hole and 51 to 123 Suns for the smaller one. (The favored values are 137 and 103, respectively.) They joined to make a black hole of approximately 225 solar masses.

The merging black holes appear to have been spinning rapidly, too, at roughly 90% and 80% of their maximum velocities, respectively. Researchers presented these results at a gravity conference in Glasgow, Scotland.

Although the templates scientists use to interpret gravitational waves' wiggles are reliable for events involving high masses, they struggle with high spins, says team member Sophie Bini (Caltech). The signal's short duration doesn't help, either. There's thus lots of uncertainty in this smashup's details.

Nevertheless, the estimated masses are eye-catching. Due to the vagaries of massive stars' final moments, supernovae shouldn't be able to make black holes with masses from about 60 to 130 Suns (*S&T:* June 2022, p. 12).

The spins, too, attract notice. Most merging black holes that LIGO has detected so far have had negligible spins, consistent with expectations for objects made by exploding stars. But when colliding black holes are themselves made by mergers, their spins should cluster at around 70% of their maximum velocity. Given the uncertainty ranges in the measurements, the spins of both of GW231123's black holes overlap with this benchmark, leaving open the possibility that they became so massive because they're the offspring of previous collisions.

The same goes for the previous mass record-holder, GW190521, which produced a black hole of roughly 140 Suns (*S&T:* Jan. 2021, p. 13). Astronomers will need more events like these in order to have a better handle on how such objects might form.

■ CAMILLE M. CARLISLE

23-million-light-years-long thread connecting two pairs of galaxy clusters in Centaurus. Astronomers didn't know it was there until Konstantinos Migkas (Leiden University, The Netherlands) and colleagues collected archival observations from the Japanese Suzaku satellite to reveal its X-ray glow, published in the May *Astronomy & Astrophysics*.

While the filament's hot gas emits low-energy X-rays, the emission is faint when spread out over millions of light-years. Previous attempts at measuring filaments' properties have found densities several times higher than expected.

This time, in addition to gathering images of the filament itself, Migkas's team also employed sharper images from the European XMM-Newton observatory to identify and remove other X-ray sources, such as supermassive black holes.

The researchers find that, compared to simulations, the filament is both as hot, at around 10 million degrees, and as sparse — with a density of 10^{-5} particle per cubic centimeter — as expected. "Obtaining the first result that matches the cosmological model perfectly was indeed a surprise," Migkas says.

Most filaments aren't so amenable to direct imaging, but *fast radio bursts* (FRBs) provide another way to map the cosmic web. These quick flashes of radio waves encode information about the matter between the burst and Earth.

Using 39 FRBs detected with the Deep Synoptic Array-110 in California, Liam Connor (Center for Astrophysics, Harvard & Smithsonian) and colleagues mapped matter out to when our universe was less than half its current age, publishing the results on June 16th in *Nature Astronomy*. If that matter were mostly locked away in galaxies and galaxy clusters, our universe would be rather lumpy. But Connor's team found a much smoother spread: Less than 15% of normal matter is in stars and galactic gas, meaning that three-quarters of baryons aren't in galaxies — they're between them.

The two results, Migkas and Connor agree, are exactly complementary, shedding new light on the nearly invisible filaments of the cosmic web.

■ MONICA YOUNG

N. FISCHER / H. PFEIFFER / A. BUONANNO (MAX PLANCK INSTITUTE FOR GRAVITATIONAL PHYSICS) / SIMULATING EXTREME SPACETIMES (SXS) COLLABORATION

◀ This frame capture shows the daylight fireball that blazed over the southeastern U.S. on June 26th.

ASTRONOMY & SOCIETY

Exploding Fireball Drops Meteorites Over Georgia

ON JUNE 26TH, a spectacular daytime fireball flared over the southeastern U.S. before disintegrating in a thunderous explosion southeast of Atlanta. The American Meteor Society (AMS) received more than 200 reports of the brilliant, midday object.

"Many instruments recorded the fall, including National Oceanic and Atmospheric Administration satellites and Doppler radars," says Mike Hankey, AMS Operations Manager.

Bill Cooke, lead of NASA's Meteoroid Environment Office, said in a statement that the fireball — which was about 1 meter (3 feet) wide and weighed more than a ton — was going 48,000 km/h (30,000 mph) when first spotted. It broke up at an altitude of 33 km (20 miles) above West Forest, Georgia. According to calculations done by the Center for Near-Earth Object Studies, the object struck the atmosphere with a total impact energy of nearly half a kiloton of TNT.

Rapid atmospheric entry shattered the meteoroid, which created a shock wave that rattled windows and produced loud booms. Some observers thought it was an earthquake.

Not long after the sonic boom, someone in McDonough, Georgia (about 50 km south of Atlanta), reported that a golf-ball-size rock had punched a hole in their roof, penetrated the ceiling, and slammed into the floor. Fortunately, no one was hurt.

Meteorite hunters soon arrived in the area looking for newly fallen meteorites, recognizable by the fresh, black *fusion crust*, a layer up to a couple millimeters thick that forms around fragments during their brief, hot flight through the atmosphere. As of press time, the incoming object appears to have been an L chondrite (a common type of stony meteorite), but is not yet officially classified.

Nearly 50 tons of meteoritic material hits Earth's atmosphere every day, mostly in the form of dust. Pieces big enough to survive and strike the ground as meteorites are rare. Rarer yet is seeing one fall and being able to pick up the pieces.

■ BOB KING

See more images and videos at skyandtelescope.org/Georgiafireball.

SPACE & SOCIETY

Proposed NOAA Budget Kills Program Designed to Prevent Satellite Collisions

TRUMP'S FIRST administration helped establish the Traffic Coordination System for Space (TRACSS), our nation's space-traffic control. Now, his second administration's proposed budget for the National Oceanic and Atmospheric Administration (NOAA) aims to dismantle the program.

The proposal "sets [the U.S.] back by decades" says aerospace engineer Moriba Jah (University of Texas, Austin), who has thrice testified to Congress on space-traffic management. "It's stupid."

TRACSS provides free space situational-awareness data (i.e., the trajectories and environments of orbiting space objects) to both civil and commercial satellite operators. Prior to TRACSS, collision-preventing data were handled by the Department of Defense (DOD). But as the number of satellites rose (from less than 5,000 in 2018 to more than 12,000 today), the burden of managing them has become overwhelming for the department.

Clayton Swope (Center for Strategic and International Studies), deputy director of the Aerospace Security Project, says that unlike a patchwork of independent space situational-awareness companies, the government can enforce a single standard for tracking data. He likens it to the Federal Aviation Administration, which provides standardized information to avoid confusion — and collisions.

But that fragmented scenario is what the proposed NOAA budget would replace TraCSS with.

On July 7th, 450 U.S.-based space companies wrote a joint letter to the Senate asking for continued funding to the NOAA office that supports TRACSS. One reason for the letter, Swope says, is that even if industry players fulfill some of TRACSS's duties, they largely won't be able to operate internationally.

The infrastructure problems that led the first Trump administration to jumpstart TRACSS remain, says Audrey Schaffer, vice president of strategy and policy at Slingshot Aerospace, adding that the DOD data will be "increasingly insufficient to meet today's traffic coordination needs."

As with the NASA and NSF budgets, TRACSS's fate is still subject to budget negotiations, which are ongoing at press time. If the proposed budget stands, Schaffer says, "we will see, frankly, a more dangerous space environment."

■ HANNAH RICHTER

Third Interstellar Object Found

The interstellar comet 3I/ATLAS is sailing through the solar system on a brief jaunt, passing within 1.8 astronomical units of Earth on December 19th. Read more on the discovery and how to see it on page 48, and find the latest images and information online at **skyandtelescope.org/3IATLAS**.

■ BOB KING

ED ALBIN / ALLSKY7 GLOBAL NETWORK / DEERLICK ASTRONOMY VILLAGE

MILKY WAY

Giant Gas Cloud Discovered 300 Light-Years from Earth

YOU WOULDN'T KNOW IT by looking, but Corona Borealis, the Northern Crown, is home to a crescent-shaped cloud of hydrogen molecules that spans some 40 Moons in apparent diameter.

The cloud, nicknamed Eos, is more than 100 light-years wide and contains 5,500 solar masses of cold gas, mostly molecular hydrogen (H_2). The densest such *molecular clouds* are the birthplaces of stars and planets. With its nearside located just 300 light-years from the solar system, Eos is the closest molecular cloud to us.

Blakesley Burkhart (Rutgers University) and colleagues published their discovery on April 28th in *Nature Astronomy*. On June 27th, coauthor Thomas Haworth (Queen Mary University of London) presented the result as well as a new analysis at the meeting of the European Astronomical Society (EAS) in Cork, Ireland.

Because the hydrogen gas in molecular clouds is notoriously difficult to detect, astronomers often use the second-most abundant molecule, carbon monoxide, as a tracer. These molecules emit radiation at radio wavelengths.

The Eos cloud evaded detection for so long because it contains hardly any carbon monoxide. But hydrogen does emit some radiation at more energetic wavelengths, thanks to a process called *fluorescence*. In this process, "excited" electrons in hydrogen molecules come back down closer to the nucleus, emitting far-ultraviolet wavelengths. Looking for that signal, the team discovered the cloud in data from the Korean Science and Technology Satellite 1, which became publicly available in 2023. Subsequent studies revealed the cloud's distance and mass.

▲ Artist's conception of what the Eos molecular cloud would look like in the sky if it were visible to the naked eye.

"It was rather unexpected that a molecular cloud so close to the Sun could have been completely missed," says Haworth.

Many molecular clouds (like the one in Orion, for instance) spawn new stars, but Eos appears to be too warm to gravitationally collapse into star-forming clumps. At the EAS meeting, Haworth presented analysis of data from the Gaia mission, to be published in *Monthly Notices of the Royal Astronomical Society*, showing that no stars have formed in this part of the sky over the past tens of millions of years.

Nor is any future star formation in Eos likely. Within 6 million years or so, X-rays from the nearby hot plume of gas known as the North Polar Spur will disperse the cloud.

■ GOVERT SCHILLING

NATURELIFEPHOTO / FLICKR (NEW YORK CITY SKYLINE) / BURKHART ET AL. 2025

IN BRIEF

What Causes Light Pollution?

With the help of citizen scientists, a research group led by Christopher Kyba (Ruhr University Bochum, Germany) has found out what causes most light pollution — and it's not what you might think. Public streetlights, which have been the focus of light-pollution policies, make up 10–20% of contaminating light sources in the areas studied in Germany. But the vast majority of artificial-light sources are largely unregulated private and commercial windows and signs. To compare contributions, the team designed an app called *Nachtlichter* ("night lights" in German), which about 250 citizen scientists used to count and classify light sources. The scientists then compared those measurements to satellite imagery. The result explains a long-puzzling discrepancy between satellite images and perceived skyglow: Satellite images, often taken around local midnight, miss a lot of private and commercial lighting that's present during evening hours. The result may also help explain why conversion of public lighting to LED has failed to decrease skyglow — any improvement may have been overwhelmed by a simultaneous increase in other light sources.

■ JAN HATTENBACH

Webb Telescope's First Exoplanet Find

Astronomers using the James Webb Space Telescope have directly imaged what appears to be a Saturn-mass exoplanet 52 astronomical units from its star. If confirmed, the find marks Webb's first direct detection of an exoplanet and the lowest-mass planet ever discovered in this way. The candidate, TWA 7b, orbits a young red dwarf star around 111 light-years away in Antlia, the Air Pump. At just 6.4 million years old, the star is still encircled by a *debris disk*, a remnant of its formation. A team led by Anne-Marie Lagrange (Paris Observatory) detected a mid-infrared source nestled within one of three concentric dust rings. (Ground-based telescopes had previously seen the rings.) The team concludes in the June 26th *Nature* that the object is likely local to the TWA 7 system. "Our observations reveal a strong candidate for a planet shaping the structure of the TWA 7 debris disk, and its position is exactly where we expected to find a planet of this mass," Lagrange says.

■ COLIN STUART

A Challenging Polar Wonder

A visual enigma awaits your gaze less than 1° from the north celestial pole.

AT THE 2025 Texas Star Party, held at the Prude Guest Ranch near Fort Davis last April, veteran deep-sky observer Larry Mitchell of Houston handed out his annual Advanced Observing Program to interested attendees. Of the 40 targets on that list, there was one prize I had long wanted to nab: NGC 3172, the "nebula" John Herschel discovered in 1831. It sits only 4.5′ from the *north celestial pole*, the imaginary point on the sky where Earth's projected geographic north pole intersects the celestial sphere (*S&T:* Dec. 2024, p. 26).

Precession has since moved this object, which we now know is a galaxy, to less than 1° away from the celestial pole. Nevertheless, it remains the closest NGC object to it. In honor of its location, Herschel called NGC 3172 Polarissima, only to rename it Polarissima Borealis after he discovered NGC 2573 near the south celestial pole, which became his Polarissima Australis. Long a visual challenge, Polarissima Borealis is one of the night sky's more enigmatic sights, having been seen by some observers using moderately small telescopes while evading detection by others with larger ones.

Many years ago, I joined a group of observers at a star party that was tackling this polar wonder through large Dobsonian telescopes of varying sizes without success. There was a good reason why no one saw it — they had confused Polarissima with the Ursa Minor Dwarf Galaxy. The observers were looking at the position of Polarissima but searching for an 11th-magnitude diffuse glow some 40′ in apparent diameter.

Polarissima is not a dwarf galaxy, nor is it large or bright. It's a face-on lenticular galaxy about 1′ in angular extent. The object is often listed at magnitude 14.9, but that's its blue photographic magnitude. Skilled observers have estimated Polarissima's visual brightness to be in the range of magnitude 13.5 to 14.0. And while the galaxy spans about 85,000 light-years — making it about 40% larger than M33, the Triangulum Galaxy, which is the third-largest member in our Local Group — Polarissima's distance of about 285 million light-years greatly diminishes our view of it.

In his 1864 *General Catalogue of Nebulae and Clusters of Stars*, Herschel describes Polarissima seen through his 18¼-inch reflector as being "very faint, round, and gradually brighter in the middle." However, as John's father, William, wrote, "When an object is once discovered by a superior power, an inferior one will suffice to see it afterwards." Indeed, some modern observers have reported seeing Polarissima through telescope apertures as small as 4 to 6 inches, while others have found it extremely faint, or very faint, through much larger instruments.

At the Texas Star Party, I got to view Polarissima through Larry's 20-inch f/5 Dobsonian, though it turned out to be quite a challenge, requiring averted vision to see it well. With extended time spent behind the eyepiece, though, the galaxy appeared as a pale circular glow, like an orb of mystical moistness in the night air, to paraphrase 19th-century American poet Walt Whitman in his poem, *The Nighttime Sky*. As John Herschel noted, the glow gradually brightens toward the center, but that wasn't immediately apparent. I would side with those observers who estimated Polarissima at 14th magnitude. Dimness aside, this was my first view of the galaxy, and it filled me with wonder and awe.

▲ **THE NORTHERNMOST NGC OBJECT** Try to find the galaxy Polarissima Borealis (NGC 3172), shown here at the center. Look for it in Ursa Minor at right ascension $11^h\ 47.2^m$, declination +89° 06′. Note the two galaxies — PGC 36268 and USNOA2 1725-00420364 — near Polarissima. North is up, and the field is about 12′ wide.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

I believe Polarissima will always be a challenge. I suspect that like other dim denizens of the deep sky, its visual appearance varies nightly, being greatly affected by differences in sky brightness, magnification, and atmospheric clarity. Depending on the aperture you use, expect the galaxy to appear anywhere from about 0.5′ to about 1′ across. Magnifications between 150× and 250× may be best. The galaxy is only about 1° east-northeast from the 7th-magnitude star HD 66368, and only about 10′ from the 9.5-magnitude star HIP 56124.

Good luck!

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

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Galaxies adorn the universe the way flowers decorate a vast garden. The brightest galaxies fall into two main classes. The more beautiful are the spirals, such as the Milky Way and the Andromeda Galaxy, which possess gas and dust that create new stars. In contrast, the less photogenic ellipticals have largely run out of gas and no longer produce stars. Most stars, including the Sun, reside in giant spirals or giant ellipticals.

But rare *collisional ring galaxies* don't conform to the standards set by their galactic peers. These exotic galaxies are stunning circlets of starlight that can rival the size of a giant spiral's entire stellar disk. Freshly formed stars and star clusters sparked by a cosmic crash color the celestial wreath blue and set its interstellar gas aglow.

So rare are ring galaxies that the closest one lies 30 million light-years away, a dozen times farther than the closest spiral. Furthermore, we must look across 430 million light-years of space to see the most famous example, which maverick astronomer Fritz Zwicky discovered around 1940: the Cartwheel Galaxy in the southern constellation Sculptor.

A Smashing Success

In 1974, Alar Toomre (MIT) hit upon how these ring galaxies arise: A small, compact galaxy smashes head-on into a spiral galaxy's disk, near its center. "It suddenly occurred to me one day, 'My gosh! We just go right through and pull inwards,'" says Toomre, who with his brother, Juri, had earlier explained several galactic collisions. "It's almost embarrassingly simple."

Other astronomers had already found that ring galaxies usually have small companions near them. John Theys, who had earned his doctorate at Columbia University the year before, even noted that these companions often lie along the ring galaxy's rotation axis — as they should, if they had just plunged through the spiral's central region.

Toomre's simulations of the collision showed what happens: When the small companion darts through, its gravity first attracts the spiral's stars and gas toward itself — and thus toward the spiral galaxy's center. But then the intruder flees, and so does its gravitational pull. The orbiting stars and gas in the target galaxy therefore rebound outward for a while, bunching up in an expanding ring that consists of different stars at different times. In this ring, gas clouds smack together, triggering star birth. As a result, a ring of intense star formation propagates outward through the galaxy's disk.

Meanwhile, the innermost stars and gas have fallen inward and are now moving outward again, traveling along the elliptical orbits they acquired from the intruder's brief gravitational pull. They meet infalling stars and gas slightly farther out. The resulting pileup can create a second expanding ring, inside the first one.

This succession of expanding rings is a bit like the water waves that occur after a stone hits a still pond. But Toomre says that this frequently used analogy is misleading. In a galaxy collision, he says, "if you go through twice as fast, you have half the effect," because the gravitational influence of the intruder galaxy lasts half as long. In contrast, throw a stone into a pond twice as fast and you create a greater disturbance. That's because the physics is different: In a galaxy collision, the intruder's gravity pulls stars and gas inward, whereas a stone striking a pond pushes water away.

"Alar Toomre's simulations were spot-on and predicted the shapes and the forms of both the expansion and the rotation of the rings," says Barry Madore (Carnegie Observatories). Madore also began studying ring galaxies in the 1970s, but as an observer rather than as a theorist.

The need for a modest collision speed is one reason you won't find ring galaxies in galaxy clusters, where galaxies usually move too fast to form rings (*S&T:* Jan. 2025, p. 12). Moreover, even if a ring galaxy were to arise there, collisions with other galaxies would soon destroy it.

Instead, ring galaxies inhabit quieter environments, either in groups akin to our Local Group or out in the field all by themselves, save for the intruder that's slinking away from the scene of the crime.

The expanding ring fades when it no longer encounters new gas to compress and shape into stars. Ring galaxies are therefore rare because they don't last long: The typical ring

NASA / ESA / HUBBLE HERITAGE TEAM (AURA / STSCI); ACKNOWLEDGMENT: J. HIGDON (CORNELL U.) AND I. JORDAN (STSCI)

galaxy shines for roughly 100 million years — about 1% the age of the universe. In the 1970s, few were known.

But that would change.

Lords of the Rings

While at the University of Cambridge, Madore examined photographic plates of the southern sky taken with the 48-inch UK Schmidt Telescope in Australia. He worked with American astronomer Halton Arp.

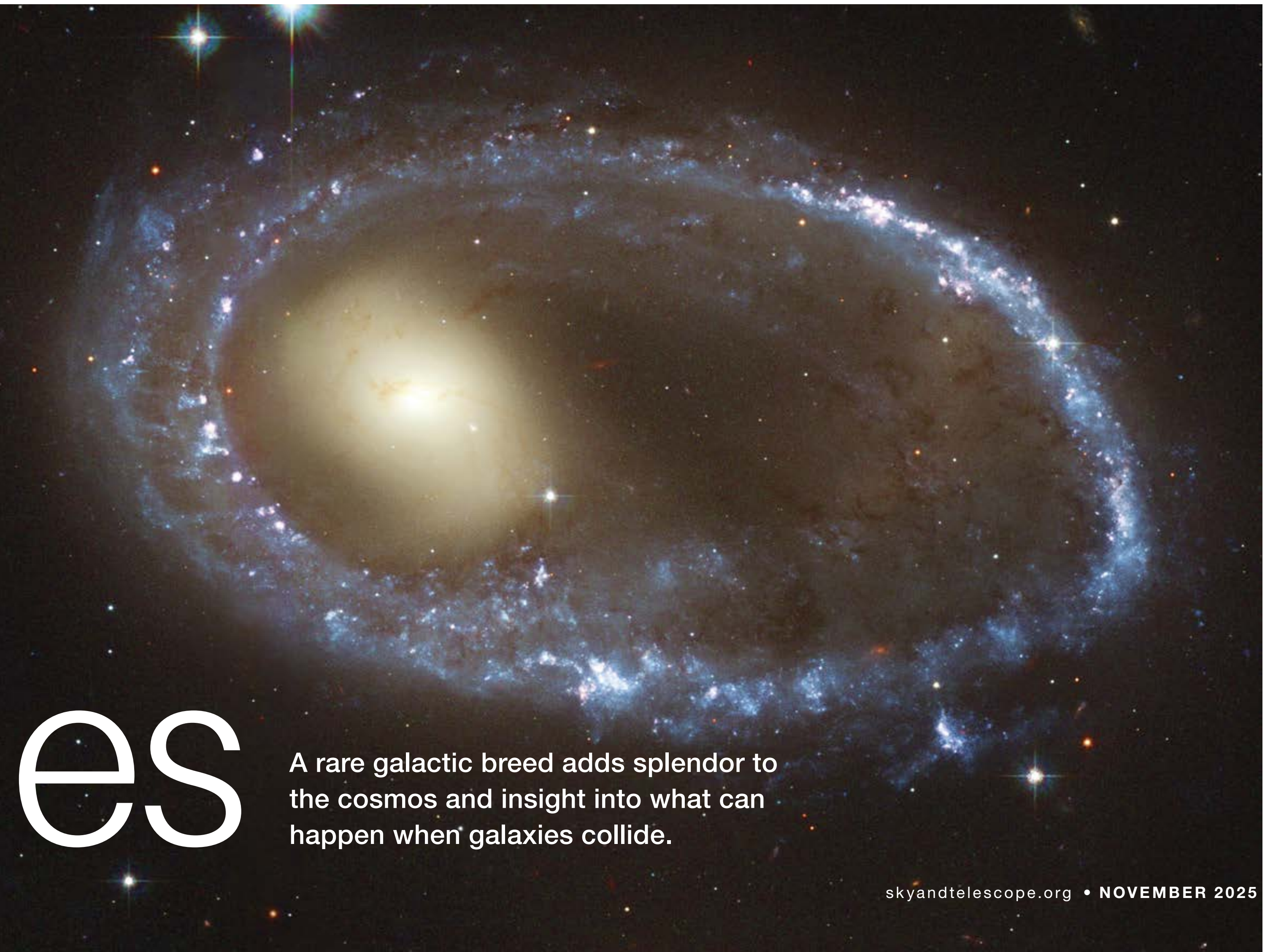
Whereas most other astronomers focused on familiar galaxy types, "Arp was much more the rogue and the outsider, working with the dregs, the peculiar galaxies — the things that didn't fit in the classification scheme," Madore says. "And that was sort of the way he was. He didn't fit in with astronomical society in almost everything he did." For example, Arp advocated the controversial view that quasars are objects ejected by fairly nearby galaxies, which meant quasars aren't as distant as their large redshifts indicate.

"It was wonderful, absolutely wonderful," Madore says. "He was just the nicest gentleman you could imagine. He never once tried to convince me of any of his ideas or theories or stands on cosmology. He just approached this as an observer: Let's go and see what's out there."

The culmination of their project was a 1987 catalog and atlas featuring more than 6,000 peculiar galaxies in the southern sky. "It is a shame that a piece of work of such inherent aesthetic appeal . . . is most probably destined to be housed in dusty astronomical libraries," said the *Irish Astronomical Journal*; "it would pass admirably as a grown-up coffee table guide to the wonders of the universe." Those wonders included more than 100 collisional ring galaxies.

Not all ring galaxies come from collisions, but it's often easy to tell which ones did. Collisional ring galaxies are usually blue, because the burst of star formation creates stars with a wide range of masses. The most massive of these newborn stars are the bluest and brightest, so they dominate the color. Another tell-tale sign: A ring galaxy born of a collision typically has an off-center nucleus, because the intruder's gravity yanked it askew. (The hit-and-runs rarely occur perfectly head-on.) A prominent example is the Lindsay-Shapley Ring.

▼ **LINDSAY-SHAPLEY RING GALAXY** This strange galaxy, cataloged as AM 0644–741, is a striking example of what happens when one galaxy plunges directly through the disk of another. (The intruder lies beyond the image's boundaries.) The collision changed the orbits of stars and gas in the target galaxy and caused gas clouds to hit one another, leading to the ring of star formation.



es

A rare galactic breed adds splendor to the cosmos and insight into what can happen when galaxies collide.

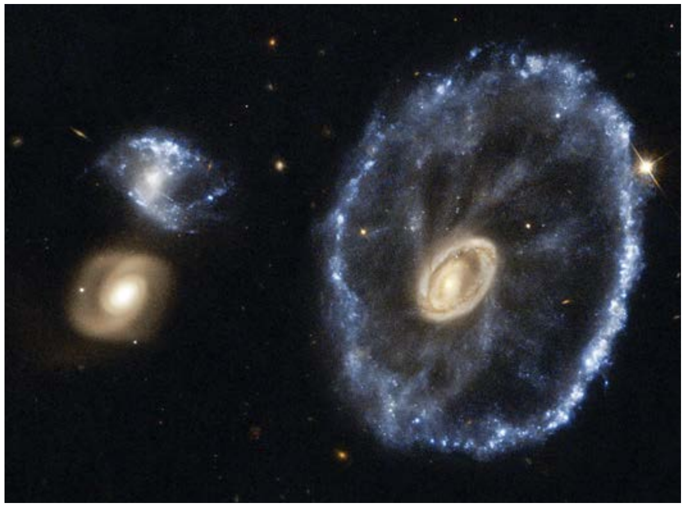
Rings can also develop in more peaceful ways. For example, resonances can occur that trap stars as they orbit their galaxies. In such cases, however, the rings are usually long-lived and consist of an older population that lacks the blue tint of the short-lived massive stars that mark collisional ring galaxies.

A Nice Ring to It

Collisional ring galaxies share another trait: beauty. "They are eye candy," Madore says. "They are very fun to look at." No wonder, then, that one of the first portraits from the James Webb Space Telescope featured the spectacular Cartwheel Galaxy, PGC 2248.

Iconic though it is, the Cartwheel is not a typical ring galaxy. Most members of the class have just one ring, whereas the Cartwheel has two. The outer ring is about 1 arcminute across, corresponding to 120,000 light-years — the same size as the Milky Way's disk of stars (*S&T:* Nov. 2019, p. 16).

But the Cartwheel spawns about 10 times more stars each year than our galaxy does. Newborn *O* and *B* stars give the outer ring its blue glow; the stars' extreme ultraviolet radiation creates regions of ionized hydrogen gas akin to the



▲▼ **CARTWHEEL GALAXY** Formed by a collision with at least one smaller galaxy, the Cartwheel boasts two distinct rings, seen here in two views: a Hubble image *(top)* and a near- and mid-infrared image by the James Webb Space Telescope *(bottom)*. The spokes may be the remains of the Cartwheel's spiral arms. The inner region has older stars and dense dust (the red in the JWST image marks the dust). Clusters of newborn stars bejewel the outer ring.

HST CARTWHEEL: ESA / HUBBLE & NASA; JWST CARTWHEEL: NASA / ESA / CSA / STSCI / WEBB ERO PRODUCTION TEAM

Lagoon Nebula in Sagittarius.

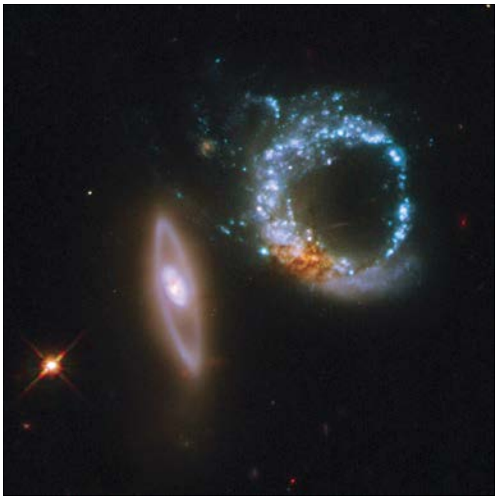
The inner ring, which also moves outward, is yellow. Why? "There's probably much less gas in the inner region," says galaxy evolution expert Curtis Struck (Iowa State University), so the inner ring gives birth to fewer stars and consists more of preexisting stars, some of which are turning into yellow, orange, and red giants. It has less gas in part because the first ring had earlier plowed through that same region and used up gas by minting new stars. Plus, supernova explosions in the first ring kicked gas away from the galaxy.

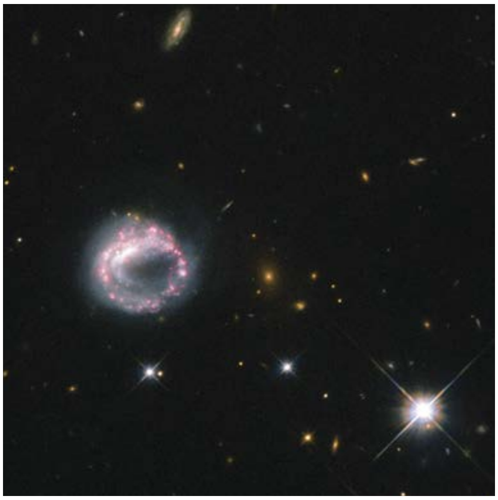
The Cartwheel is unusual in another way, too. Despite previous claims to the contrary, no one knows which galaxy produced the rings. "It's really sad to say that, because that's been another big mystery for a long time," Struck says. Two small galaxies — a yellow one at 9 o'clock in the Hubble image, a blue one at 10 o'clock — are suspects, but so is a third galaxy located in the same direction as the blue galaxy and three times farther out. Given all the galaxies nearby, more than one of them may have hit the Cartwheel, he says. That might explain a feature that makes the galaxy look so striking: The first ring is 4.2 times larger than the second, a greater contrast than two-ring galaxies usually exhibit.

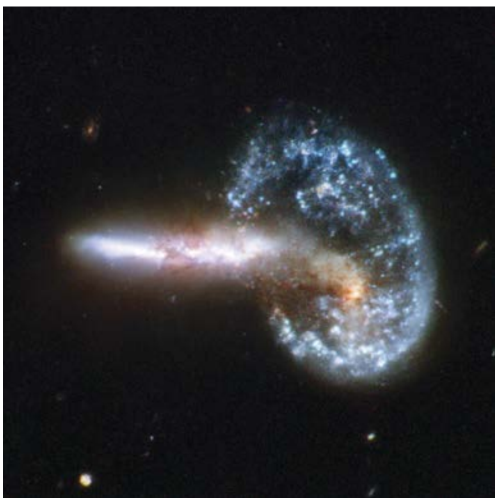
Another special galaxy is Arp 147, located 450 million light-years from Earth in the constellation Cetus, the Sea Monster. Arp 147 is a *double* ring galaxy: two ring galaxies side-by-side. That's because each galaxy hit the other near its center. Each galaxy had a disk, which the collision converted into a ring.

The larger ring galaxy is blue; the smaller one is pale. "My guess would be the smaller one got more of its gas knocked out, and it wasn't able to have gas clouds compressed into star formation," Struck says. As a result, whereas the blue ring galaxy sports new and blue stars, the pale ring galaxy is made more of preexisting stars that the collision herded into a ring.

Madore calls attention to another ring galaxy, known as II Zwicky 28, that's dotted by pink regions of ionized hydrogen gas. "You are looking at a ring galaxy without a collider," he says. "*Maybe* one solution is that it's been hit by a dark matter galaxy."







◀ **ARP 147** *Top:* This pair of ring galaxies likely formed when the paler galaxy on the left passed right through the galaxy on the right. The dusty reddish knot in the blue ring may be the galaxy's original nucleus.

◀ **II ZWICKY 28** *Middle:* Astronomers haven't found an obvious culprit for this galaxy's appearance. Some have suggested that the impactor lies hidden inside the ring, while others wonder if it was hit by something more exotic: a starless galaxy made only of dark matter.

◀ **ARP 148** *Bottom:* This system is a unique snapshot of an ongoing collision, as the impact transforms one galaxy into a ring.

ARP 147: NASA / ESA / M. LIVIO (STSCI); II ZWICKY 28: ESA / HUBBLE & NASA, ACKNOWLEDGMENT: JUDY SCHMIDT; ARP 148: NASA / ESA / HUBBLE HERITAGE (STSCI / AURA) AND (ESA / HUBBLE COLLABORATION) / A. EVANS (UNIVERSITY OF VIRGINIA, CHARLOTTESVILLE / NRAO / STONY BROOK UNIVERSITY)

Such a galaxy would possess no stars and thus emit no light. Instead, the invisible galaxy would consist solely of dark matter — the same mysterious substance that makes up most, but not all, of our own galaxy. "It's really wild and out there, and Arp would love it," he says. If the dark galaxy is real, Madore says, its gravity should distort images of galaxies behind itself, an effect he hopes to find. On the other hand, a more prosaic possibility exists: Perhaps the intruder galaxy was so fragile that it destroyed itself in creating the ring.

A Nine-Ring Galaxy — or Circus?

In the February 10, 2025, *Astrophysical Journal Letters*, Imad Pasha, Pieter van Dokkum (both at Yale), and their colleagues advanced a controversial claim: They discovered a large and beautiful galaxy in the constellation Pisces, LEDA 1313424, that they say sports an incredible nine rings, something never before seen (*S&T:* June 2025, p. 9). The astronomers nicknamed the galaxy, which is 560 million light-years from Earth, the Bullseye. The outer rings are blue and the inner rings are yellow, similar to the pattern in the Cartwheel Galaxy.

"The rings that we see here match remarkably well with the theoretical prediction over a very large distance range," Pasha says. In a 2010 paper, Struck reported the discovery of a simple relation that a multi-ring galaxy should exhibit if it

A BULLSEYE? Astronomers are currently debating whether LEDA 1313424 is a multi-ringed collision survivor or a tightly wound spiral that just looks like a ring galaxy.

NASA / ESA / IMAD PASHA (YALE) / PIETER VAN DOKKUM (YALE) has a flat rotation curve — that is, if all stars revolve around the galaxy's center at the same speed: The first and outermost ring should be three times larger than the second ring, which should be 5/3 times larger than the third ring, which should be 7/5 times larger than the fourth ring, which should be 9/7 times larger than the fifth ring, and so on. Pasha says the Bullseye conforms to this prediction.

"The rings are a combination of preexisting stars and newly formed stars," says van Dokkum, who thinks the intruder galaxy passed right through the large galaxy's center, explaining why its nucleus was not yanked off-center the way it normally is in ring galaxies. "That's also how you get so many rings; otherwise, the rings sort of run into each other."

The Bullseye Galaxy's stellar mass is about 60 billion solar masses, the same as the Milky Way's. But "its center does not look like a normal spiral," Pasha says, because strong spectral lines of ionized nitrogen, oxygen, and sulfur indicate disturbed gas there, which most spirals lack. He attributes the disturbance to the collision, which occurred 50 million years ago.

The intruder, he says, is the small blue galaxy at 9 o'clock in the Hubble image. A gas trail connects this galaxy with the large one. "That's a really, really clear indicator," he says.

Pasha says an even more distant ring probably exists some three times farther out than the farthest ring his team found. "But we don't expect to be able to see it in any of the current data, because it would be much fainter and more diffuse than ring 2, which we barely detect anyway," he says.

The discovery has provoked debate. Struck thinks the Bullseye is indeed a many-ringed galaxy. "I'm not sure I buy nine [rings], but there are certainly multiple rings," he says. "Their spacing goes along pretty much with the theory."

But Madore strongly disagrees. "I don't think it's a ring galaxy, period," he says. "Those are not rings; those are spiral arms." And the claim that the faint blue outer feature is a ring? "Oh, baloney!" he retorts. "That is a classic interaction tidal tail. It's not a ring." It's probably material freed by the small yellow galaxy at 12 o'clock in the Hubble image, he suggests.

Toomre also doubts that the Bullseye is a ring galaxy. He thinks it may be a tightly wound spiral galaxy similar to another beautiful galaxy in Pisces, NGC 488.

Fortunately, both sides agree that the dispute is easy to resolve. If the Bullseye is truly a ring galaxy, the rings should be moving away from the galaxy's center, whereas if the galaxy is simply a picturesque spiral, they should not be. Doppler shifts of different parts of the galaxy will indicate movement toward or away from us and thereby reveal the truth.

Galactic Metamorphosis

Ring galaxies may explain another unusual galactic breed: gargantuan but extremely diffuse spiral galaxies such as Malin 1, named for outstanding astrophotographer David Malin (*S&T:* Aug. 1987, p. 123). With a distance of 1.1 billion light-years and a disk spanning an extraordinary

▲ **NOT A RING GALAXY** NGC 488's tight spiral arms make it look similar to multi-ring galaxies, but it's "just" a spiral.

ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA / WIKIMEDIA COMMONS / CC BY-SA 3.0

650,000 light-years, Malin 1 is one of the largest spiral galaxies in the universe. Yet the galaxy barely produces any stars, and its light is extremely spread out, making it difficult to see.

Malin 1 and its few fellow phantom giants have long raised questions about how such mammoth spiral disks arose. Two decades ago, Michela Mapelli (then University of Zurich, Switzerland) and her colleagues proposed that these mysterious galaxies were once ring galaxies. As a ring galaxy expands and fades, the astronomers said, it becomes an enormous but diffuse spiral galaxy like Malin 1 — an idea that Struck calls plausible.

The Bullseye is already 460,000 light-years across. If it is in fact a ring galaxy, it will grow even larger and more diffuse as its rings expand. "It may be one of these transitional forms where we can pinpoint the mechanism to create a whole class of galaxies that we don't understand very well," van Dokkum says. Thus, someday the Bullseye Galaxy may look like Malin 1.

Of course, we won't be around to watch that great transition. Whatever the verdict about the true nature of the Bullseye happens to be, astronomers would like more examples to see whether ring galaxies constitute the link that explains the origin of giant diffuse spirals.

In any event, ring galaxies certainly add a dash of unexpected beauty to the cosmos and illustrate the colorful lives that galaxies lead.

■ Contributing Editor **KEN CROSWELL** is an astronomer and poet. He is the author of a book about the Milky Way, *The Alchemy of the Heavens*, and a book about cosmology, *The Universe at Midnight*.

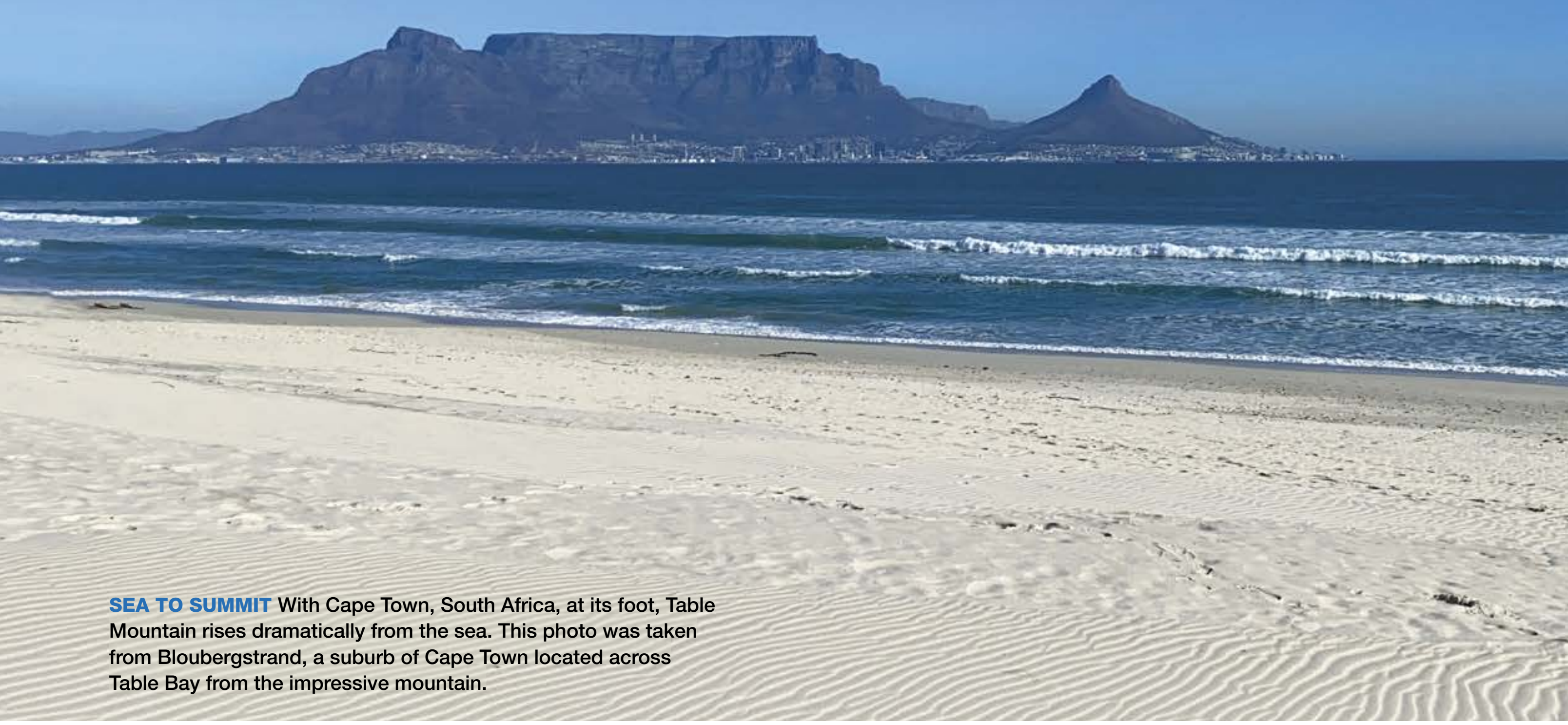
As an amateur astronomer living in South Africa, one of the most interesting sights in the night sky is the constellation Mensa — the beautiful and imposing Table Mountain depicted in the stars. Apart from being the only terrestrial landform to share the sky with ancient gods, heroes, and mythical creatures, Table Mountain is remarkable in its own right. It boasts fascinating geology, an abundance of floral species, and a rich history. But most importantly for astronomy, the mountain exerted a powerful influence on a trio of eminent astronomers: Nicolas Louis de Lacaille, John Herschel, and Thomas Maclear.

Towering more than 1,000 meters (3,000 feet) above sea level, Table Mountain is composed primarily of quartzitic sandstone deposited 540 million years ago by broad rivers and inland seas. The mountain came into being about 320 million years ago, during the geological smash-up of Earth's landmasses that formed the supercontinent of Pangaea. The collision uplifted the sedimentary rock around the Cape Peninsula to form a 50-km-long (31-mile-long) mountain range with Table Mountain standing at its northern end. The towering, 600-meter-thick slab of sandstone, with its sheer, silver-gray cliffs is extremely hard and resistant to erosion, making it one of the oldest mountains in the world. It stands on a 70-meter-thick layer of alternating pink siltstone, maroon mudstone, and pale-brown sandstone, all resting on a bedrock of Cape Granite. The indigenous Khoikhoi people called this ancient mountain Hoerikwaggo, which translates to "Mountain in the Sea" — an apt and beautifully poetic name reflecting the deep connection between the towering structure and the vast ocean that stretches beyond.

In May 1503, the Castilian-Portuguese navigator Antonio de Saldanha found himself separated from the rest of his three-ship fleet. Owing to poor piloting, he didn't even know if he'd yet sailed past the Cape of Good Hope, as the southernmost point in the African continent was then known. To get his bearings, he needed a vantage point. Fortunately, he was within sight of an enormous, flat-topped mountain overlooking a sheltered bay. He sailed in, anchored his ship, and proceeded to climb the mountain via a massive gorge that slashes the front of the mountain up to the summit plateau. It must have been a grueling climb, battling through dense vegetation populated with lions, hippos, hyenas, and leopards!

The Mountain of Stars

Meet three distinguished astronomers whose work was influenced by a majestic African landform.



SEA TO SUMMIT With Cape Town, South Africa, at its foot, Table Mountain rises dramatically from the sea. This photo was taken from Bloubergstrand, a suburb of Cape Town located across Table Bay from the impressive mountain.

The view from the summit allowed him to ascertain his position and locate the other two ships in his fleet. The climb proved helpful in other ways. There was a strong stream flowing down the gorge, which provided water to resupply his fleet. Thus, he named the bay Aguada de Saldanha (the "watering place of Saldanha," which eventually became modern day Table Bay). And he named the mountain Taboa do Capo (Table of the Cape).

In 1601, Dutch seafarer and cartographer Joris van Spilbergen mistook a bay farther north as Aguada de Saldanha (modern day Saldanha Bay) and, thinking he'd made a new discovery, named the bay with the magnificent mountain Tafel Baai, or Table Bay, on account of the "high mountain, flat on top and square like a table." Thus, the mountain became known as Tafelberg, or Table Mountain, to settlers of the Dutch East India Company, who arrived at the Cape of Good Hope in 1652 and established a trading post — a colony that would eventually become present-day Cape Town.

◀ **PRODIGIOUS FRENCH ASTRONOMER** Lacaille not only laid the foundation for Southern Hemisphere astronomy, but he also holds the distinction of being the first person to systematically observe the entire sky north and south of the celestial equator. His career was a short one, however. Lacaille was just 49 years old when he died in Paris, France, in 1762.

Immortalized in the Stars

On April 19, 1751 — almost exactly 100 years after the Dutch arrived — French astronomer Nicolas Louis de Lacaille first set foot on the Cape of Good Hope with his dog Gris-Gris, a stray he'd picked up at the start of his voyage south from France. Lacaille had been sent by the Academy of Sciences in Paris to catalog the southern stars and measure a meridian arc in the Southern Hemisphere to help determine the shape of the Earth. His observatory, which he set up in the rear courtyard of a private house near the shore of Table Bay, was dominated by Table Mountain's huge, angular mass a mere 7 km away.

Lacaille's astronomical achievements during his two-year stay were remarkable. He measured the positions of an astounding 9,766 stars with a modest ½-inch refractor that boasted a mere 8× magnification. His positions provided the first reliable catalog of the southern stars to aid navigation. He also recorded 42 deep-sky objects — 24 of which were new discoveries, including 47 Tucanae, the Carina Nebula, and the Tarantula Nebula.

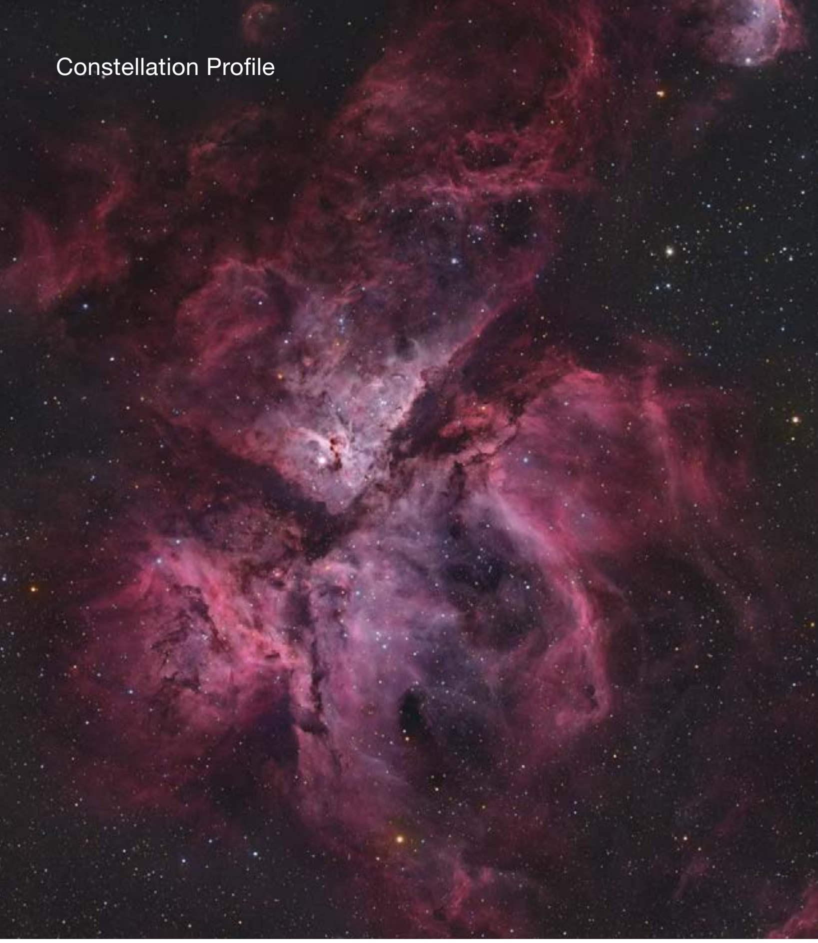
Of his many accomplishments, Lacaille may be best remembered today for populating the unmapped regions of the far-southern sky with 14 new constellations. He also restored to Argo Navis (the Ship Argo) the stars that English astronomer Edmund Halley had swiped in 1679 to create Robur Carolinum (Charles's Oak — the tree in which King Charles II hid while fleeing Oliver Cromwell's republican forces in 1651). Lacaille then promptly dismantled Argo Navis, creating for us the constellations Vela (the ship's Sails), Carina (the Keel), and Puppis (the Stern).

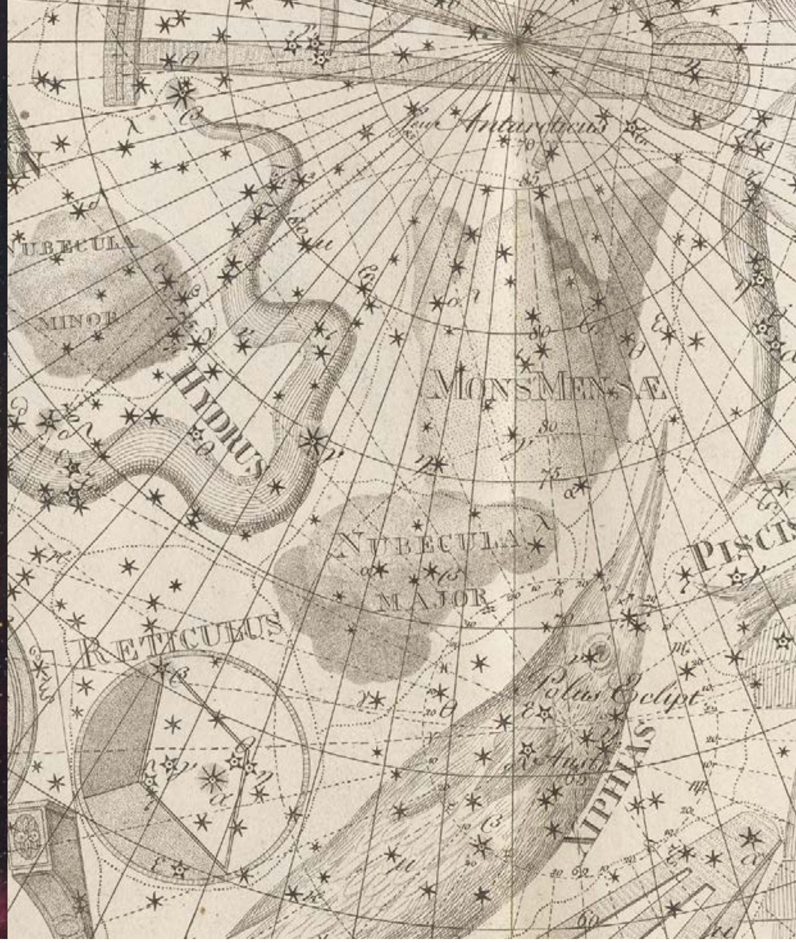
Lacaille also gave us Mensa. At first blush, it seems out of place among the various implements of science he had placed in the sky to symbolize the Age of Enlightenment, such as Telescopium (the Telescope), Antlia (the Pump), Microscopium (the Microscope), Circinus (the Drafting Compass), and others. But Mensa also appears to have been an imaginative way to incorporate the magnificent Large Magellanic Cloud into a constellation. As he wrote in his 1756 report to the French Academy of Sciences, "Finally, I placed below the large cloud Table Mountain, famous at the Cape of Good Hope for its table-like shape, and mainly for a white cloud which covers it in the form of a tablecloth when a violent south-east wind approaches; moreover, most Navigators call Cape clouds what we call Magellanic clouds, or the large and small clouds."

Indeed, Table Mountain is famous for the dramatic orographic clouds that frequently wash over its summit. These formations are created by strong winds that push warm, moisture-laden air upwards against the mountain, where it condenses in the cooler air at higher elevations. The clouds then pour down over the precipices, resembling an immense

▶ **MAJESTIC, ANCIENT, AND HISTORIC** Table Mountain has captivated both terrestrial and celestial explorers for centuries. English painter William Hodges created this depiction in 1772, while onboard Captain James Cook's ship, *HMS Resolution*. The mountain was immortalized in the stars as the constellation Mensa by French astronomer Nicolas Louis de Lacaille, who surveyed the night sky from a location near the shores of Table Bay, starting in 1751.

PHOTO OF TABLE MOUNTAIN: DENZIL COWLEY; LACAILLE PORTRAIT: MELLE LE JEUNEUX / WIKIMEDIA COMMONS / PUBLIC DOMAIN; PAINTING OF TABLE MOUNTAIN 1772: WILLIAM HODGES / WIKIMEDIA COMMONS / PUBLIC DOMAIN





▲ **A BILLOWING CLOUDSCAPE** The impossibly beautiful and intricate Carina Nebula was one of two dozen deep-sky objects discovered by Lacaille during his survey of the southern skies from the Cape of Good Hope. The nebula resides in the Carina-Sagittarius arm of the Milky Way, at a distance of around 8,500 light-years.

▲ **A CLOUD-COVERED MOUNTAIN** Table Mountain (Mons Mensae) capped by the beautiful Large Magellanic Cloud (Nubecula Major), is shown in this crop from Chart XX of Johann Bode's 1801 atlas *Uranographia*. (The mountain is presented upside down.) By 1845, the constellation's name would be shortened to Mensa, as it is known today.

waterfall tumbling in slow motion from the flat summit to the warm air below, where it slowly dissipates. It's no wonder that Lacaille was inspired to immortalize the spectacular mountain and its clouds.

In the first version of his planisphere (published in 1756), Lacaille gave a collection of faint stars the French name Montagne de la Table (Table Mountain). His second edition (1763) carried the Latin translation, Mons Mensae. In 1844, John Herschel proposed shortening the name to just Mensa, and in 1845 English astronomer Francis Baily (of "Baily's beads" fame) adopted this name in his *British Association Catalogue*. It has been known as Mensa ever since.

After carefully observing Jupiter's satellites to determine Cape Town's longitude (specifically, that of his observatory on Strand Street), Lacaille set about the important task of measuring a meridian arc to confirm Isaac Newton's contention that Earth wasn't a perfect sphere, rather, that it was an oblate spheroid that bulged at the equator. Lacaille's results proved startling, to say the least. They appeared to indicate Earth was pear-shaped, with an enlarged Southern Hemisphere! Because of his reputation for meticulous and accurate measurements, his findings perplexed the scientific community for the next 90 years. As we'll see later, Table Mountain played an important role in solving this mystery.

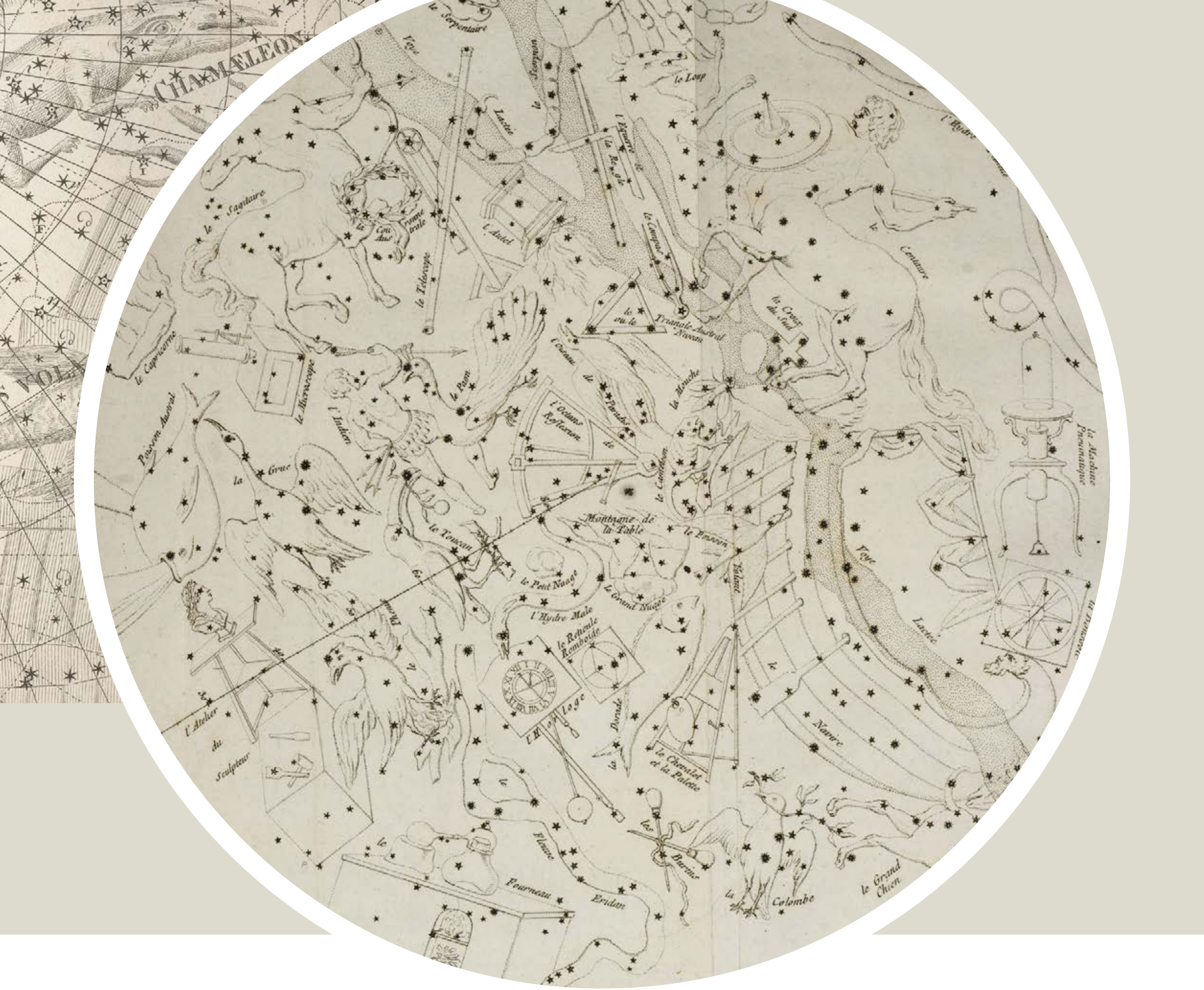
▶ **TABLE MOUNTAIN'S CELESTIAL DEBUT** Lacaille's beautiful and artistic planisphere of the southern sky depicts his 14 new constellations, including Mensa (Montagne de la Table) at center. The chart was first published in 1756 in the *Mémoires* of the Royal Academy of Sciences.

Under the Towering Precipices

Ships at sea can glimpse Table Mountain from as far as 150 km away, and on January 15, 1834, John Herschel did just that. As he recorded in his diary, "At early dawn this morning James [Rance, personal servant to Herschel] knocked on our cabin door and called out Land! Rose & hurried on Deck whence the whole range of the Mountains of the Cape from Table Bay to the Cape of Good Hope was distinctly seen, as a thin, blue, but clearly defined vapour. The Lions Head was seen as an Island the base being below the horizon . . . It was a truly magnificent Scene . . ."

Later in the same entry he reported, "The shore, still nearing, grew bolder & more rugged & broken 'The wild Pomp of Mountain Majesty' developed itself & certainly nothing finer than this approach of South Africa can be conceived." The next day, Herschel described the scene from an anchorage in Cape Town's harbor: "The situation is most remarkable, hemmed in on the sides by steep promontories & backed by the Mural precipice of the Table Mountain which rises sharp & sudden behind it."

CARINA NEBULA: HAREL BOREN / WIKIMEDIA COMMONS / CC BY-SA 4.0; MENSA CHART FROM URANOGRAPHIA: ETH-BIBLIOTHEK ZÜRICH / E-RARA / PUBLIC DOMAIN

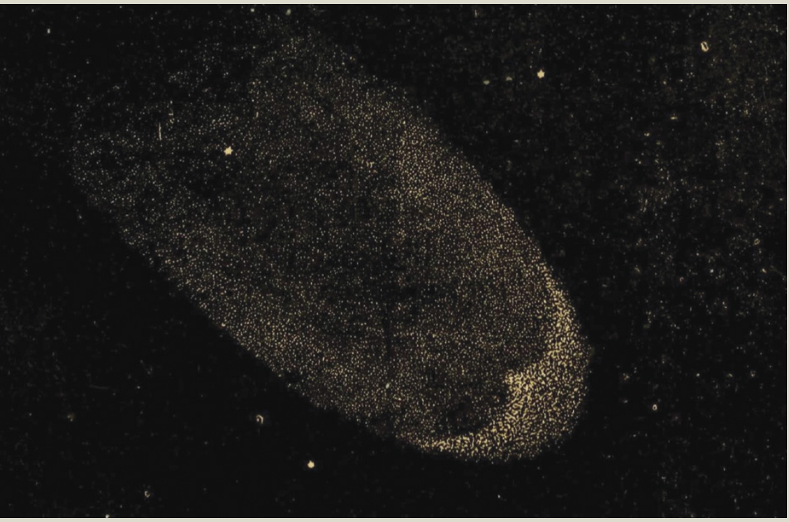


ETH-BIBLIOTHEK ZÜRICH / E-RARA / PUBLIC DOMAIN

Thus, John Herschel, one of the world's greatest astronomers, arrived in Cape Town, where he spent the next four years exploring the southern skies to extend the survey undertaken by his father, William. He selected a Dutch estate called Feldhausen to serve as his home and observatory. In a letter dated June 10, 1834, to his aunt, Caroline Herschel, he described the location, ". . . you can imagine nothing more magnificent than its situation which is nearly under the towering precipices of the Table Mountain . . ." Within weeks he had erected his 20-foot (18¼-inch aperture) telescope and had first light on February 22, 1834.

Herschel penned frequent and poetic entries in his diaries about Table Mountain's dramatic "tablecloth" of clouds. Unfortunately, this same feature thwarted his efforts to view Halley's Comet during its much-anticipated 1835 return, even after several others in Cape Town had succeeded in doing so on October 24th that year (*S&T:* Sept. 2025, p. 28). The astronomer had been searching for the comet since January but had been denied a sighting by the mountain's "vast pile of clouds." Finally, on October 28th, he "Knocked up a temporary stand for the 7 feet Equatorial telescope — dismantled it and carried it out to the 1st Sand hills on the flats there erected it just at Sunset & was rewarded with the 1st glorious sight of Halley's Comet!!!"

Hershel's interests extended beyond astronomy and comets to geology, which led him to make detailed observations and sketches of Table Mountain's unique features. In fact, his efforts took him far and wide on horseback and ox wagon in search of rocks, minerals, and crystals. True to his nature, Herschel's geological investigations went far beyond mere fieldwork — he considered the large forces continuously reshaping Earth's surface, and the vast time scales they spanned. His efforts contributed significantly to the science of geology, both inspiring new theories and testing existing ones.



▲ **REGULAR VISITOR** After it returned in 1758 as predicted, Lacaille named the famous comet in Edmund Halley's honor. During its 1835 apparition, Herchel managed to observe and sketch Halley's Comet only after he relocated his telescope to avoid Table Mountain's notorious "tablecloth" of clouds.

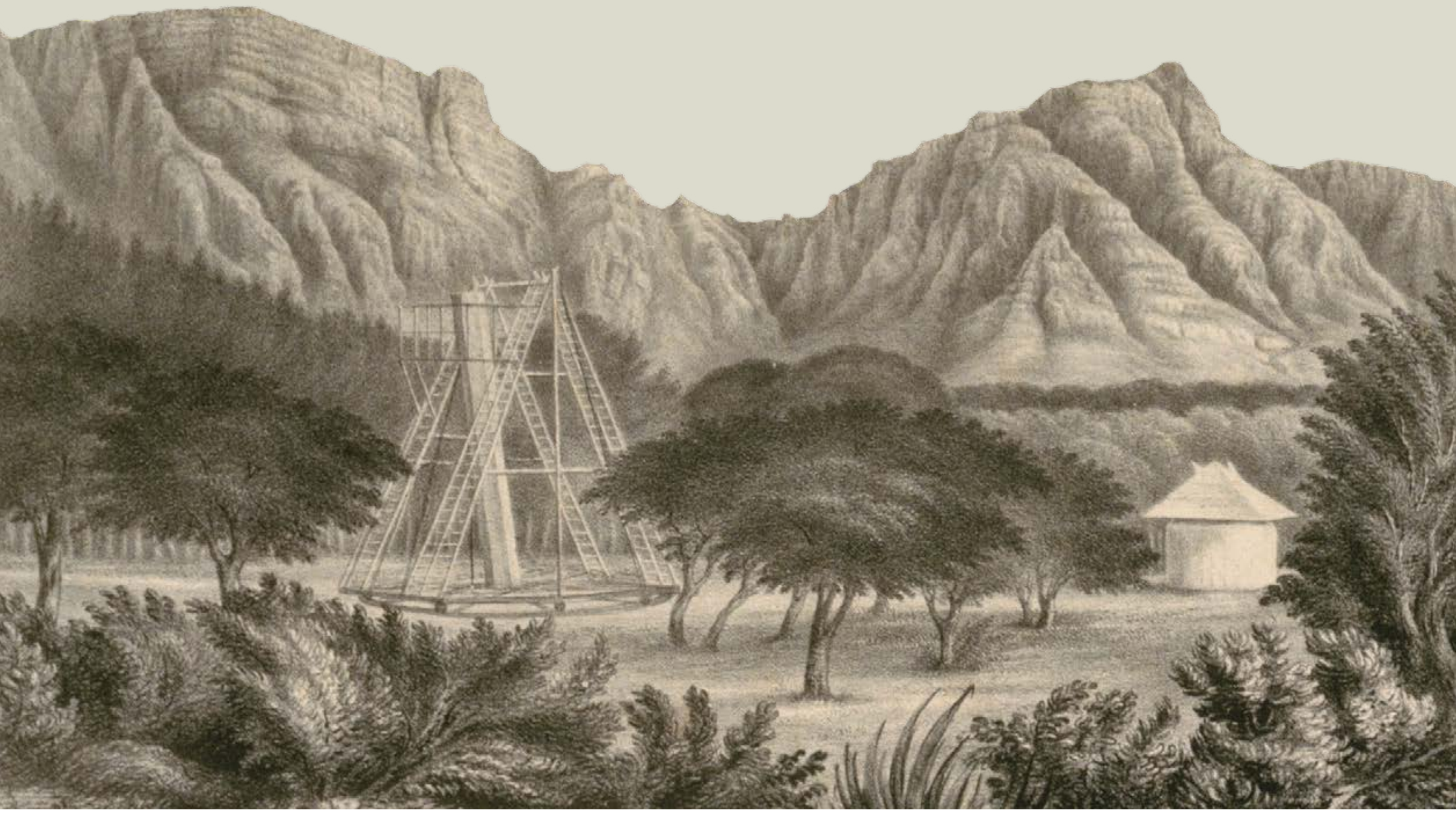
▼ **PROTECTED BY MENSA** John Herschel's 20-foot (18¼-inch aperture) reflector telescope was situated on a gentle slope at the base of Table Mountain, which sheltered both the instrument and the observer from the area's violent and relentless southeast summer winds. Herschel himself made this evocative drawing.

A Historic Beacon

Irish-born Thomas Maclear was an eminent astronomer who would develop a deep connection to Table Mountain. Although an ardent amateur astronomer, Maclear was educated as a doctor. In 1815, he completed his medical studies in England, after which he was appointed house surgeon at an infirmary in the town of Bedford, just outside of London. He made friends with Admiral William Henry Smyth, the charmingly eccentric and accomplished astronomer who had settled in Bedford after retiring from the Royal Navy. Their friendship changed the course of Maclear's life by intensifying his already passionate interest in astronomy. Smyth also instructed him in mathematics and took him to meetings of the Royal Astronomical Society in London. And when in 1823, he established medical practice nearby in Biggleswade, he set up an observatory in the garden. His meticulous observations soon led to his appointment as Fellow of the RAS in 1831. It was at the Society that he became acquainted with John Herschel. The two became lifelong friends and collaborated during their years together on the Cape.

In 1833, the post of Her Majesty's Astronomer for the Cape of Good Hope became available. Maclear had achieved such distinction for his astronomical work as an amateur that he had no competitor and was duly appointed to the position. He arrived in Cape Town on January 7, 1834, just eight days before Herschel. (Interestingly, Smyth's son, Charles Piazzi Smyth,

HALLEY'S COMET SKETCH, OCT 29, 1835: THE LIBRARY OF CONGRESS / INTERNET ARCHIVE / PUBLIC DOMAIN; HERSCHEL'S TELESCOPE IN SOUTH AFRICA: ROYAL MUSEUMS GREENWICH



became Maclear's assistant in October 1835 at the age of 16, a post he held until 1845.)

One of Maclear's most important tasks was to re-measure Lacaille's meridian arc to solve the pear-shaped Earth enigma. British surveyor and geographer George Everest of the Indian Survey (and later of Mount Everest fame) had visited the Cape in 1820 and concluded that the gravitational effects of Table Mountain and the Piketberg Mountains could have significantly affected Lacaille's delicate plumb-line measurements.

Maclear and his assistants (including the young Smyth) commenced their efforts in 1840 and completed the task in 1848. Everest was correct — the problem was that Lacaille used the location of his observatory on Strand Street as the southern point in his meridian arc, which was an unfortunate choice with Table Mountain looming just a stone's throw away. His northern point was similarly unfortunate, having selected Klipfontein, a farm in the Piketberg Mountain range. The gravitational effects of a nearby mountain ensures a plumb will not hang perfectly vertical — a requirement for accurate meridian-arc measurements.

After confirming Lacaille's faulty results, Maclear began his own measurements using a method of triangulation that utilized "beacons" (stone cairns) strategically placed at the terminals of a selected baseline and at other prominent locations within the survey area. This allowed him to accurately measure angles and distances across the region. Maclear extended his triangulation southward to Cape Point, beyond the gravitational influence of Table Mountain, and northward to a point near Kamieskroon, some 400 km north of Cape Town. To the relief of all, he was able to show that Earth's Southern Hemisphere indeed had the same radius as its Northern Hemisphere. Earth wasn't pear-shaped after all!

Some of Maclear's beacons are still used today by cartographers. The most famous is the Maclear Beacon on Table Mountain, marking the mountain's highest point, 1,086 meters above sea level. The beacon itself consists of a 3-meter-high mound of rocks. In 1929, the structure collapsed, but in 1979, on the centenary of Maclear's death, it was at last restored to its former glory.

Unlike Lacaille and Herschel, Maclear never left South Africa. He retired in 1870 and settled in Mowbray, Cape Town, where he died on July 14, 1879, at age 85.

Table Mountain in the Stars

Mensa occupies a barren patch on the celestial sphere, which forced Lacaille to fashion his Table Mountain from a handful of stars, none brighter than 5th magnitude. (Indeed, so faint is Mensa that it isn't even plotted on this magazine's Southern Hemisphere Sky Chart on page 44!) He formed the mountain's sheer cliffs with 5.1-magnitude Alpha (α) Mensae, 5.2-magnitude Gamma (γ), and 5.4-magnitude Eta (η). He used the rest of the stars to outline the mountain's granite base, except for 5.3-magnitude Beta (β) Mensae, which he placed in Table Mountain's rolling tablecloth clouds — suggested by the Large Magellanic Cloud. Of all Mensa's stars, Beta is perhaps the most interesting in a telescope. Nestled up to this lovely, yellow Milky Way star, just 3.2′ to its southwest, is the little white spark of R71 — a rare LMC luminous blue variable star. It normally shines at 11th magnitude, but during infrequent outbursts it might brighten to magnitude 9.2 or occasionally even brighter. Nonetheless, even in its quiescent state R71 is one of the LMC's most luminous stars.

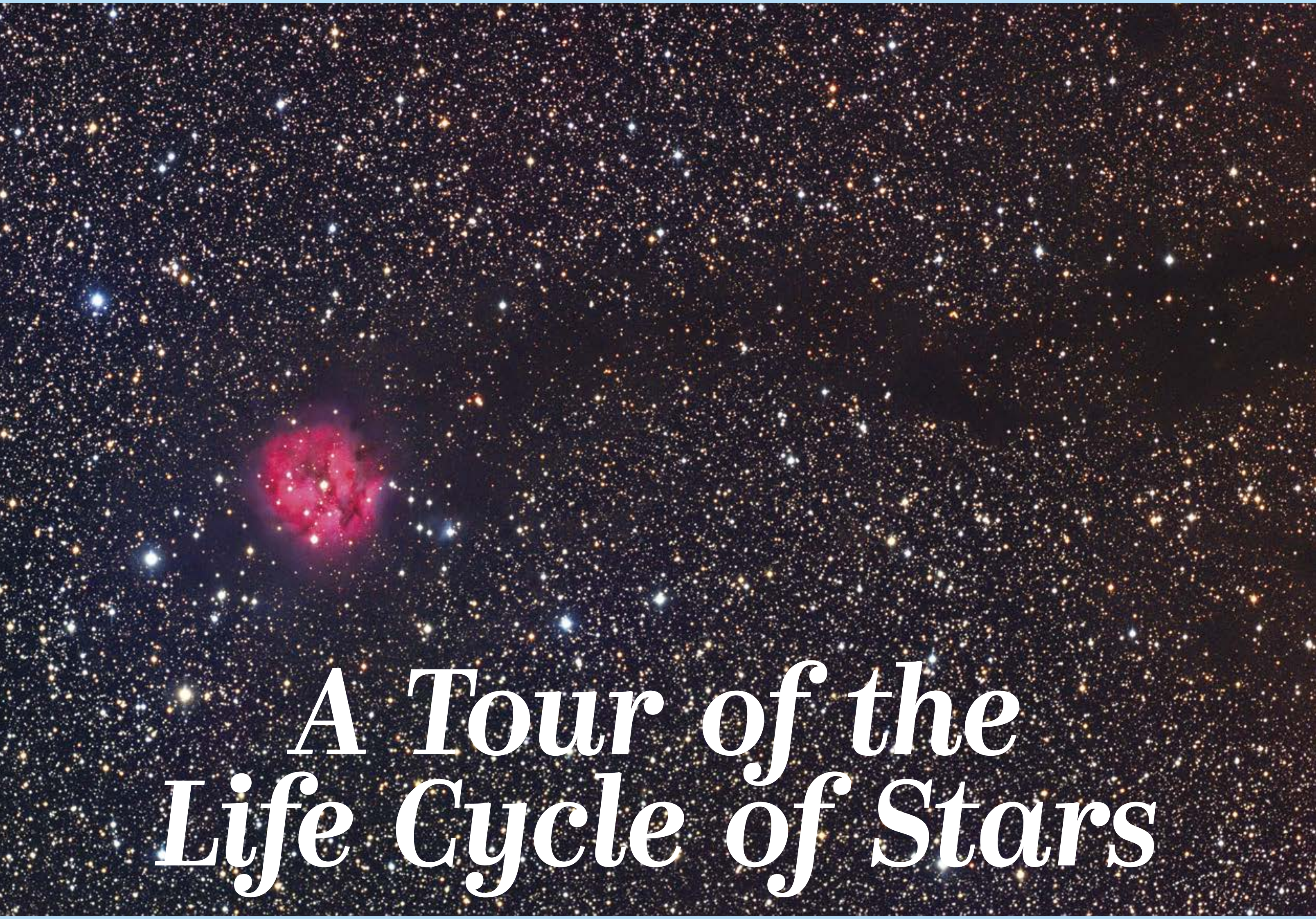
Although a significant portion of the LMC's richly shimmering mass extends into Mensa, its most extraordinary object sits an astounding 14½° south of the ragged galaxy's center and close to the border with Octans, the Octant. Globular cluster NGC 1841 is roughly 6½° from the south polar star Sigma (σ) Octantis, making it the southernmost globular in the sky. I like to think of this ancient, far-flung cluster as the celestial counterpart to Maclear's cairn of rocks sitting atop the majestic mountain that Lacaille had placed in the sky.

■ **SUSAN YOUNG** lives in South Africa and has been observing the southern stars for decades under the superbly dark skies of the Kalahari. She maintains a web site at **largemagellaniccloud.com**.

◀ **DOCTOR BY PROFESSION, ASTRONOMER BY INCLINATION** In addition to his contributions to astronomy and his monumental geodetic survey, Thomas Maclear published works on meteorology, geographical exploration, and hydrography.

▶ **AN ENDURING MONUMENT** Although only 3 meters (10 feet) high, Maclear's Beacon on Table Mountain stands as a towering tribute to Thomas Maclear's eight years of toil and hardship to measure a meridian arc from South Africa.

MACLEAR 1833 PORTRAIT: FLORA HERSCHELIANA / WIKIMEDIA COMMONS / PUBLIC DOMAIN; MACLEAR'S BEACON: BARRY NE / WIKIMEDIA COMMONS / CC BY-SA 4.0



A Tour of the Life Cycle of Stars

Let's explore key milestones in stars' lives.

To some, the stars seem eternal. But like us, stars are mortal — they are born, they live and prosper, and then they eventually die. Of course, stars live a lot longer than we do, from a few million years to billions of years depending on their mass. That relative longevity makes it hard to understand the ponderous pace of stellar evolution by studying a single star, which is why astronomers study many stars in various life stages to get an idea of how they form and evolve.

In this celestial tour, we'll explore examples of some key phases of a star's life, both large, massive stars that burn hot and die young, as well as smaller, average-size stars like our Sun that live more stable, measured lives.

Stellar Nurseries

Stars in the Milky Way form mostly in the galaxy's spiral arms, in dark clouds of gas and dust that span hundreds of light-years. Gravity and turbulence cause parts of these clouds to coalesce into small, dense pockets that form clusters of hundreds of new suns. Let's look west of the zenith tonight to see a star-forming region in the constellation Cygnus, the Swan, that includes **IC 5146**, which is the Cocoon Nebula and its associated star cluster, about 3.8° east-southeast of the open cluster M39. The long, dark finger of **Barnard 168** (B168) extends almost 2° to the west of the Cocoon Nebula. B168 harbors pockets of star formation, especially in the darker, western section called the Northern Streamer, about halfway between the emission nebula and M39.

In my 85-mm f/7 refractor with a Tele Vue 35-mm Pan-

▲ **BRIGHT AND DARK NEBULAE** IC 5146, the Cocoon Nebula, is a star-forming region in the constellation Cygnus, the Swan. It glows red due to hydrogen gas being illuminated by young stars in its interior. It lies around 4,000 light-years away and spans about 15 light-years. To its west is Barnard 168, a sinuous, 2°-long dark tendril of opaque gas and dust amid the rich star field of Cygnus. North is up in all images.

KPNO / NOIRLAB / NSF / AURA / ADAM BLOCK optic eyepiece that offers 17× magnification and a 4° field of view, I see B168 etched prominently east-west against the Milky Way's rich star field. Lovely in photographs, the Cocoon Nebula itself presents a challenge to the visual observer. To me, this luminous blister is a circular 10′-wide splotch in the refractor at 25×. At magnitude 7.2, it's easily visible with the help of an ultra-high contrast (UHC) filter; the nebula includes a pair of embedded 10th-magnitude stars. With my 10-inch f/4.7 Dobsonian at 92×, the nebula appears brighter but offers little structure, though I see hints of the newly formed stars within that are only a few million years old.

◀ **A STAR IS BORN** T Tauri, a young, low-mass star in the Taurus star-forming region, was discovered by English astronomer John Russell Hind in 1852. It represents a class of pre-main-sequence variable stars that are less than about 10 million years old. Here, T Tauri illuminates NGC 1555, also known as Hind's Variable Nebula. The star visible at lower right is 8th-magnitude HD 27560, and the field is approximately 14′ wide.

Dark nebulae like B168 hide from view the star-forming processes taking place inside. To see a star in the act of formation — a *protostar* — let's swing our telescopes eastward to Taurus, the Bull, to see fascinating 10th-magnitude **T Tauri**. The namesake of a class of nascent stars, T Tauri lies about 1½° west-northwest of Epsilon (ε) Tauri among the stars of the Hyades cluster, although, at a distance of 470 light-years, T Tauri is three times farther away. Each of the three unresolvable components of T Tauri is very young, less than about 10 million years old and yet to begin fusing hydrogen to helium in its core. Instead, these stars generate their energy solely through gravitational contraction.

My 10-inch Dobsonian at 133× shows this protostar easily enough, although I can't quite discern its yellow-orange hue. An erratic variable star that fluctuates in brightness from magnitude 9.3 to 10.7 over a few months, T Tauri lies immediately east of NGC 1555, Hind's Variable Nebula. The object is a 1′ × 1′ reflection nebula that's visually challenging even in a 12-inch telescope.

The Lives of Mid-Size Suns

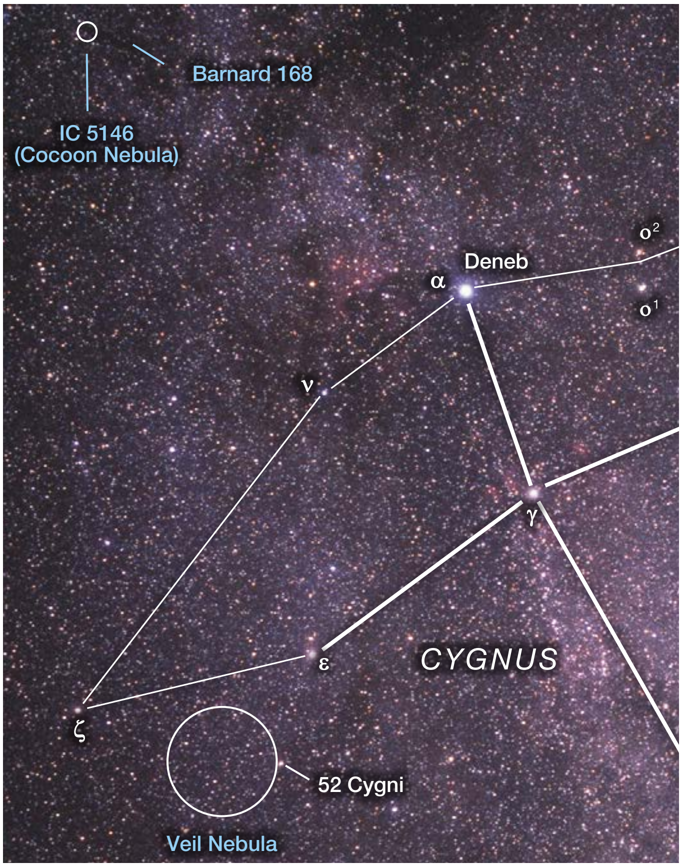
When stars like T Tauri begin fusing hydrogen into helium in their cores, they enter "adulthood" as full-fledged *main-sequence* stars. Such stars fall into one of seven main spectral classes, which are labeled in order of decreasing intrinsic brightness as *O*, *B*, *A*, *F*, *G*, *K*, or *M* (see the sidebar on page 30). Let's observe each stellar class — from massive, brilliant *O*- and *B*-type supergiants to dim *M*-type red dwarfs.

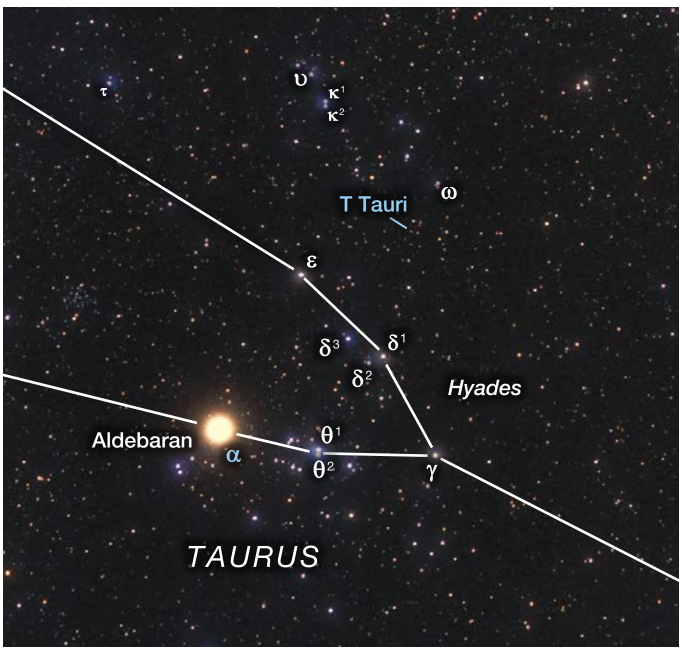
Let's start with **Xi (ξ) Persei**, named Menkib, a 4th-magnitude *O*-type star and one of the hottest, bluest stars visible

M27 LOOK-ALIKE Located in the constellation Perseus, M76 is approximately 3,400 light-years from Earth. It's a planetary nebula, an expanding shell of gas around a dying star. M76's twin lobes of outflowing gas earned it the nickname Little Dumbbell Nebula, since it resembles the appearance of another famous planetary: M27 in the constellation Vulpecula, the Fox.

T TAURI: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY
M76: NASA / ESA / STSCI

to the unaided eye. With a mass of 30 suns and a temperature of 35,000 kelvin, Menkib appears icy blue in my 10-inch Dobsonian. Like many solitary stars, it offers no additional detail in a telescope. However, Xi Persei illuminates the adjacent California Nebula, an interstellar hydrogen cloud about 2° long that's visually within reach of rich-field telescopes in very dark skies. *O*-type suns like this comprise just one of every 2 million stars in our solar neighborhood.





Now let's look toward the sprawling open cluster Melotte 20 that surrounds Alpha (α) Persei, also called Mirfak. These stars belong to a collection of newly formed *O* and *B* stars known as the Perseus OB3 association that includes the *B*-type, 3rd-magnitude main-sequence star **Delta (δ) Persei**, about 4° southeast of Mirfak. In my 10-inch Dob, it exhibits a paler blue color than Xi Persei and is situated in a superb, starry field along the northern Milky Way.

The splendid triple **Iota (ι) Cassiopeiae** consists of three mid-size main-sequence stars arranged in a tiny triangle, with a primary *A*-type star of magnitude 4.7 and a closely spaced *F*-type secondary of magnitude 6.9 at a separation of 3.0″. A third *K*-type companion of magnitude 9.1 lies 6.9″ away. I see all three easily under good seeing in the 85-mm refractor at 133×. The primary appears bone-white, the secondary slightly warmer, while the third component looks pale orange.

Nearby **Eta (η) Cassiopeiae** (Achird) also features two main-sequence stars — a *G*-type primary of magnitude 3.5 and a *K*-type secondary of magnitude 7.4. They present a lovely color contrast in my 85-mm at 46×, with the primary showing a yellow-gold hue and the secondary some 13.5″ away appearing deep orange.

Our last stop on the main-sequence phase is the dim pair of *M*-type dwarf stars GX and GQ Andromedae. They comprise the binary star **Groombridge 34**, located about 5° northwest of the Andromeda Galaxy (M31). Separated by 34.1″, GX and GQ shine at magnitudes 8.3 and 11.4, respectively. I see a hint of reddish orange color in GX, but GQ offers little color even in the 10-inch Dobsonian. GX is just 1/50th as bright as our own Sun with a mass about 39% as large. Groombridge 34 lies just 11.6 light-years away. While red dwarfs don't look spectacular, they comprise three-quarters of the hundreds of billions of stars in the Milky Way that generate their energy through thermonuclear fusion.

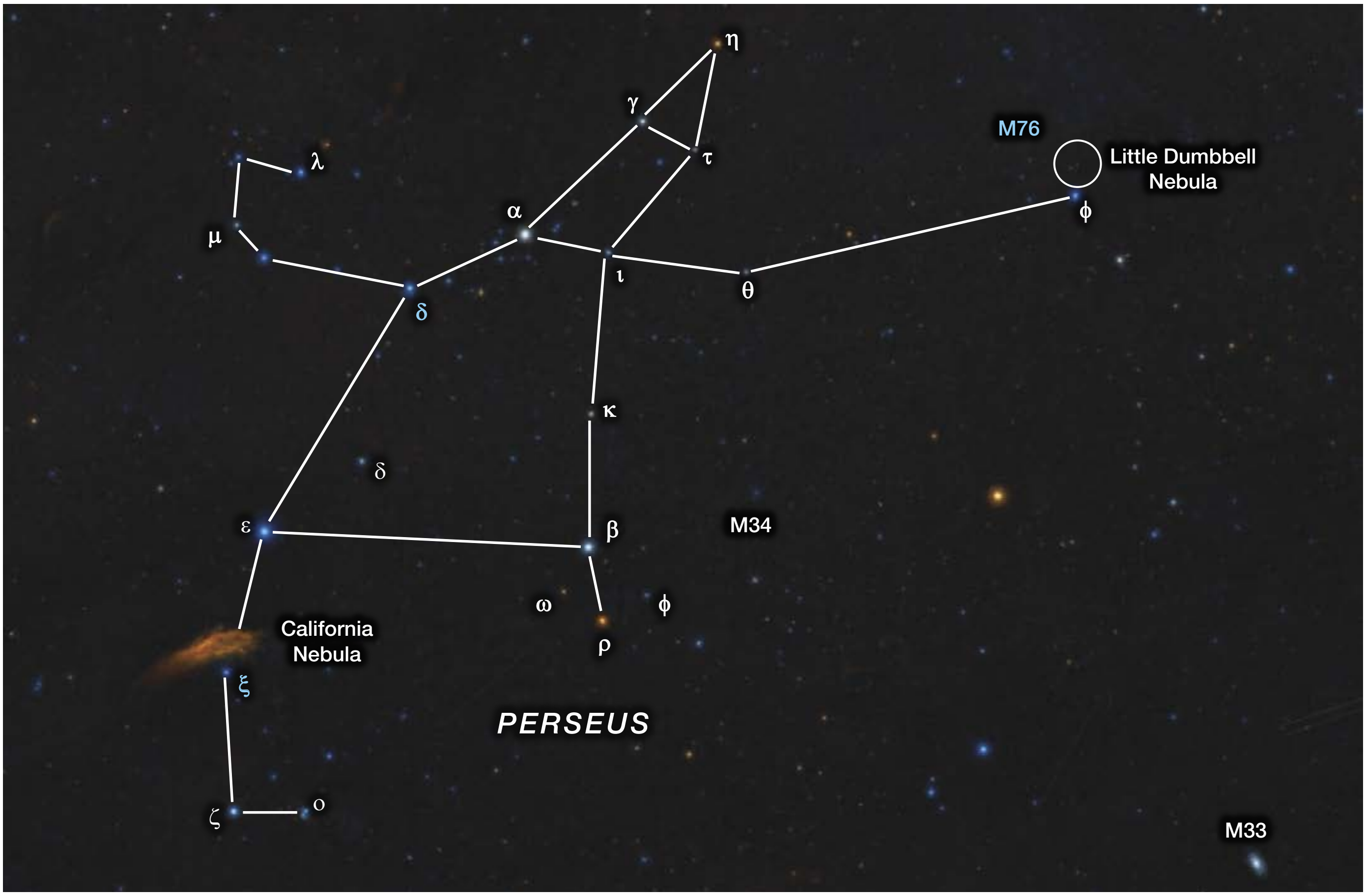
Evolved Stages: Small and Mid-Size Stars

Eventually, stars run low on hydrogen fuel and enter their final act. Massive *O* and *B* stars burn hydrogen quickly and die after several millions of years. Mid-size *A* through *K* stars last for hundreds of millions to billions of years. And red dwarfs consume their fuel frugally and last for tens to hundreds of billions of years.

As it runs out of hydrogen, the core of a mid-size star produces less energy to push back against the infalling outer layers. Its central region contracts and heats sufficiently to begin nuclear fusion of the shell of hydrogen around the flagging, helium-rich core. This extra energy expands the star's outer layers, and it becomes a red giant as it cools, reddens, and grows much brighter.

Alpha (α) Tauri, Aldebaran, low but rising in the east in November, offers a prime example. In binoculars, this brilliant, 1st-magnitude star appears as the bright orange "eye" of

AKIRA FUJII (2)

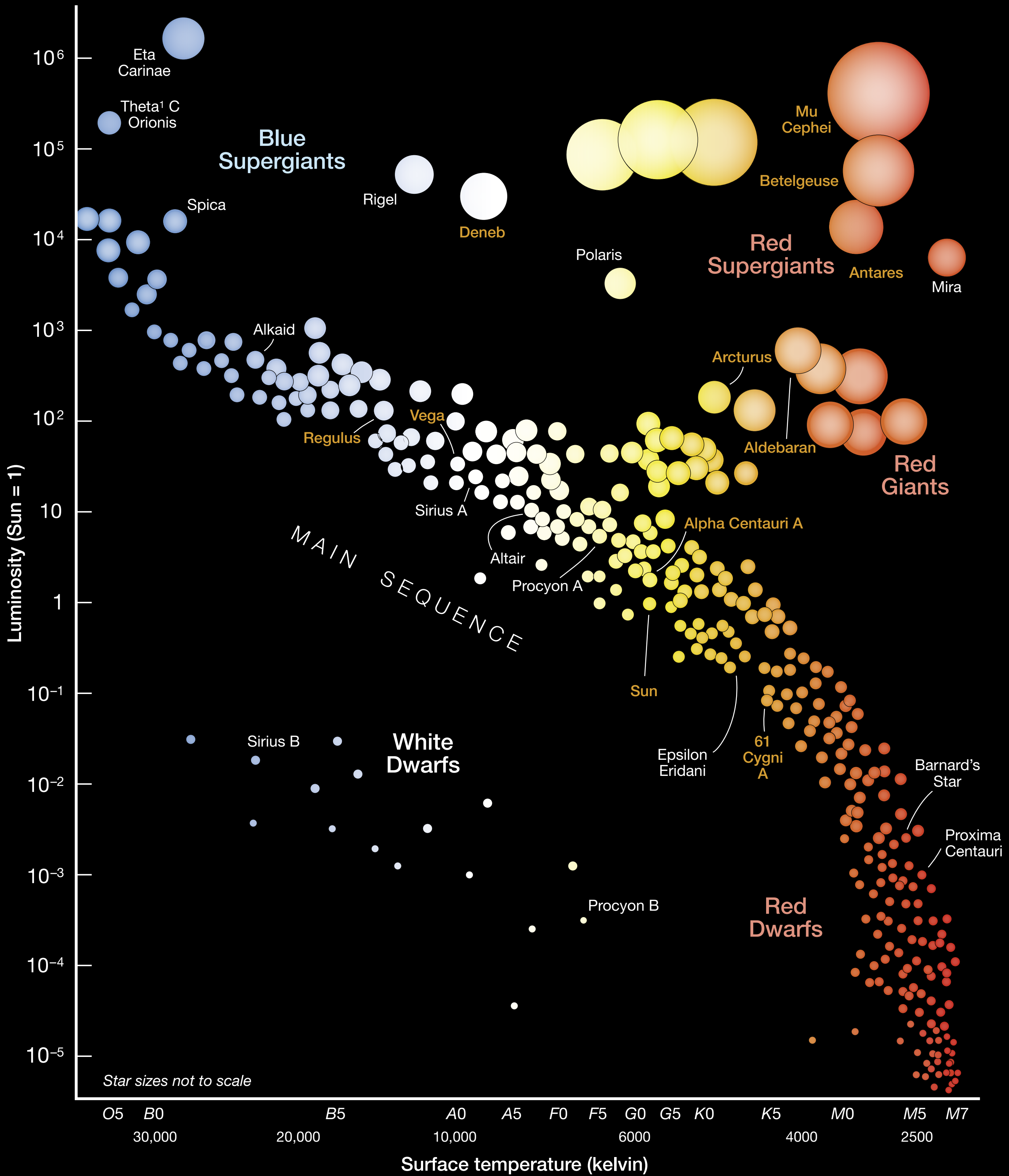


POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

A History of Stellar Evolution

Object	Name	Type	Constellation	Mag	Size/Sep	RA	Dec.
IC 5146	Cocoon Nebula	Emission nebula	Cygnus	7.2	10′ × 10′	21^{h} 53.4^{m}	+47° 16′
Barnard 168	—	Dark nebula	Cygnus	—	100′ × 10′	21^{h} 53.4^{m}	+47° 16′
T Tauri	—	Protostar	Taurus	9.3 – 10.7	—	04^{h} 22.0^{m}	+19° 32′
Xi Persei	Menkib	*O*-type star	Perseus	4.1	—	03^{h} 58.9^{m}	+35° 47′
Delta Persei	Adid Borealis	*B*-type star	Perseus	3.0	—	03^{h} 42.9^{m}	+47° 47′
Iota Cassiopeiae	—	Triple-star system	Cassiopeia	4.7, 6.9, 9.1	3.0″, 6.9″	02^{h} 29.0^{m}	+67° 24′
Eta Cassiopeiae	Achird	Double star	Cassiopeia	3.5, 7.4	13.4″	00^{h} 49.0^{m}	+57° 49′
Groombridge 34	GX, GQ Andromedae	Double star	Andromeda	8.3, 11.4	34.1″	00^{h} 18.4^{m}	+44° 01′
Alpha Tauri	Aldebaran	Red giant star	Taurus	+0.9	—	04^{h} 35.9^{m}	+16° 31′
WZ Cassiopeiae	—	AGB/carbon star	Cassiopeia	7.1	—	00^{h} 01.3^{m}	+60° 21′
M76	Little Dumbbell Nebula	Planetary nebula	Perseus	10.1	187″	01^{h} 42.3^{m}	+51° 35′
van Maanen's Star	—	White dwarf star	Pisces	12.4	—	00^{h} 49.2^{m}	+05° 23′
40 Eridani B	—	White dwarf star	Eridanus	9.5	—	04^{h} 15.3^{m}	–07° 39′
Mu Cephei	Garnet Star	Red supergiant	Cepheus	4.1	—	21^{h} 42.5^{m}	+58° 47′
Veil Nebula	—	Supernova remnant	Cygnus	~5.0	180′	20^{h} 50.6^{m}	+30° 55′
M1	Crab Nebula	Supernova remnant	Taurus	8.5	6′ × 4′	05^{h} 34.5^{m}	+22° 01

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



Eta
Carinae
Theta¹ C
Orionis
Blue
Supergiants
Spica
Rigel
Deneb
Polaris
Mu
Cephei
Betelgeuse
Red
Supergiants
Antares
Mira
Alkaid
Arcturus
Vega
Regulus
Aldebaran
Red
Giants
Sirius A
Altair
Procyon A
Alpha Centauri A
MAIN SEQUENCE
Sun
Epsilon
Eridani
61
Cygni
A
Sirius B
White
Dwarfs
Barnard's
Star
Proxima
Centauri
Procyon B
Red
Dwarfs
Star sizes not to scale
Luminosity (Sun = 1)
10⁶
10⁵
10⁴
10³
10²
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
O5 B0 B5 A0 A5 F0 F5 G0 G5 K0 K5 M0 M5 M7
30,000 20,000 10,000 6000 4000 2500
Surface temperature (kelvin)

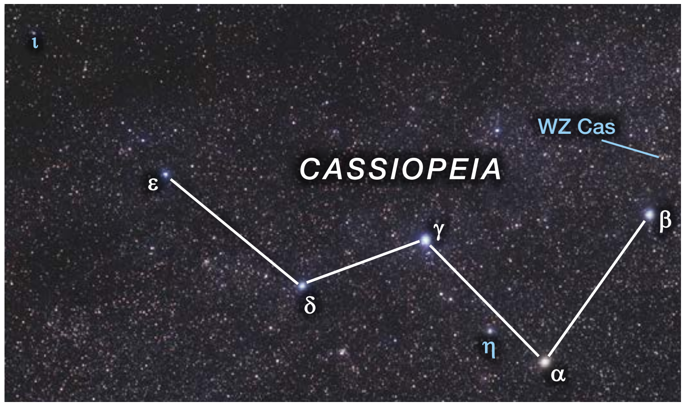
Stellar Classification and the Color-Magnitude Diagram

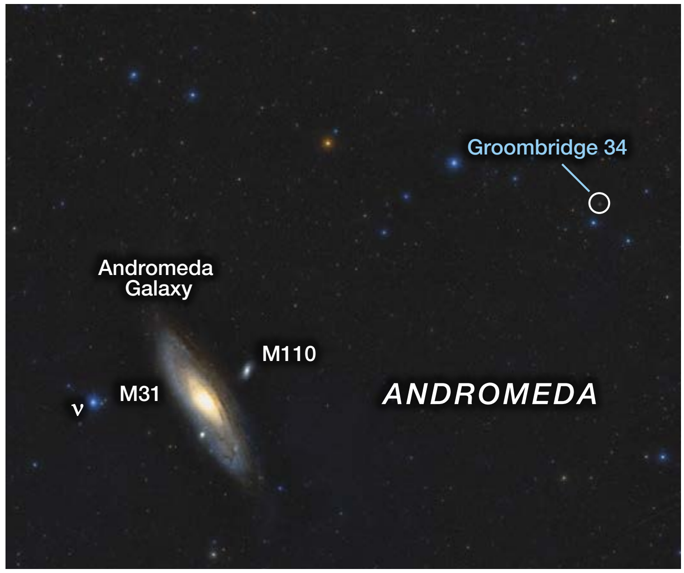
In the early 1900s, astronomers discovered a curious relationship between the color (effective temperature) and the intrinsic brightness of many stars. Blue stars shine hotter and brighter, white and yellow stars of intermediate temperature shine less brightly, while red stars are coolest and dimmest of all. Astronomers call this plot of color versus brightness the color-magnitude, or Hertzsprung-Russell (HR), diagram. The tidy and slightly curved line upon which many stars fall is called the *main sequence*.

We now understand that stars spend the majority of their lives on the main sequence and remain there so long as they fuse hydrogen into helium in their cores. A star leaves the main sequence once its core begins to fuse heavier elements. Mid-size stars swell, cool, and grow much larger and brighter to become *red giants*, and then they cast off their outer layers to finally become *white dwarfs*. The most massive *O* and *B* stars also move off the main sequence in a complex process that alters their spectral type as they become blue, yellow, and red *supergiants*. In time, they die in immense supernova explosions and leave their cores behind as neutron stars or black holes.

Astronomers classify stars from the hottest (and bluest) to the coolest (and reddest) as spectral type *O*, *B*, *A*, *F*, *G*, *K*, and *M* (made memorable by a favorite of astronomy graduate students, "Oh Boy An F Grade Kills Me"). Each type splits into a finer scale denoted by numbers 0 to 9. To distinguish a main-sequence star from giants and supergiants, researchers add a Roman numeral to the spectral type. Main-sequence stars have a Roman V appended, while the numerals I to IV denote more evolved stars. For example, Luyten's Star, a red dwarf in Canis Minor, has a spectral type *M*3.5V; the red supergiant Betelgeuse in Orion a type *M*2I, and the red giant Aldebaran a type *K*5III. Our Sun is a *G*2V main-sequence star.

HERTZPRUNG-RUSSELL DIAGRAM Developed by astronomers Ejnar Hetzsprung and Henry Norris Russell, this graph plots stellar luminosity against stellar color. It shows the relationship between the stars' absolute magnitudes, or luminosities, and their stellar classifications, or effective temperatures. The diagram was created independently in 1911 by Hertzsprung and in 1913 by Russell, and represented a major step toward understanding of stellar evolution.



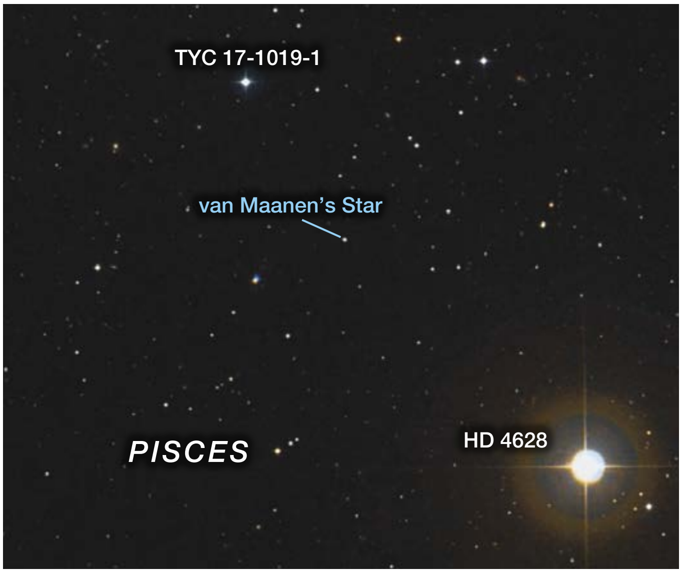


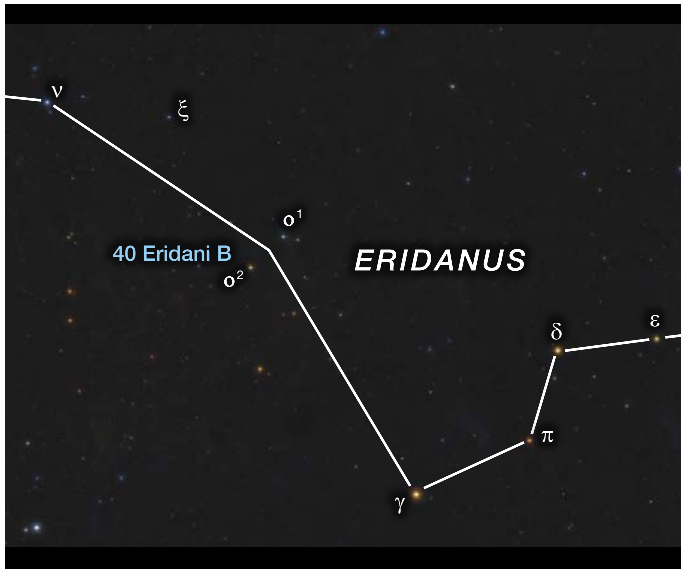
the celestial Bull against the stars of the more distant Hyades star cluster. Older and a little more massive than the Sun, Aldebaran offers a preview our star's future demise.

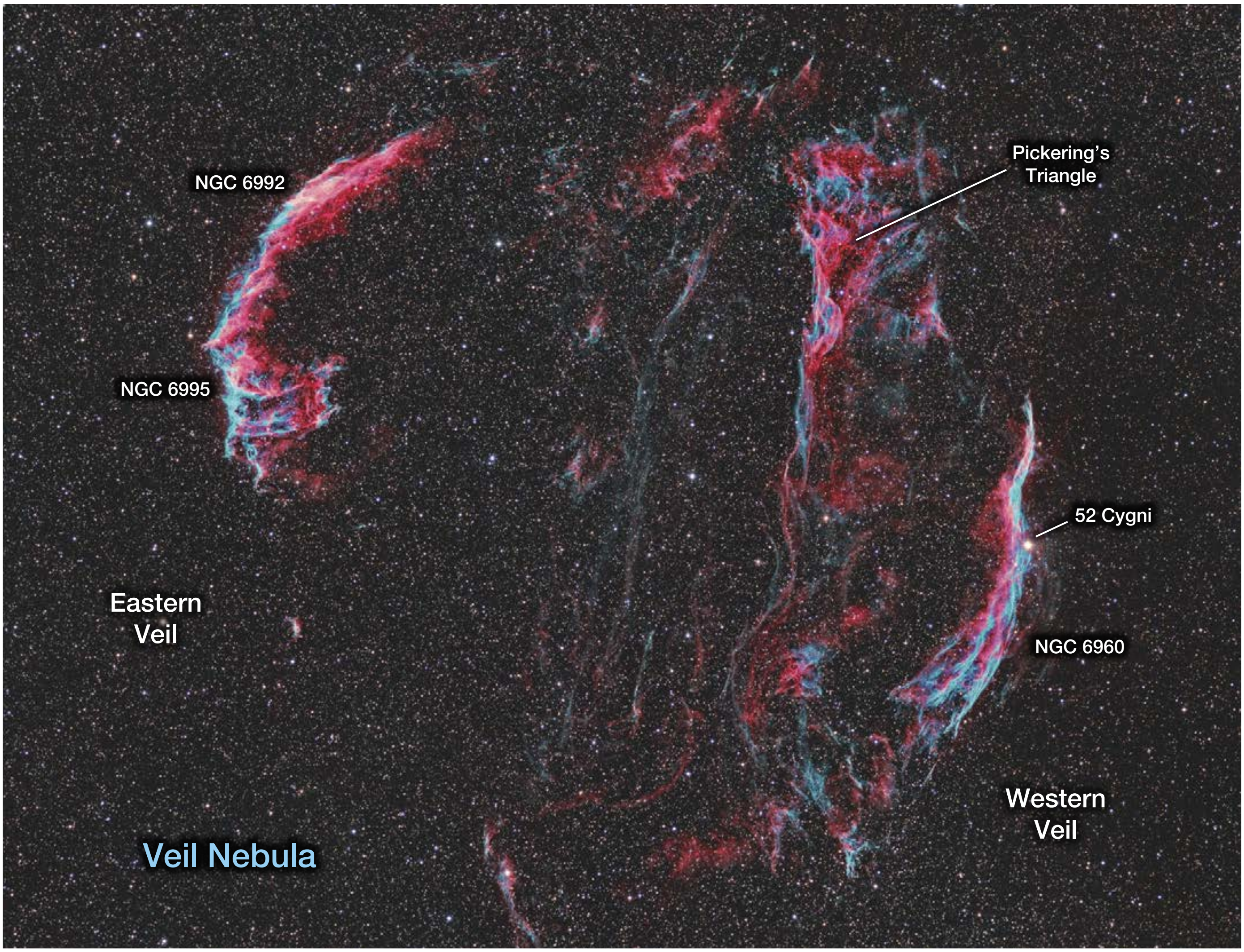
Eventually, a red giant's helium-rich core compresses and begins fusing helium into carbon. The star shrinks and dims slightly, but when the helium runs out, the game is up. A thin shell of helium continues to burn around a carbon-oxygen core that can't grow hot enough for further nuclear reactions. It balloons into an immense red asymptotic giant branch (AGB) star. Convection deep inside dredges up carbon into the cooler atmosphere where it forms molecules that preferentially pass red light and give the star a deep red-orange color. One such carbon star is **WZ Cassiopeiae**, about 1½° northwest of Caph, Beta (β) Cassiopeiae. WZ nominally shines at magnitude 7.1, but dims by roughly a full magnitude every 186 days. It appears eerily red in my 10-inch reflector at 92×, especially when defocused slightly.

As the core sputters intermittently, an AGB star ejects and sets aglow its outer layers as a planetary nebula, such as **M76**, which lies nearly 1° north-northwest of 4th-magnitude Phi (φ) Persei. Sometimes called the Little Dumbbell Nebula because its bilobed structure resembles the brighter Dumbbell Nebula (M27) in Vulpecula, this 10th-magnitude planetary

HERTZPRUNG-RUSSELL DIAGRAM: LEAH TISCIONE / S&T; CASSIOPEIA: AKIRA FUJII; ANDROMEDA: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY







▲ **SUPERNOVA REMNANT** Astrophotographer and Contributing Editor Ron Brecher of Ontario, Canada, produced this two-panel mosaic of the Veil Nebula's gossamer structure with a Takahashi FSQ-106 refractor, a QHY-367C Pro one-shot color camera, and Optolong UV/IR and L-Ultimate filters. See the September 2021 issue, page 28, for an article by Contributing Editor Howard Banich on sketching the Veil Nebula.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY (2) pops into view at my suburban location in my 85-mm refractor at 67× with the help of a UHC filter. At 133×, I could see clearly its bar-like shape, which extends about 3′ northeast to southwest on its long axis, and spans 1.8′ on its short axis. My 10-inch Dobsonian at 133× reveals a dark gap at the nebula's middle that separates its two lobes. M76 appears symmetrical, and in my 10-inch scope with averted vision I could see evidence of faint arcs at the end of each lobe. A 16th-magnitude central star that eludes my eye ionizes the nebula, causing it to glow.

After a planetary nebula dissipates, its hot and dense core remains as a dim white dwarf. Observers with large apertures can spot **van Maanen's Star**, the third-nearest white dwarf to the Sun and the closest solitary white dwarf. It's located in a sparse field about 2° south of Delta Piscium and 13′ northeast of HD 4628, a 5th-magnitude, orange *K*-type main-sequence star. At magnitude 12.4, this white dwarf isn't much to look at, even in my 10-inch.

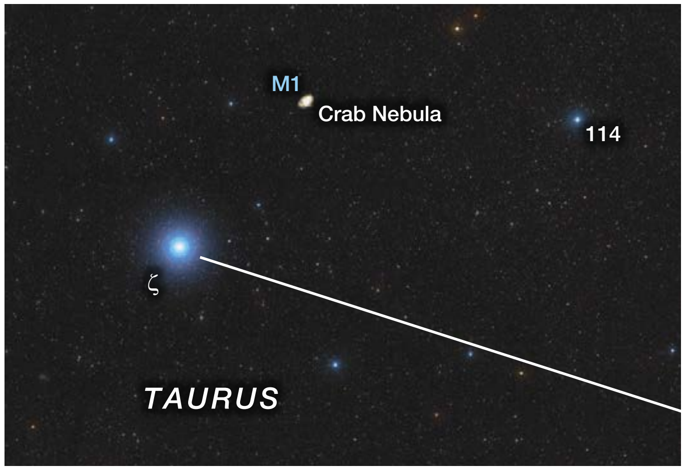
However, if you're out later on a November night, a more readily observable white dwarf lies in the lovely triple system 40 Eridani, low in the eastern sky. Also designated Omicron^2 (o^2) Eridani, the system's yellow primary (40 Eridani A), named Keid, shines at magnitude 4.4. Just 82.7″ to the east-southeast, you'll see a pair of fainter stars separated by 7.9″ — the blue-tinged, 9.5-magnitude white dwarf **40 Eridani B** and the 11.2-magnitude red dwarf 40 Eridani C. The white dwarf is a fairly easy target in my 10-inch at 133×, where it appears bone-white compared to its dimmer, creamy companion. What a delight to see this stellar cinder, the exposed core of a star!

The Demise of Massive Stars

Like their smaller brethren, massive stars burn through hydrogen and helium and develop carbon-rich cores. But they have enough mass to squeeze the carbon atoms into heavier elements, a process that continues until the star's interior resembles the layers of an onion, with heavier elements undergoing fusion in the core and lighter elements fusing in concentric shells around it. The star's brightness changes only slightly, but it undergoes a complex series of contractions and expansions with corresponding changes in color.

The lovely *M*-type red supergiant **Mu (μ) Cephei** offers a prime example of an evolved massive star that has swollen to 1,000 times the size of our Sun. Although it lies more than 5,900 light-years away, Mu shines with an apparent magnitude of 4.1 (see the center star chart on pages 42–43). William Herschel dubbed it the Garnet Star because of its deep-orange hue. It appears the color of a Seville orange in my 85-mm refractor at 67×. The star lies at the northern edge of the large, circular Elephant's Trunk Nebula (IC 1396), a favorite of astrophotographers.

The cascade of nuclear fusion in large, massive stars ends with an iron-rich core that produces no net energy. Shell burning continues, but eventually the star quickly collapses under its own gravity, crushing the core, then snapping back in an immense supernova explosion. We haven't seen a naked-eye supernova in the Milky Way since 1604. However, we can see remnants of a nearby supernova in the famous **Veil Nebula** complex, also called the Cygnus Loop, where shockwaves from a supernova that exploded about 21,000 years ago collide with the interstellar medium.



Lovely in any telescope, this sublime complex reveals intricate details at any magnification, though I prefer to see the whole thing in one view. The Veil Nebula spans about 3°, so I usually turn to my 85-mm refractor and 35-mm Panoptic to get a 4° field of view. Under dark skies, the graceful, arching eastern section of the nebula (NGC 6992 and NGC 6995) appears brightest and offers a hint of lacework detail. The fainter western section, NGC 6960, overlaps with the 4.2-magnitude foreground star 52 Cygni. In the small scope, I can see just hints of the fainter Pickering's Triangle section between the Veil's two main arcs.

After the supernova explosion, the leftover core of the massive star — if it survives at all — will be a superdense neutron star or a black hole. Can we see these exotic remnants? We're not going to see a black hole, but at least one neutron star lies within visual reach of large amateur scopes. It resides near the center of 8.5-magnitude **M1**, the Crab Nebula, in Taurus. Can I see it? Not with my 10-inch reflector I can't. Contributing Editor Bob King tried unsuccessfully to see this 16.5-magnitude object with his 15-inch reflector, but he managed the feat with a 30-inch reflector at 572× in good seeing.

If you'd like to try your luck, wait until the Crab Nebula climbs to the meridian. If you can find the star, or even if you aim your telescope so the Crab lies within your field of view, you can at least say that you'd looked at a neutron star and completed this stellar life-cycle tour.

■ Contributing Editor **BRIAN VENTRUDO** is a writer, scientist, and longtime amateur astronomer. He enjoys surfing the Milky Way with wide-field telescopes from his home near Calgary, Canada (see his website **CosmicPursuits.com**).

FURTHER READING: For a deeper dive into the life cycle of stars, see the Going Deep column in the October 2024 issue, page 58.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

Here Come the Su

LIGHTNING AND THUNDER
In May 2024, X-ray flares and particle explosions from the Sun created a strong geomagnetic storm at Earth.

NASA / SDO

The latest round of solar activity shows that predicting our star's behavior is still a challenge.

The Sun was supposed to be boring.

It had been lackluster for years, showing fewer spots, flares, and plasma eruptions than expected throughout the 2010s. Solar activity oscillates up and down on an 11-year cycle, but the cycle that began in late 2008, called Solar Cycle 24, was decidedly less than stellar.

In 2019, a panel of experts convened to forecast what would happen next — the fourth of a series of such panels going back decades. The latest panel's job was to predict the duration and severity of Solar Cycle 25, expected to begin late in 2019 or 2020. Panel members solicited predictions from the community, receiving more than 50 individual forecasts. They then sought to synthesize the forecasts and assemble them into a single prediction, bounded by appropriate margins of uncertainty.

In April 2019, on the eve of the new cycle's beginning, they released their report. "We expect Solar Cycle 25 will be very similar to Cycle 24: another fairly weak cycle, preceded by a long, deep minimum," stated prediction panel co-chair Lisa Upton (now at Southwest Research Institute, Boulder) in a press release at the time.

But within a year, Cycle 25 blew past expectations. Sunspot activity ramped up, even coming close to the outer boundaries of the uncertainty ranges from the synthesized forecast. And it didn't stop there: The past few years have featured solar activity that's stronger than it has been in a good while.

The original forecast called for a peak in July 2025, with around 115 active sunspots per month. But by July 2024 (a full year earlier than expected), activity was already cresting with close to 200 total spots — a number not seen in two decades, or two cycles ago, and 40% greater than the prediction panel had forecast.

At its peak in 2024, the Sun was launching a *coronal mass ejection* (CME) roughly every other day, some of which sent energetic charged particles flying toward Earth. Our star often hosted multiple prominences at any one time, too. Skywatchers enjoying the total solar eclipse that passed over much of North America on April 8th that year were delighted to see bright red prominences extending beyond the Moon's dark disk. Shortly after that, in May 2024, multiple CMEs struck Earth with a ferocity not seen since 2003. The geomagnetic storms (collectively named Gannon in memory of

Starlink Snafu

A 2022 geomagnetic storm dragged 38 of 49 Starlink satellites, newly launched by SpaceX, back into Earth's atmosphere.

space-weather physicist Jennifer Gannon) produced aurorae across the globe, visible as far south as Mexico, Portugal, and northern China.

In time, the Sun will do its usual magnetic thing and wind itself down, reaching a minimum of activity around 2030. Current observations are already showing a decline, an indication that the peak may have come and gone — although whether we are really over the hump is debated, as it can take time for a trend to reveal itself in the variable month-to-month data, Upton explains.

"While we're getting fairly good at being able to say, 'Well, we think this cycle is going to be about this amplitude,' we're nowhere near the capability of being able to predict when a peak will be over," she says.

It's not that Cycle 25 is especially strong — it's far weaker than the cycles of the 1980s and '90s and nowhere near the frenzy of activity of the late 1950s. But it seems to be bucking a decades-long slowdown in solar activity. (That might in turn be part of a much longer oscillation, though we'll need another century of data to know for sure.) The current cycle has refused to behave in any sensible direction: too weak to establish a new trend in solar output, yet too strong to continue the pattern of declining activity.

Most importantly, despite our decades of advances in instrumentation and theory and our centuries of solar observations, Cycle 25 has shown how much the Sun still has to teach us.

What We Know — and What We Don't

In 1843, German astronomer Samuel Heinrich Schwabe — a self-taught amateur — became the first person to clearly identify a regular solar cycle (*S&T:* Apr. 2025, p. 72), which he estimated to be 10 years long after 17 years of dedicated observations. Several years later, when the Swiss astronomer Rudolf Wolf dug through historical records, he was able to reconstruct Schwabe's cycle (more precisely measured as 11 years long) going all the way back to 1755, which he marked as the beginning of the first numbered solar cycle.

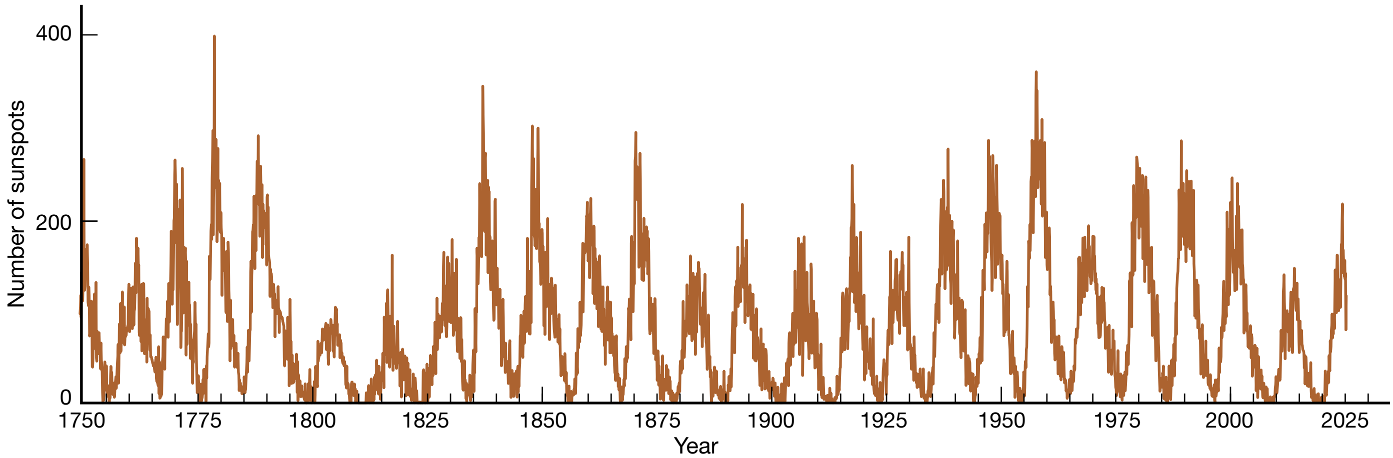
In the early 20th century, American astronomer George Hale was the first to observe magnetic fields beyond Earth, embedded in sunspots. He also noticed that the polarity of the Sun's magnetic field flipped between cycles, and he proposed that there was some sort of connection between the two phenomena.

In 1961, Horace Babcock (Caltech) made the first correct qualitative description of what the Sun is doing as its activity cycles up and down. In Babcock's model, during solar minimum — which by convention is the start of a new cycle — the Sun's enormous magnetic field is relatively uniform. It looks much like Earth's does, similar to that of a gigantic bar magnet. But the Sun is not solid like Earth is, and so its equator rotates faster than its poles. This *differential rotation* twists up the magnetic field like spaghetti at the end of a twirling fork.

The twisted magnetic field lines plunge in and out of the visible surface of the Sun. Where they do, a sunspot appears.

GANNON STORM Observers under 2024's unexpected geomagnetic upheaval saw aurorae as far south as the Mojave National Preserve in California, pictured here. (The white lights come from nearby Las Vegas.)

JERRY MASON



▲ **THROUGH THE YEARS** For centuries, astronomers have recorded the number of sunspots (the orange line denotes monthly sunspot count) and noted their 11-year cycle. However, the behavior of any one cycle — especially the strength and timing of its peak — is challenging to predict.

BEATRIZ INGLESSIS / *S&T*; SOURCE: NOAA SPACE WEATHER PREDICTION CENTER

Sunspots appear black because the enormous magnetic pressure of the bundled field lines suppresses the boiling motions of plasma, creating a cooler patch. Even though sunspots still have temperatures of thousands of degrees, they are slightly cooler than their surroundings, so they appear dark to us in the visible spectrum.

The magnetic fields stretch upward in big, snarly loops into the Sun's outer atmosphere, the *corona*. Sometimes, the fields become so tangled that they snap and rearrange themselves, releasing huge quantities of energy once stored up as magnetic tension.

The released energy can trigger a variety of solar weather phenomena. Sometimes it's just a simple flare, as magnetic energy converts into a flood of X-rays. Other times, sudden rearrangements launch plasma from the lower corona out into the solar system, creating a CME. When these plasma clouds strike Earth, their effects can range from a mild auroral light show to a nasty geomagnetic storm.

As the twisted magnetic fields release their pent-up energy, and as remnant fields flow toward the poles, solar activity starts to diminish. Eventually, the Sun's magnetic field settles back into its much simpler north-south configuration, but now with the poles reversed. At that time, the dance of plasma and magnetism starts anew with a fresh cycle.

Unfortunately, magnetic fields are notoriously complex, especially in the plasma-dominated regimes in and around the Sun. So while most physicists believe that this general story holds true, the devil — and the accurate predictions — is in the details.

For example, nobody knows exactly why the Sun takes roughly 11 years to complete this cycle or why it's been able to maintain that rhythm for hundreds and perhaps even millions of years. And more importantly, while this general picture may be enough for textbooks, it's insufficient to enable precise predictions of solar behavior in the future, whether to satisfy the space community's planning needs or to prepare those of us on Earth hoping for a show.

Diverse Expectations

To be fair, solar forecasting is a relatively new discipline, mixing equal parts science and art. The first prediction panel met in 1989, at the beginning of Cycle 22, and while techniques, data sets, and observatories have much improved in the decades since then, mysteries still abound when it comes to the Sun and its activity.

Solar forecasting generally involves an attempt to include as many details of the underlying physical processes as possible, while still holding true to historical patterns. The simplest models involve no physics whatsoever. They are straightforward attempts built upon centuries of record-keeping, with simple mathematical expressions used to replicate that past behavior and predict future cycles.

In 2018 a group of researchers led by Fuyu Li (then at Yunnan Observatories, China) took this approach one step further by fitting a more complex function to the historical records. The method led them to predict that Cycle 25 should be stronger than the previous cycle and would peak with around 170 sunspots in October 2024. This count is close to what we've seen, for sure, but the similarity may have just been luck, since the prediction didn't take into account any of the physics actually powering the Sun's cycles.

Another approach was led by Scott McIntosh (National Center for Atmospheric Research) and published in 2020, a year after the Solar Cycle 25 prediction panel convened. McIntosh and colleagues included not just the number of sunspots but also the exact timing of the transition to each new cycle through 270 years of historical data. The researchers then fitted a mathematical expression to accommodate all of these data, predicting that Cycle 25 would be among the most powerful cycles since record-keeping began, with a whopping 230 or so sunspots at its peak. While Cycle 25 certainly beat everybody's expectations, it did not rise to this forecast's intensity.

More sophisticated models fold in known physics about the relationships between the Sun's plasma, its tangled network of magnetic fields, the sunspots those fields generate, and the phenomena that they can produce. These kinds of models have only been possible in the past couple decades, as advances in computational capacity have made simulating the dynamic solar magnetic field feasible.

But even with powerful computers at scientists' disposal, it's impossible to keep track of all the details and interactions. So researchers try to find signposts that can guide them to which particular physical processes are most important. And here is where different research groups disagree, leading to a variety of forecasts.

For example, in 2018 Upton and David Hathaway (then at Stanford University) started with the idea that the strength of the Sun's polar magnetic field during the minimum phase of the cycle is the best predictor for upcoming activity. They took measurements of Cycle 24's polar magnetic fields and used a computer model to predict how those fields would evolve over the years. Their forecast lowballed the new cycle, predicting it would be even weaker than the last, continuing what at that time appeared to be a general downward trend in solar activity.

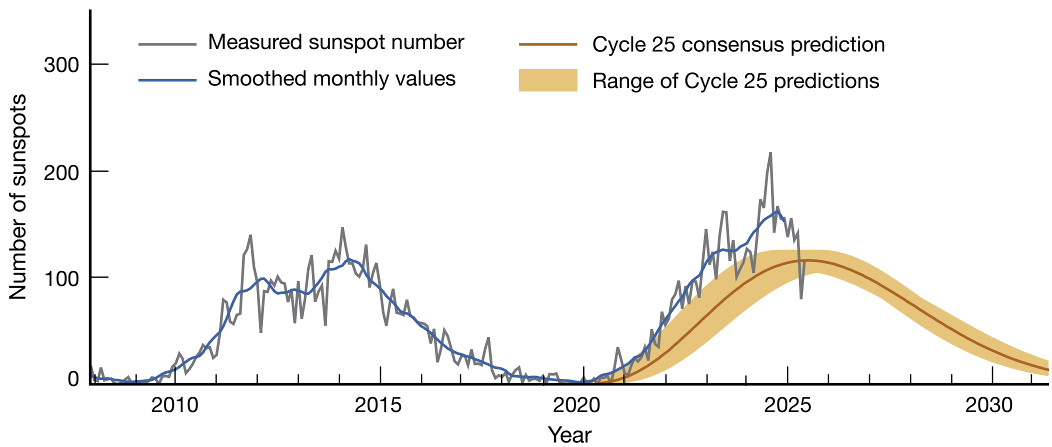
However, also in 2018, a pair of researchers, Prantika Bhowmik and Dibyendu Nandy (then both at the Indian Institute of Science Education and Research, Kolkata), came much closer. They simulated the Sun's entire magnetic field, including surface fields as well as interior ones. They then put in more than a century of sunspot counts to produce a detailed model of what the Sun's field is doing when. They found that changes in the Sun's activity from one cycle to the next are linked to random variations in sunspots' orientation. The subsequent evolution of those magnetized spots determines the strength of the Sun's large-scale magnetism.

Once Bhowmik and Nandy were able to reproduce 100 years of past activity, they used the simulation to predict what the next decade would look like. Their forecast, published in 2018 in *Nature Communications*, said that Cycle 25 would be similar to or slightly stronger than the previous cycle, peaking in 2024 (give or take a year) with between 109 and 139 sunspots. While Cycle 25's strength beat their expectations, they accurately augured the peak's timing, and they were also correct that the cycle ended up breaking the decades-long trend of weakening activity.

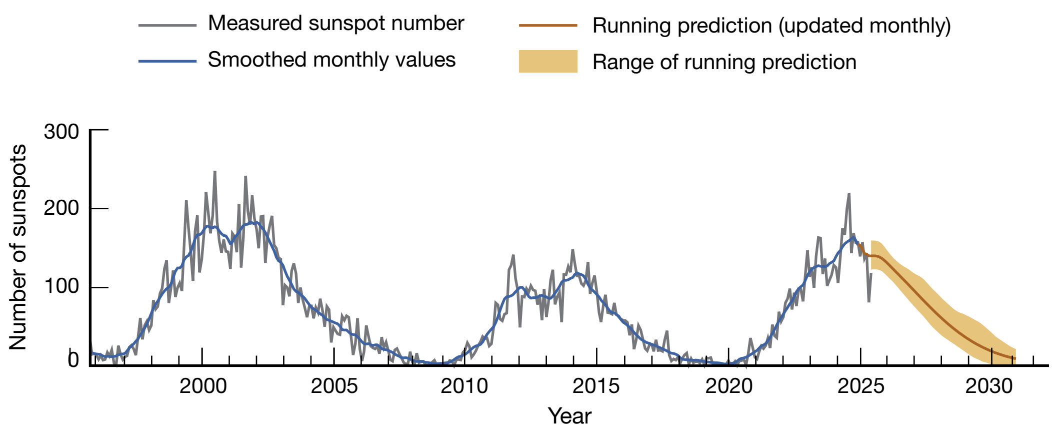
The Future of Forecasting

Forecasters for the next solar cycle have more tools at their disposal than their predecessors did. A fleet of ground- and space-based observatories already monitor the Sun 24/7, and more are joining them, providing an unprecedented wealth of observational data that scientists can use to calibrate, refine, and extend existing models.

▶ FIRST PREDICTION Many scientists thought Cycle 25 would be roughly as weak as Cycle 24, but the sunspot counts (dark gray line) blew past the predictions (red line) and even past the outer boundaries of the uncertainty ranges (shaded orange).

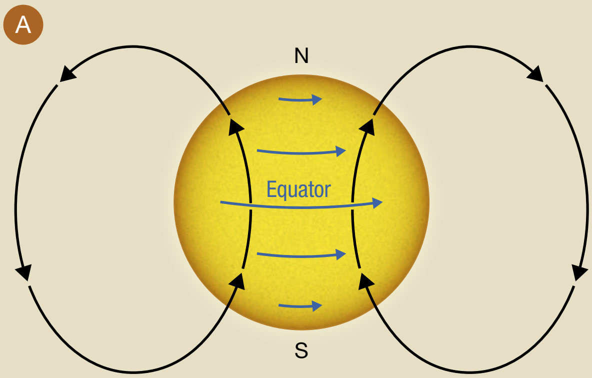


▶ NEW PREDICTION As Cycle 25 begins its slide down toward minimum, and because new data and new techniques are rapidly being made available, the National Oceanic and Atmospheric Administration now updates the solar cycle forecast every month. This prediction (red line, orange shading) was posted in July 2025.

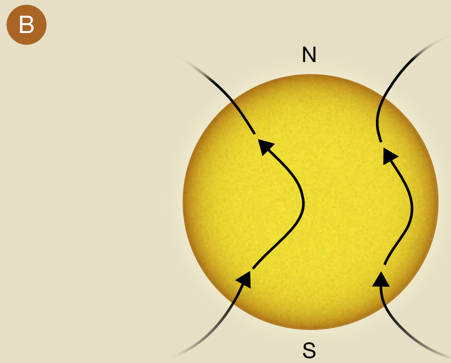


BEATRIZ INGLESSIS / S&T; SOURCE: NOAA SPACE WEATHER PREDICTION CENTER (2)

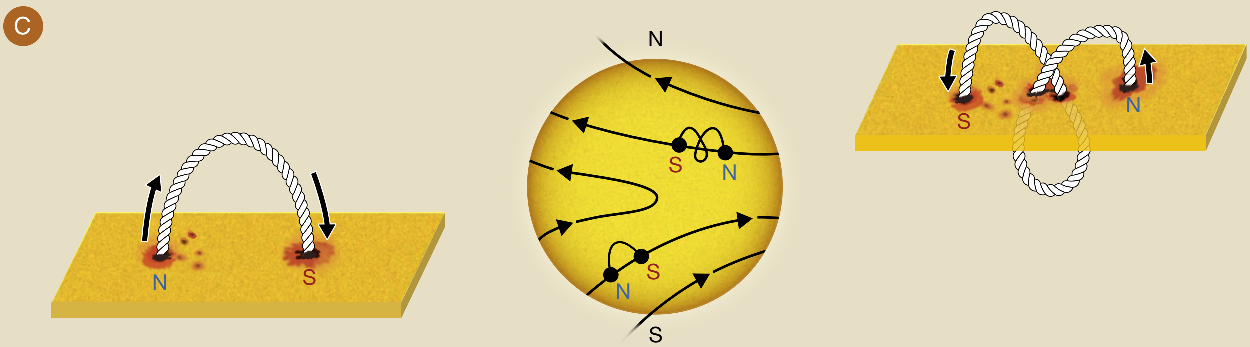
What We Think We Know About the Solar Cycle



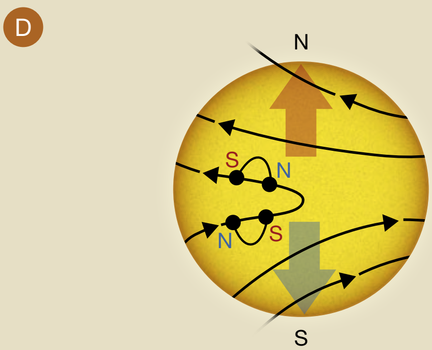
▲ The Sun starts with a simple magnetic field, one that has a north (N) and south (S) pole like a bar magnet. But unlike a bar magnet, the Sun isn't a solid body — its equator rotates faster than its poles.



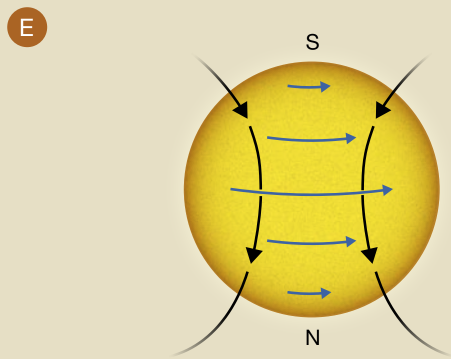
▲ This *differential rotation* deforms the magnetic field, which begins to wrap around the Sun.



▲ As magnetic field lines wend their way around the Sun, the magnetic field strengthens in the direction along the equator. In places, it rises through the visible surface as *sunspots*. At their simplest, sunspots are tilted pairs of opposite magnetic polarity — one north and one south *(left)*. Larger groups may have more complex configurations *(right)*. Regardless, the sunspot that's closer to the pole, known as the following sunspot, has a polarity opposite that of the hemisphere it's in.



▲ As the cycle wears on, sunspots emerge ever closer to the equator, where magnetic fields of opposing pairs meet and cancel out. Plasma flows in the Sun transport leftover magnetic fields — dominated by the following footprints — toward the poles, reversing the field there.



▲ The magnetic field at the poles is thus crucial for setting up the next solar cycle, which begins, as before, with a neatly ordered field — but with the polarity of the hemispheres reversed.

BEATRIZ INGLESSIS / S&T

Since the beginning of Cycle 25 in 2019, several new heliophysics missions have launched, including the European Solar Orbiter and India's Aditya L1 spacecraft.

These spacecraft join new and ongoing campaigns on the ground, including the Chinese Large Solar Telescope and the Daniel K. Inouye Solar Telescope, both of which began operations at the start of the current cycle. Inouye, named after a Hawaiian senator and located on Maui, is the world's largest solar telescope, boasting a 4-meter primary mirror. It's capable of resolving features on the Sun as small as 20 kilometers, or 12 miles, across (*S&T:* Nov. 2023, p. 14).

The newest entry is NASA's Polarimeter to Unify the Corona and Heliosphere (PUNCH), designed to watch CMEs unfurl and pass through the inner solar system. With PUNCH, "we can really see if a CME at this part of the solar cycle is different from a CME from the same part of an earlier cycle," explains Nicholeen Viall (NASA Goddard Space Flight Center), chair of the American Astronomical Society's Solar Physics Division. Those data can then inform computer models of the Sun. "More power to the simulations," she says, "but those simulations need to be driven by data."

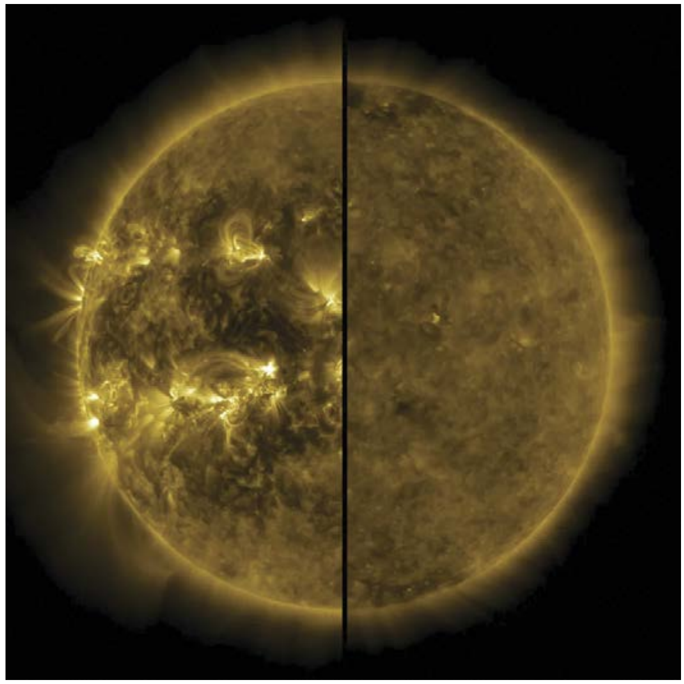
That interplay between data and simulations is critical, because it's not just observations that have advanced in the past decade. New computational codes that include sophisticated modeling of the Sun's raging inferno can trace out the solar magnetic field on a day-to-day basis. These models are capable of simulating everything from the motion of large flows of plasma within the Sun to the complex interplay in the region between the visible solar surface and the corona.

Even historical records are up for revision. In 2015, a team led by Frédéric Clette (Royal Observatory of Belgium) completed the arduous task of aligning older sunspot-counting methods with modern techniques, enabling comparisons over the full 415 years of records. This kind of clarification is necessary for forecasts' accuracy, whether they rely purely on observations or attempt to fold in solar physics.

Investments in new techniques are already paying dividends. Previously, solar cycles were predicted roughly every decade or so, with the onset of a new minimum. But with new data coming in constantly, and new techniques deployed to model the existing data and make new predictions, the National Oceanic and Atmospheric Administration now updates the solar cycle forecast every month.

Upton sees a lot of reasons to be optimistic. "We were much closer [this cycle] than any prediction panel before that," she says. In the lead-up to Cycle 24, for example, the panel was "split in half," with one side predicting a monster and the other predicting a nothing-burger. This cycle, however, "we're starting to converge. We're not perfect at it yet. We still have more to do, but we're getting there. We're getting close."

For Upton, Viall, and others in the field, one key ingredient will be detailed, consistent, long-term measurements of the polar magnetic fields, of which we currently have a paucity of observations. "The sunspots break apart, and those fields go to the poles," Viall says. "And do they clump up? Do they get shredded? Where do they go?"



▲ **A STUDY IN CONTRAST** These images show the Sun in April 2014, during the peak of Cycle 24 (left) vs. December 2019, when solar activity hit the minimum and Cycle 25 began (right).

NASA / SDO

Ground-based observatories have offered a few decades' worth of noisy observations of higher solar latitudes. But now, Solar Orbiter is giving scientists their first good look at our star's poles. Launched in 2020, the spacecraft initially focused largely on the Sun's equator. But successive flybys of Venus are tilting the spacecraft's trajectory farther out of the solar system's plane, giving the craft more direct views of the poles. Already, it has provided the highest-resolution images yet of the south pole.

But Solar Orbiter will still have a limited viewing angle, and its snapshots may be insufficient to understand the evolution of polar magnetic fields as the solar cycles wax and wane. Thus, U.S. solar and space physicists have proposed a dedicated mission concept, dubbed Solaris, that would provide high-quality, continuous measurements of the polar regions. These data would then be fed into more sophisticated models, enabling researchers to test their theories and predictions over the entire Sun.

With improved observations and theoretical understanding, heliophysicists will be able to find out where they were right — and more importantly, where they went wrong — as quickly as their systems can ingest the data pouring out of the network of solar observatories.

But, as Upton cautions: "The Sun loves to surprise us."

■ **PAUL SUTTER** is a cosmologist at Johns Hopkins University and author of *Your Place in the Universe: Understanding Our Big, Messy Existence*.

SKY AT A GLANCE
November 2025

1 DUSK: Face southeast to see the waxing gibbous Moon gleaming a bit more than 5° upper right of Saturn. The pair grows closer as the evening wears on. Turn to page 46 for more on this and other events listed here.

1 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:23 p.m. PDT (see page 50).

2 DAYLIGHT-SAVING TIME ENDS at 2 a.m. for most of the U.S. and Canada.

2 DAWN: Venus and Spica are about 3½° apart as they rise in tandem above the east-southeastern horizon shortly before sunrise.

4 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:12 p.m. EST (7:12 p.m. PST).

6 EVENING: The Moon, a day and a half past full, trails the Pleiades by a bit more than 6° as they climb in the east-northeast.

7 EVENING: Algol shines at minimum brightness for roughly two hours centered at 7:01 p.m. EST.

9 EVENING: Turn to the east-northeast to see the waning gibbous Moon less than 3° lower right of Gemini's brightest light, Pollux. Jupiter, in turn, is around 4° lower right of the Moon.

13 MORNING: The waning crescent Moon follows Regulus in Leo by around 4½° in the east.

17 MORNING: The Leonid meteor shower peaks and should put on an enjoyable show as the Moon won't interfere with viewing opportunities. See page 50 for details.

17 DAWN: The thin lunar crescent and Virgo's lucida, Spica, adorn the east-southeastern horizon with a little less than 2° separating them. Catch this sight before the Sun rises.

24 EVENING: Algol shines at minimum brightness for roughly two hours centered at 8:55 p.m. PST.

27 EVENING: Algol shines at minimum brightness for roughly two hours centered at 8:44 p.m. EST.

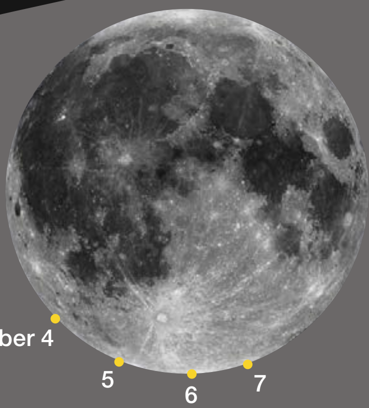
29 DUSK: High in the southeast, the Moon, one day past first quarter, hangs 4½° upper left of Saturn.

▲ The Leonid meteor shower is known for its fireballs, such as the one shown here over the Mediterranean Coast in November 2001.
TUNÇ TEZEL

NOVEMBER 2025 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart



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

NASA / LRO

MOON PHASES

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

FULL MOON
November 5
13:19 UT

LAST QUARTER
November 12
05:28 UT

NEW MOON
November 20
06:47 UT

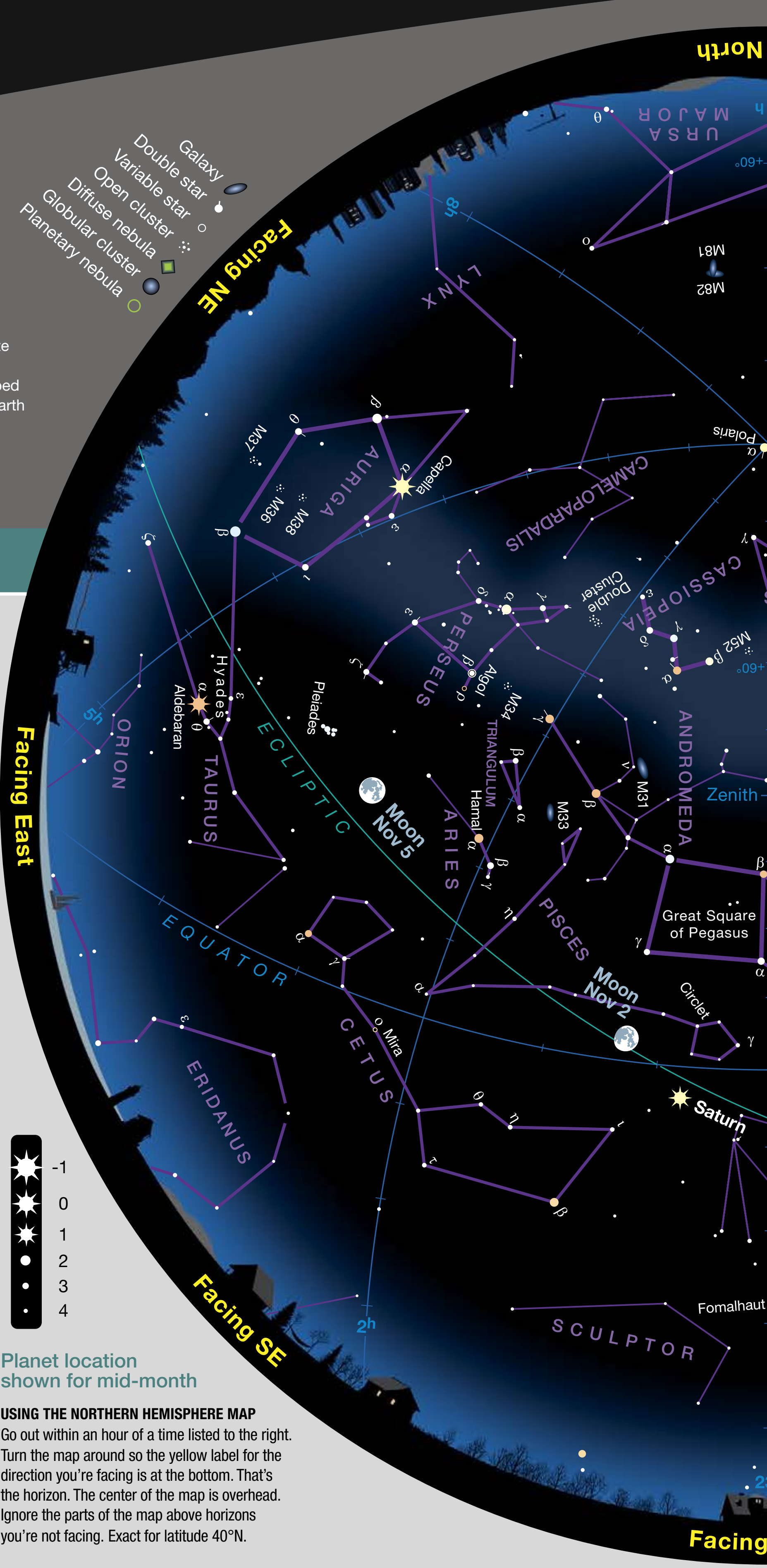
FIRST QUARTER
November 28
06:59 UT

DISTANCES

Perigee	November 5, 22^h UT
356,833 km	Diameter 33′ 29″
Apogee	November 20, 3^h UT
406,691 km	Diameter 29′ 23″

FAVORABLE LIBRATIONS

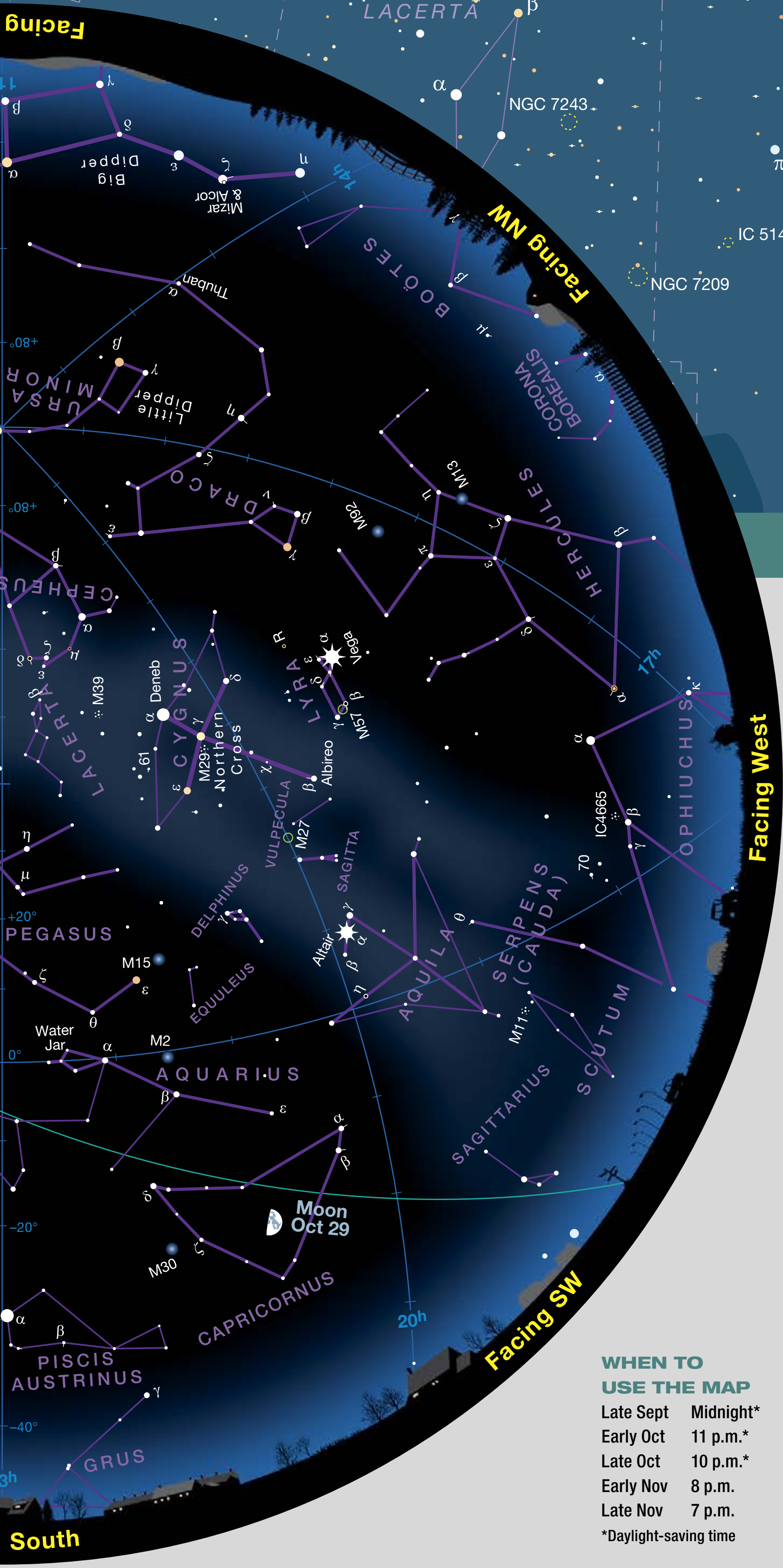
• Inghirami Crater	November 4
• Le Gentil Crater	November 5
• Scott Crater	November 6
• Helmholtz Crater	November 7

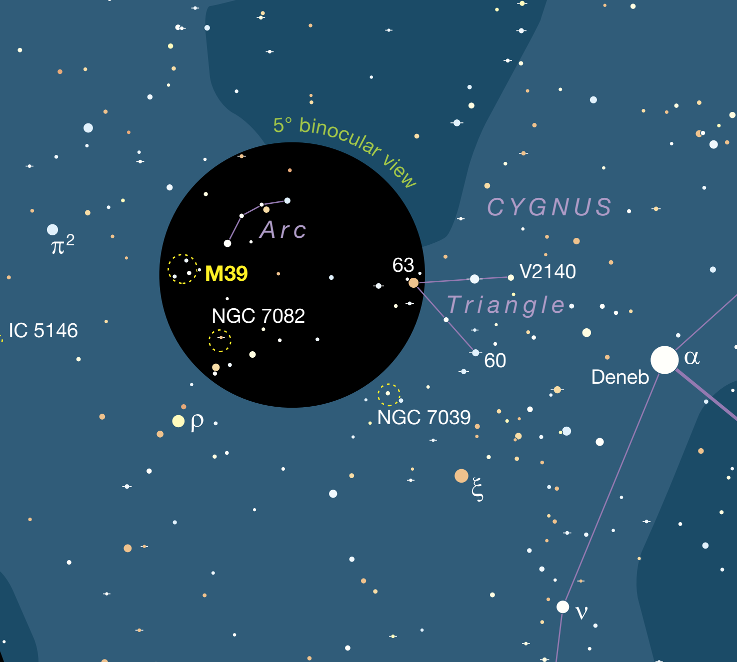


Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

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





WHEN TO USE THE MAP

Late Sept	Midnight*
Early Oct	11 p.m.*
Late Oct	10 p.m.*
Early Nov	8 p.m.
Late Nov	7 p.m.

*Daylight-saving time

Binocular Highlight by Mathew Wedel

Tailing the Swan

Cygnus, the Swan, holds seemingly endless treasures for binocular observers. This month we'll follow some fun stellar pointers on the way to **M39**, a truly great open cluster.

Let's start at Deneb, Alpha (α) Cygni, the tail of the Swan. Scan about 4° east-northeast from the constellation's first-magnitude lucida to find an isosceles triangle of stars, measuring a little less than 2° on each of its long sides. The corner stars are V2140 Cygni, 60, and 63 Cygni, all 5th or 6th magnitude. Use the triangle as a pointer with 63 Cygni at its apex and follow the arrow a further 3° east-northeast. Here you'll find a neat little arc of four fainter stars, each between 5th and 7th magnitude, collectively spanning roughly 1½° from northwest to southeast. From the easternmost (and brightest) star in the arc, it's just 1° farther east-southeast to M39. If your binoculars have a 5° field of view, you can fit M39, the arc, and at least the tip of the triangle into the field together.

The brightest members of M39 are arrayed in a strikingly perfect equilateral triangle, roughly ½° across. The cluster is bounded and spangled with stars between 7th and 9th magnitude, giving it an integrated magnitude of 4.6. Under sufficiently dark and clear conditions, M39 is visible without optics and it's a rewarding target with binoculars of any size. I've shown the cluster to friends from a hill in San Francisco, California, (mis)using compact birding binos, and I've plumbed M39's depths with my 15×70s from a remote Arizona desert. And the cluster itself can be just a starting point. The whole celestial hinterland between Cygnus and Cepheus, the King, is worthy of patient exploration. Take your time and have fun! ■

In the autumn, **MATT WEDEL** sometimes spends more time in Cygnus than he does in his office.

NOVEMBER 2025 OBSERVING

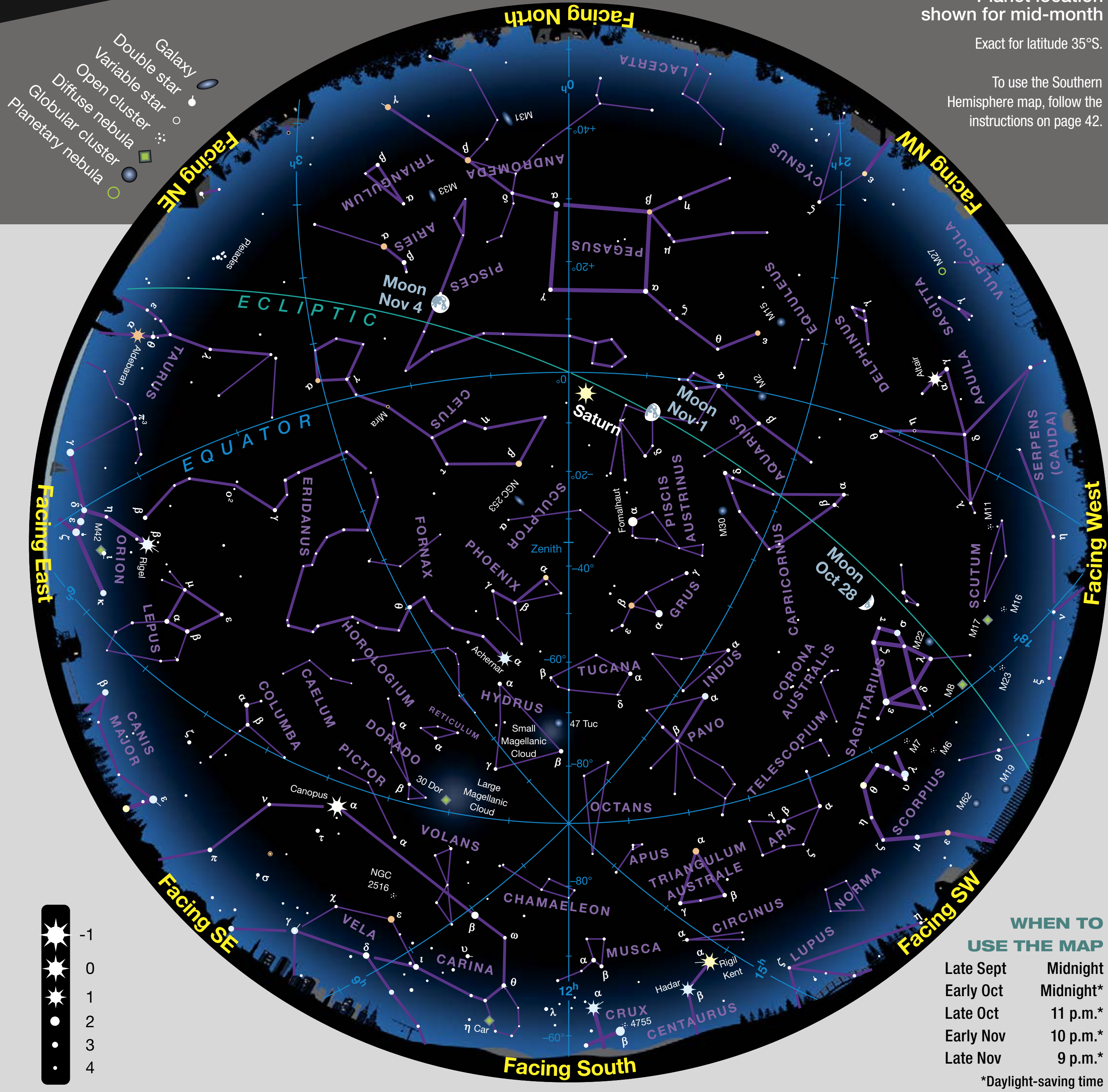
Southern Hemisphere Sky Chart

by Jonathan Nally

Planet location shown for mid-month

Exact for latitude 35°S.

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



WHEN TO USE THE MAP

Late Sept	Midnight
Early Oct	Midnight*
Late Oct	11 p.m.*
Early Nov	10 p.m.*
Late Nov	9 p.m.*

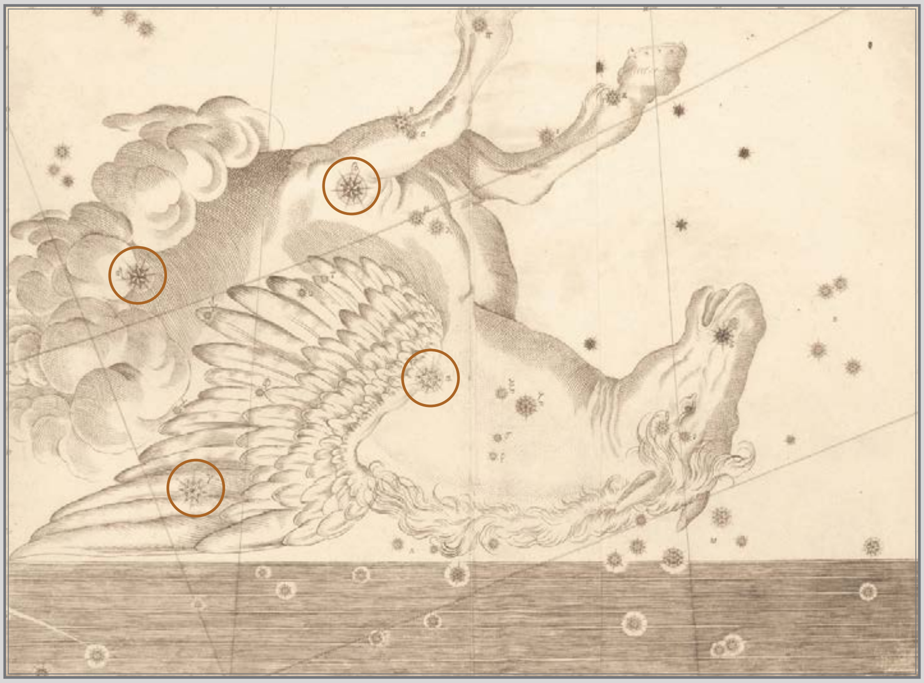
*Daylight-saving time

AFTER OUR VISIT to Grus, the Crane last month, let's take a look at another member of the southern sky's flock of bird constellations, **Phoenix**. It's named after the mythical avian that's reborn and rises from the ashes of its former self. Located midway from the celestial equator to the south celestial pole, Phoenix is within reach of skywatchers in the southern U.S.

Using the chart above, you can identify the constellation's three main stars. Brightest of all is Alpha (α) Phoenicis, also known as Ankaa. This 2.4-magnitude orange giant is located about 85 light-years from Earth. Next is Beta (β), a tight binary system comprising a pair of yellow giants that orbit each other every 170 years — their combined magnitude is 3.3. Lastly, we have Gamma (γ), a 3.4-magnitude spectroscopic binary that's slightly variable. ■

Squaring Off with Pegasus

This landmark constellation has a confused asterism.



▲The constellation Pegasus as it appears in the 1661 edition of Johann Bayer's 1603 *Uranometria* star atlas. Bayer was the first to assign Greek letters to its stars. In this case, the Great Square of Pegasus is labeled with the stars α, β, γ, and δ, as circled here.

RAREMAPS.COM / WIKIMEDIA COMMONS / PUBLIC DOMAIN

In his 1833 *A Treatise on Astronomy*, English astronomer John Herschel quipped that the "constellations seem to have been almost purposely named and delineated to cause as much confusion and inconvenience as possible." Add to that an assortment of *asterisms* — familiar groupings of stars that are not constellations — and confusion over celestial nomenclature amplifies.

Pegasus, the Winged Horse, is a prime example of the latter. One of the night sky's landmark constellations, Pegasus is an incomplete stellar figure whose half-body was originally formed by a remarkable quadrilateral of four naked-eye stars — Alpha (α), Beta (β), Gamma (γ), and Delta (δ) Pegasi — about 15° apart. Now, look at this month's Northern Hemisphere Sky Chart on pages 42–43. The quadrilateral is labeled as the Great Square of Pegasus, but you won't see a label for Delta Pegasi, for that name no longer exists.

Today, the Great Square of Pegasus is a misnomer, as only three of its stars belong to Pegasus: Alpha, Beta, and Gamma. The Square's northeastern corner star is now designated Alpha Andromedae and marks the position of the Chained Maiden's head. That means the Great Square of Pegasus has two Alpha stars — Alpha Pegasi and Alpha Andromedae. Let's look back now at the history of this confused asterism.

Today's name for the Great Square's northeastern corner star is Alpheratz, derived from an early Arabic phrase meaning "the Horse's Navel." Clearly, Alpheratz originally belonged to Pegasus.

Greek poet Aratus of Soli (circa 315–240 BC) appears to have been the first to modify the way we see this star. In his *Phaenomena*, a poem that describes the constellations and weather, Aratus explains how Pegasus touches Andromeda "with his lower belly. One common star gleams on the Horse's navel and the crown of [Andromeda's] head." He then links it to the Great Square: "Three other separate stars, large and bright, at equal distance set on flank and shoulders, trace a square upon the Horse."

Greco-Roman astronomer Ptolemy, who wrote the *Almagest* star catalog circa AD 150, included the Great Square's northeastern corner star as the first star in his list for the Pegasus constellation. He follows Aratus by noting that the star is the Horse's "navel, which is common to the head of Andromeda," but he doesn't include or mention the star in his list for Andromeda.

Johann Bayer took the next step by labeling the star as Delta Pegasi in his 1603 *Uranometria* star atlas. His depiction of the constellation shows the Great Square fully in Pegasus. But in deference to Ptolemy, he, too, notes that this star also represents Andromeda's head.

And this is how the dual nature of Alpheratz stood well into the 19th and early 20th centuries. As American astronomer Garrett Serviss explains in his 1908 book *Astronomy with the Naked Eye*, "Delta [Pegasi], or Alpheratz, is common to the constellations Pegasus and Andromeda, and is sometimes assigned to one and sometimes to the other." Enter the International Astronomical Union, which, in 1930 officially assigned Alpheratz to Andromeda, placing the star outside the Winged Horse's boundary lines and leaving the Great Square of Pegasus in a muddled state.

Of course, anyone today who simply refers to the asterism as the "Great Square" will have no problem with nomenclature at all. But if we wish to be consistent and not confuse newcomers, then we have another alternative. We could call the asterism the Autumn Square, which would add to the seasonal asterisms already in popular use: the Summer Triangle, the Winter Triangle, and the Winter Hexagon.

■ 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.

The Moon Serenades Saturn . . . Twice

Earth's constant celestial companion has a busy month.

SATURDAY, NOVEMBER 1

One of the most enjoyable naked-eye activities presented each month is to watch the **Moon** visit the bright planets strung out along the ecliptic. Because the *sidereal month* — the time it takes the Moon to return to the same place in the sky (27.3 days) — is shorter than a calendar month, sometimes it visits a planet twice. And so it does with **Saturn** this month.

The first of these encounters takes place this evening as the waxing gibbous Moon closes in on the Ringed Planet. As twilight fades, catch the pair high in the southeastern sky with a bit more than 5° of sky between them. But of course, the Moon doesn't sit still — it shifts roughly its own diameter eastward every hour. Throughout the night it gets closer and closer to Saturn and by the time the pair sets in the predawn hours of the 2nd, they're less than 3° apart.

The second encounter between the two occurs on the evening of November 29th when the Moon sits a bit more than 4½° upper left of Saturn. In effect, the Moon has lapped the planet since their earlier meeting on the 1st. That's because Saturn is almost stationary, having drifted just ½° westward during that span of time. And while the Moon revisits the same spot in the sky in less than 30 days, 30 *years* will elapse before Saturn returns to the same corner of northeastern Aquarius it occupies tonight.

SUNDAY, NOVEMBER 9

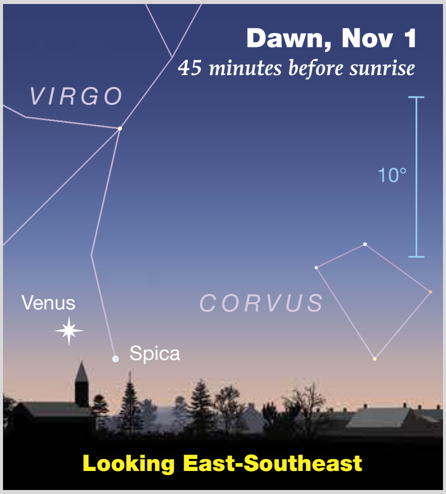
Late this evening the **Moon** meets its second planet this month when it ventures into Gemini to visit **Jupiter**. A bit less than 3½° separates them when they're at their closest at around 4:20 a.m. EST on the morning of the 10th. However, the most visually interesting moment occurs earlier, when the waning gibbous sits directly between Jupiter and 1.1-magnitude **Pollux**, Gemini's brightest star. That happens a bit before 1:30 a.m. EST on the 10th. Jupiter itself shines at magnitude –2.4, making it 25 times brighter than nearby Pollux.

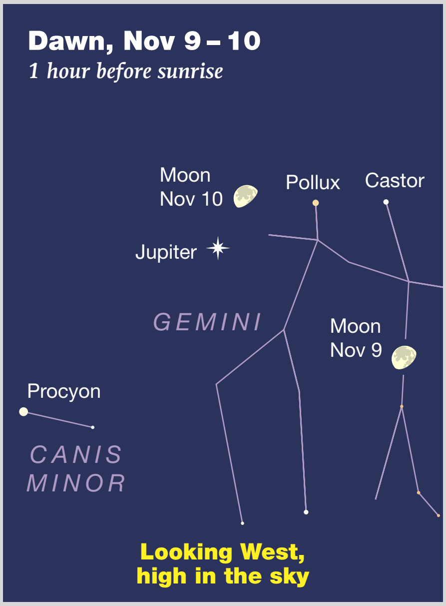
MONDAY, NOVEMBER 10

Sailing eastward along the ecliptic and away from Jupiter, the next port of call for the **Moon** is the **Beehive Cluster** (M44) in Cancer. It's one of only three naked-eye clusters in the Moon's path, the others being the Pleiades and the Hyades, both in Taurus. Although the Moon and Beehive rise late in the evening, your best view of the conjunction happens shortly after midnight, on the morning of the 11th. By then the cluster will be high enough for its stars to shine through the thin layer of the atmospheric haze that often clings to the horizon. That said, this is going to be an event that requires binoculars. The waning lunar disk is 60% illuminated, which creates enough glare that even the brightest bees in the hive are going to struggle to compete. The Moon is directly north of the Beehive's center at around 12:30 a.m. EST on the 11th.

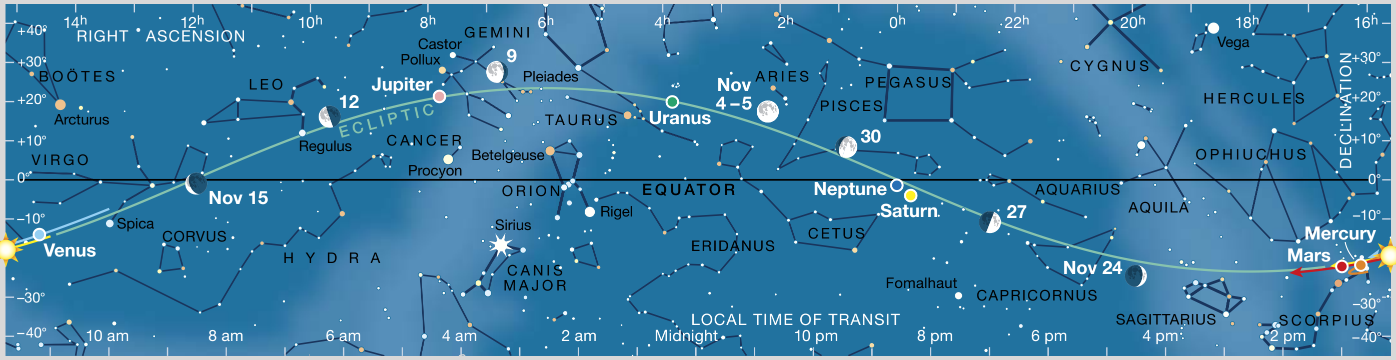
MONDAY, NOVEMBER 17

The closest pairing between the **Moon** and a bright star this month happens at dawn today when a thin, waning crescent sits just 2° below **Spica**. The Moon





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



▲ The Sun and planets are positioned for mid-November; 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.

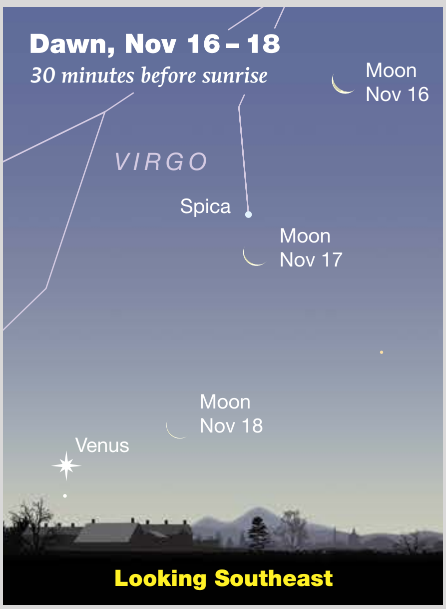
is moving away from the 1st-magnitude star even as they rise at around 4:30 a.m. local time, so the earlier you look, the better — and by "better" I mean the closer together they appear. Also, the farther south you are, the smaller the gap between the twosome will be. Indeed, the event is an occultation for a lucky few at the southwestern tip of South America. However, this meet-up is mostly noteworthy because it marks the final Spica occultation in the current series, which started in June 2024. The next sequence doesn't kick off until 2031.

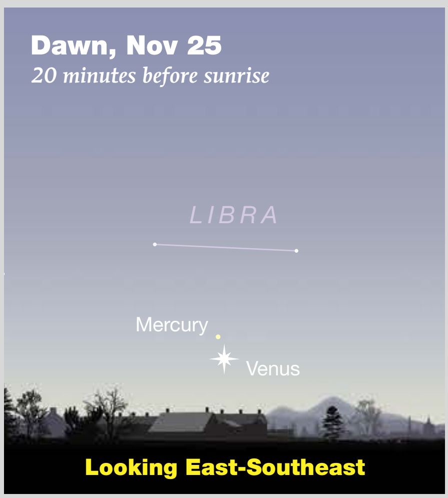
If you're up to watch the Moon and Spica pair off, you can't help but notice Venus lower left of the lunar crescent. The brilliant Morning Star gets its own visit from the Moon on the following morning, the 18th. That's when a razor-thin, 3%-illuminated lunar crescent sits about 8¼° upper right of Venus.

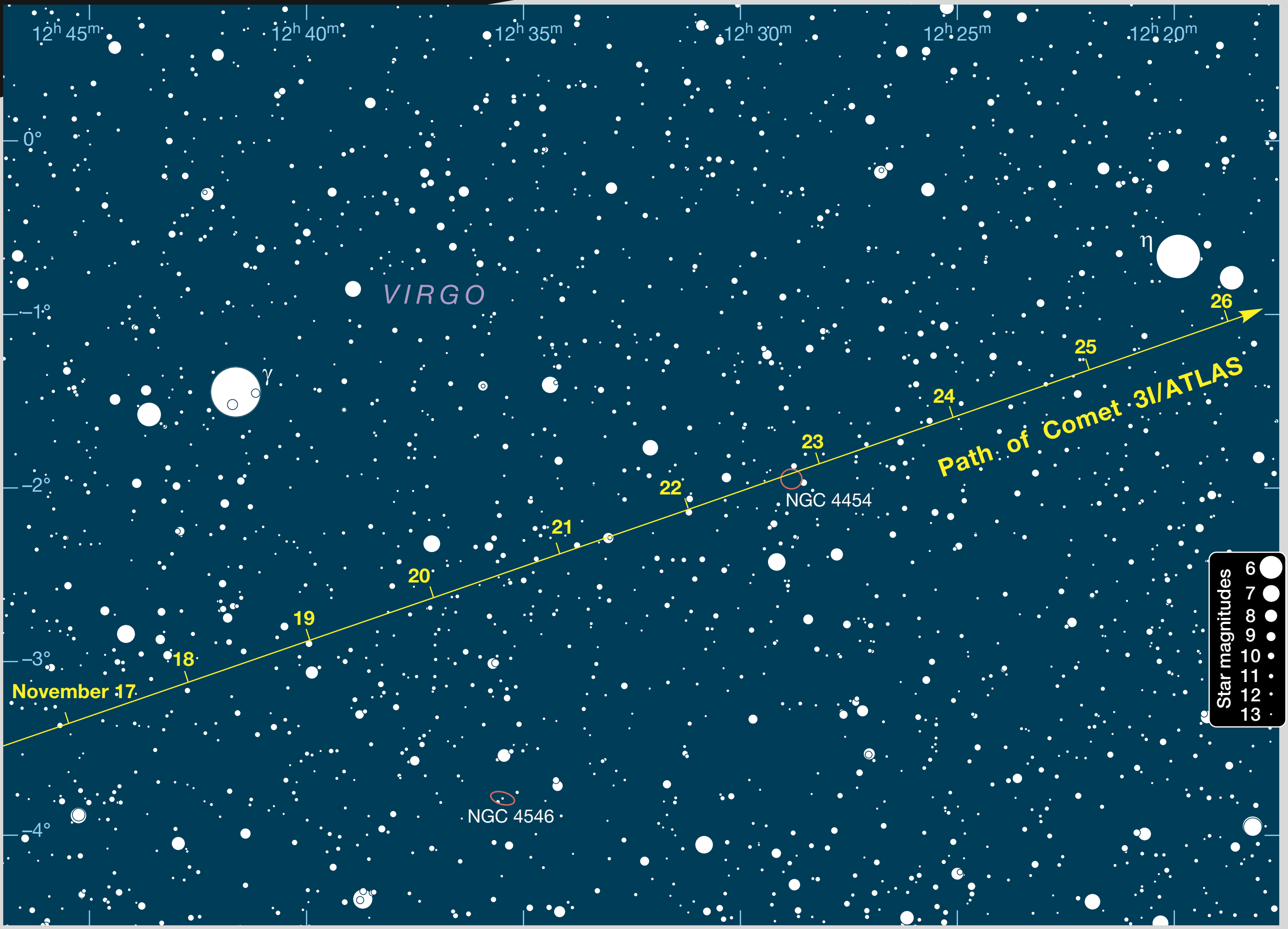
TUESDAY, NOVEMBER 25

The solar system's two innermost planets meet low in the east-southeast at dawn today. **Mercury** (magnitude 2.0) and **Venus** (magnitude –3.9) are separated by a shade less than 1½°. Sounds good, right? Unfortunately, you'll need three things to get a look at this event. First (and most crucially), a completely unobstructed horizon. Thirty minutes before sunrise, Venus (the lower of the two) has an altitude of just 2.9° while Mercury is only slightly higher, at 4.3°. Second, you'll need a sky completely clear of haze — something that can be quite rare at this time of year. Third, you'll need your binoculars. Although it's lower, brilliant Venus won't be much of a problem to spot, but Mercury is going to be tough. There's a good chance it will elude you. Don't fret though — this is only the start of Mercury's final and best apparition for 2025. The planet rapidly gains altitude and brightness with each passing day. It reaches magnitude +0.1 by the 30th and sits 10.2° above the horizon half an hour before sunrise. The planet is at its very highest for the apparition on December 6th, when it shines at magnitude –0.5. Venus, on the other hand, is approaching the end of its morning reign and becoming more and more difficult to catch. It finally has its conjunction with the Sun on January 6, 2026, after which it re-emerges as the Evening Star in early February.

■ Consulting Editor **GARY SERONIK** keeps an eye on the sky from his home in southern British Columbia, Canada.







▲ Comet 3I/ATLAS is at its best during November when it passes south of 2.7-magnitude Gamma (γ) Virginis. On the morning of November 22nd, it approaches the 11.9-magnitude galaxy NGC 4454. The comet's position is shown for 0^h UT on the dates indicated. Only galaxies near the comet's path are plotted.

A Comet Bonanza Featuring an Interstellar Interloper

Comet 3I/ATLAS is an especially rare treat for backyard scopes.

Most comets this year have been better targets for astrophotographers than observers. Happily, this month is different. As many as five fuzzballs bright enough to view in a 10-inch or larger telescope roam the sky. Most remarkable of all is 3I/ATLAS, a rare visitor from another star system.

Discovered on July 1, 2025, the object has either been too faint to see in backyard scopes or hidden in the Sun's glare until now. A viewing opportunity finally opens mid-November, when the alien visitor brightens to around 12th magnitude and climbs to 20° altitude nearly two hours before sunrise. As it makes its way across Virgo, the comet moves north and west at a rate of nearly ¾° per day. With its solar elongation increasing and the Moon exiting the scene on the 17th, a viewing window opens at the time the comet reaches peak brightness. Sometimes we do get lucky!

▶ Comet 3I/ATLAS displayed a strongly condensed coma and hint of a tail in this mid-July photo made with the 8.1-meter Gillett Gemini North Telescope from the island of Hawai'i. Gas and dust shroud the icy nucleus, estimated to be about 20 kilometers (12 miles) across.

INTERNATIONAL GEMINI OBSERVATORY / NOIRLAB / NSF / AURA / K. MEECH (IFA / U. HAWAI'I)

Predicting the behavior of a typical comet is tricky enough, but there likely are factors we're not aware of when it comes to an interstellar visitor such as this. At the time of writing, the ephemeris provided by Daniel Green, Director of the Central Bureau for Astronomical Telegrams, estimates that 3I/ATLAS could reach magnitude 12.5 in mid-November and fade to 13.5 by mid-December. If those predictions hold true, then the comet should be faintly visible in a 10-inch scope and perhaps even in an 8-inch under pristine skies.

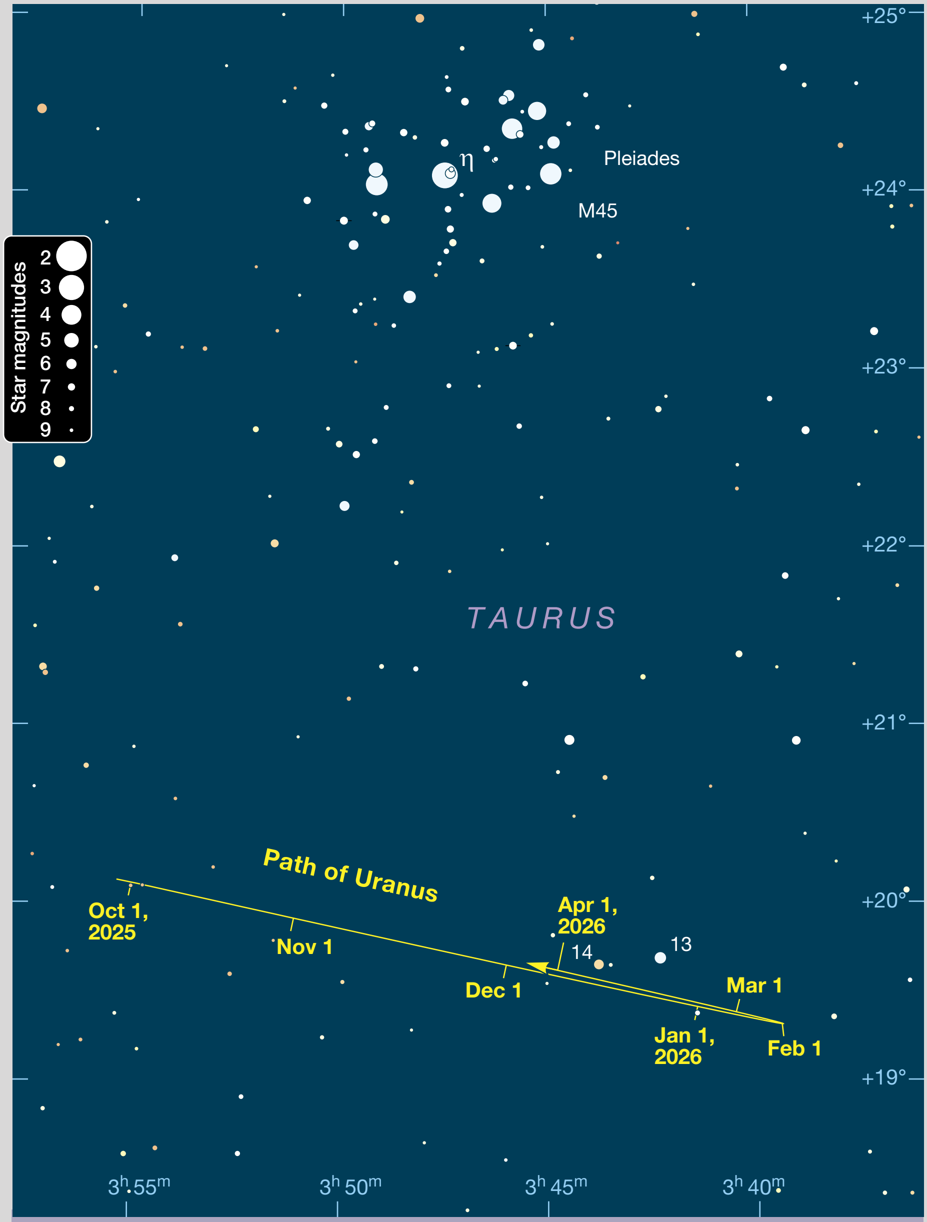
Normally, a faint whiff of fluff like this only attracts attention from the most ardent comet aficionados, but 3I/ATLAS is no ordinary visitor. It betrayed its alien pedigree shortly after discovery through its extreme velocity — around 60 kilometers per second (134,000 mph) — and its hyperbolic orbit. Unbound to the Sun, 3I/ATLAS was likely booted from its original star system through some gravitational happenstance and has been traveling across the galaxy for millions or even billions of years.

Images captured in July reveal a strongly condensed, compact object with a wisp of a tail. Observers should be alert to any sudden brightness changes that could signal a temporary outburst or a fragmentation event. Join the Comet Mailing List (**https://groups.io/g/comets-ml**) to share your observations.

A few amateurs glimpsed the previous interstellar comet, 2I/Borosov, in December 2019, when it peaked at around magnitude 14.5. I made several attempts to see it with my 15-inch reflector, but poor weather and the object's low altitude kept it from view. So, if you're like me, you're perched on the edge of your seat for this second chance to see a representative of an entirely different class of comets.

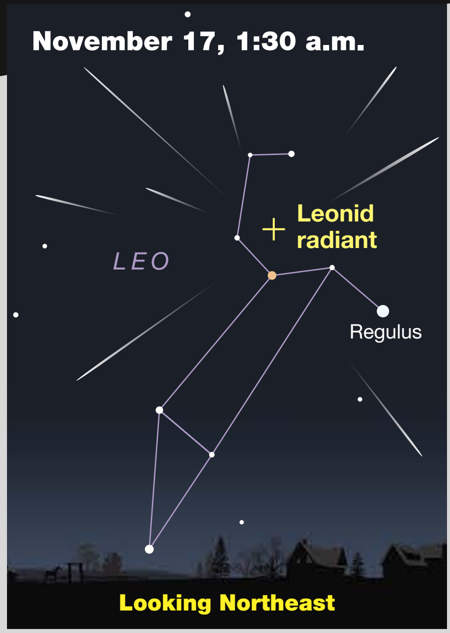
If dawn's delight whets your appetite for more, two additional comets flaunt their dust at dusk. Best placed is Comet Lemmon (C/2025 A6), which is within reach of 6-inch or larger telescopes during the first 10 days of the month, when it shines brightest and highest in late-evening twilight. Fortunately, the Moon is out of the picture during this period. Glowing around 10th magnitude, the comet glides east across southern Ophiuchus, passing 2° southwest of the bright globular cluster M12 on November 3rd. As it fades, it sinks closer to the horizon. By mid-month, Comet Lemmon dips to 11th magnitude and hovers just a few degrees high at twilight's end.

You can learn more about these and other comets at Gideon van Buitenen's excellent website, **astro.vanbuitenen.nl**.



▲ **URANUS AT OPPOSTION** The solar system's seventh planet arrives at opposition on November 21st, just 4½° south of the Pleiades star cluster in Taurus. Shining at magnitude 5.6 with a disk 3.8″ across, Uranus is faintly visible without optical aid under dark, moonless skies. It inches westward in retrograde motion, and as December begins it lines up with similarly bright stars 14 and 13 Tauri. The fortunate alignment will aid in spotting the distant ice giant with binoculars. Even a small telescope will reveal the planet's tiny disk, and its brightest moons (Titania and Oberon) are visible in 8-inch and larger instruments used at high magnification. To find out when and where to look, visit the Tools page of **skyandtelescope.org** for our "Moons of Uranus" interactive observing aid.

Promising Leonids



CIRCUMSTANCES ARE FAVORABLE for the Leonid meteor shower this year. Famous for its rare, spectacular outbursts, this normally modest display reaches maximum around 18:00 UT on November 17th, making that morning best for observers in the Americas. The Moon is just three days from new and won't interfere. Best viewing begins around 1 a.m. local time and continues to the start of dawn. In a typical year, the Leonids produce 10 to 15 swift meteors per hour.

Leonids originate from particles shed by Comet 55P/Tempel-Tuttle and appear to dart from the Sickle asterism in Leo, the Lion. This year there may be enhanced activity on the 17th around 19:00 UT and again at 22:30 UT from a dust trail laid down by the comet in 1699. Additional dust streams from 1167 and 1633 may stir up some early Leonids around 22:00 UT on the 9th (Asia and Australia are favored) and the 15th at around 3:00 UT for European and African skywatchers.

November also features the Northern Taurid and Southern Taurid meteor showers. They peak on the nights of the 5th and 12th, respectively. While those dates coincide with the full and last-quarter Moon, the showers are rich in fireballs, giving observers a fighting chance at seeing a few meteors from both displays. The showers stream from radiants in central Taurus, south of the Pleiades.

Minima of Algol

Oct.	UT	Nov.	UT
1	17:27	2	6:23
4	14:15	5	3:12
7	11:04	8	0:01
10	7:53	10	20:50
13	4:42	13	17:39
16	1:30	16	14:28
18	22:19	19	11:17
21	19:08	22	8:06
24	15:57	25	4:55
27	12:46	28	1:44
30	9:35	30	22:33

These geocentric predictions are from the recent heliocentric elements Min. = JD 2457360.307 + 2.867351E, where E is any integer. They were derived by Roger W. Sinnott from 15 photoelectric series in the AAVSO database acquired during 2015–2020 by Wolfgang Vollmann, Gerard Samolyk, and Ivan Sergey. For a comparison-star chart and more info, see **skyandtelescope.org/algol**.

▲ Perseus approaches the zenith after midnight in November. Every 2.87 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to estimate its brightness in respect to comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).

Action at Jupiter

JUPITER IS APPROACHING the prime of its current apparition. At mid-month it rises in the evening and transits the meridian at around 4 a.m. local time — a full hour before the start of morning astronomical twilight. On the 15th, Jupiter presents a disk 42.4″ across and shines conspicuously at magnitude –2.4 from eastern Gemini, where it sits less than 7° south of Pollux, the constellation's brightest star.

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

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

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

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

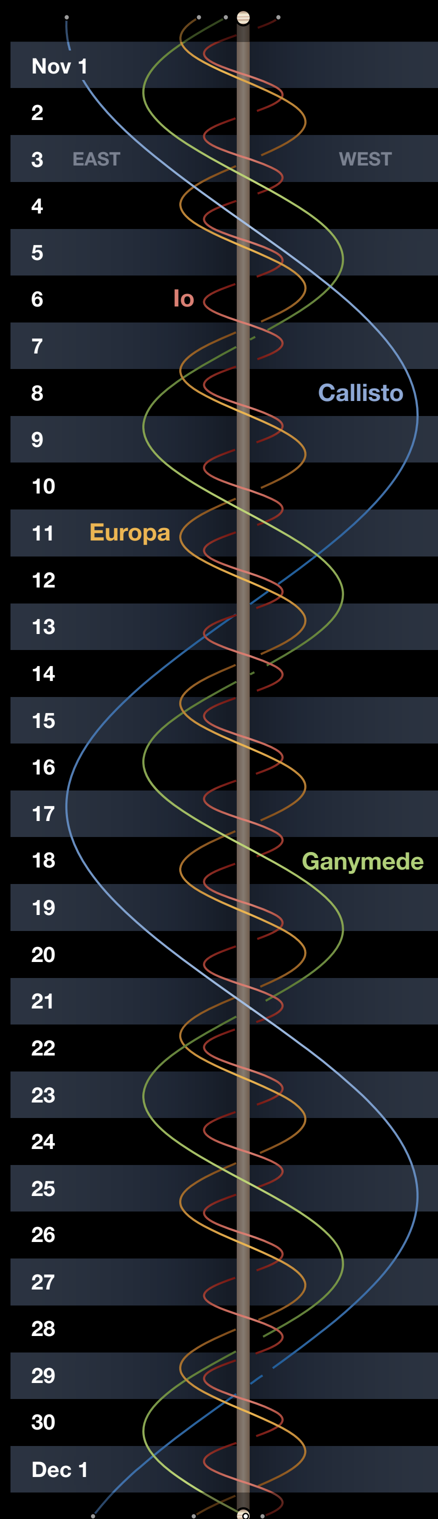
These times assume that the spot will be centered at System II longitude 85° on November 1st. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 85° and 1⅔ minutes later for each degree more than 85°.

Phenomena of Jupiter's Moons, November 2025

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

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.

Tumultuous Times on Jupiter

Several events portend a dynamic show for the current apparition.

Jupiter was very active during the planet's most recent apparition, which concluded in late June when the planet was in conjunction with the Sun. Backyard observers were the first to detect two intense storm systems and closely monitored their development. The presence of unusual color and structure in the planet's Equatorial Zone (EZ) added to the most interesting display in years.

Outbreak in the South Equatorial Belt

With an axial tilt of only 3°, Jupiter doesn't experience appreciable seasonal changes. However, the planet emits almost twice as much energy as it receives from the Sun. This excess is due to a combination of primordial heat left over from the planet's formation and heat generated by ongoing gravitational contraction. Jupiter's internal energy source combines with its rapid axial spin to drive the weather in the planet's dynamic atmosphere.

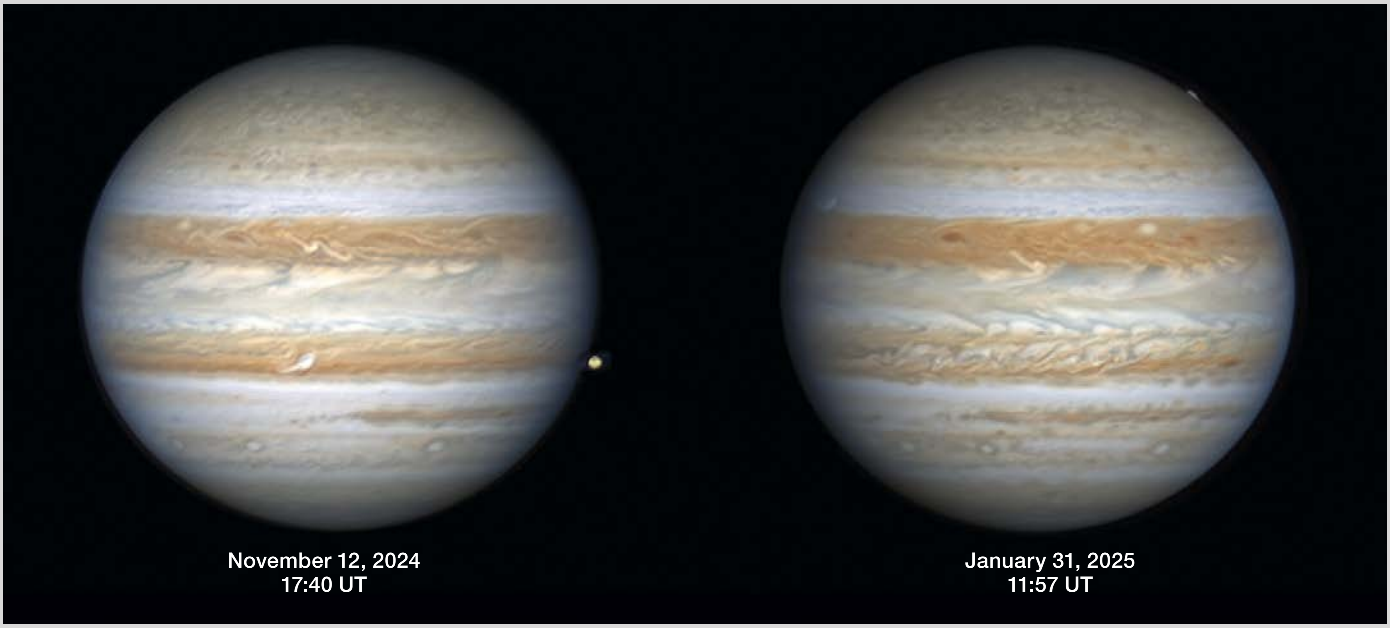
On November 11, 2024, a small, brilliant white spot suddenly appeared in the middle of the South Equatorial Belt (SEB), heralding an outbreak that developed into an impressive spectacle during the following months. These bright spots are huge, convective thunderstorms that expand and rapidly drift eastwards, creating a bright streak in the SEB.

By December 30th, Japanese observer Shinji Mizumoto had tracked the appearance of no fewer than six conspicuous plumes erupting at or near the original source, located at the trailing end of the lengthening rift, as well as one at the preceding end of the streak that appeared on December 25th. By mid-January 2025, when the outbreaks at the following end subsided, the entire disturbance spanned some 75° of Jovian longitude. By early April as Jupiter receded into the evening twilight the feature had lengthened by an additional 20°.

Outbreak in the North Temperate Belt

An even more spectacular outbreak along the southern edge of the North Temperate Belt (NTBs) began early this year on January 10th. Located in the gas giant's most powerful jet stream at 22° to 24° north latitude, NTBs outbreak events are some of the planet's most energetic and fast-moving phenomena.

▼ *Left:* On November 12, 2024, Christopher Go recorded the compact bright spot heralding an outbreak in the middle of the South Equatorial Belt. *Right:* By January 31, 2025, the storm system had expanded into a long swath of turbulence.

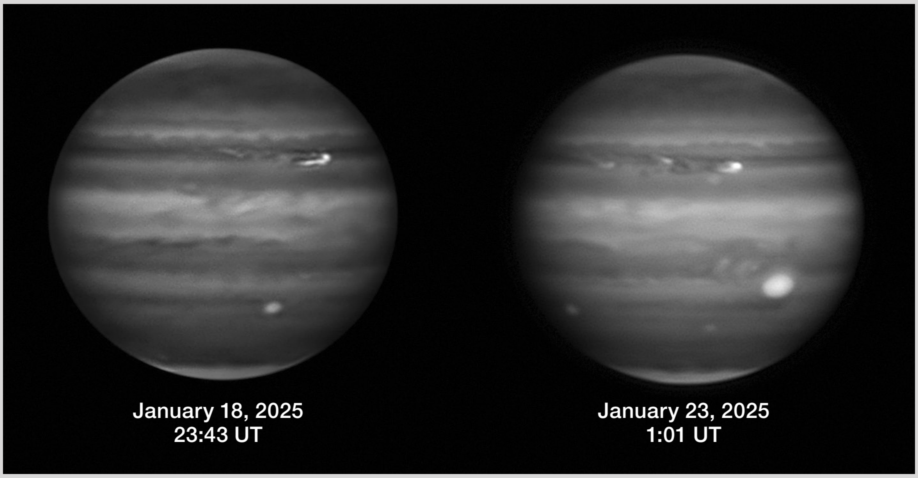


The NTBs outbreak was expected — for more than a year the NTB had been obscured by a thick canopy of white clouds composed of frozen ammonia. At regular intervals of four to five years, sufficient thermal energy builds up beneath this high cloud deck, and moist convective storms erupt from a deeper layer of water-rich clouds well below the visible cloud tops to pierce the upper canopy.

The first hint of the outbreak was recorded on January 10, 2025, as a tiny, intensely bright spot in near-infrared and methane band images (685 and 889 nanometers, respectively). Within a day, a convective plume towering to a very high altitude was detected in visible-light wavelengths and soon became the brightest feature on the entire planet. It accelerated rapidly, leaving a long, bright wake resembling a comet's tail in the NTBs. This turbulent wake contained several short-lived, dusky patches believed to be wavelets traveling more slowly than the prevailing jet-stream winds.

On January 27th, a second plume appeared at the same latitude but preceding the first plume by 20° of longitude. This feature rapidly became as bright as the earlier plume. On the following day, the orbiting Juno spacecraft imaged Jupiter's nightside, capturing frequent, intense flashes of lightning in the heart of the first plume. One week later the first plume overtook the wake of the second plume and disintegrated in a matter of days due to horizontal wind shear. During February, six additional plumes appeared along the NTBs. Persisting for three to 10 days, each one dissipated as it caught up with the wake of the plume ahead of it.

Following the NTBs outbreaks in 2007, 2012, 2016, and 2020, material dredged up by the erupting plumes and exposed to solar radiation gave the NTBs an ochre tint that lasted for several years. Produced by the same photochemical reactions that give the Great Red Spot its distinctive hue, this coloration may be striking again this year.



▲ Eric Sussenbach of Curaçao (in the southern Caribbean) recorded localized upwelling along the southern edge of the North Temperate Belt (NTBs) that appeared bright white through a methane-band filter earlier this year on January 18th *(left)* and 23rd *(right)*.

Coloration Event in the Equatorial Zone

Easily visible through a 4-inch telescope, dusky bluish spots are arrayed at intervals of about 30° along the southern edge of the North Equatorial Belt. Known as North Equatorial Dark Formations (NEDFs), these spots were unusually large and conspicuous during the last apparition. The narrow, curved festoons that project from these markings into the EZ merged to form broad segments of a greyish-brown Equatorial Band (EB) encircling most of the planet. Combined with the presence of an elongated bright feature known as the South Equatorial Disturbance along the turbulent northern edge of the South Equatorial Belt, they gave the EZ a striking three-tiered structure.

This unusual aspect is often the harbinger of a yellow or orange tint developing throughout the EZ. Will it still be present during the current apparition? Based on the observational record it's difficult to say. The appearance of the EZ in 1999 and 2006 was uncannily similar to the previous apparition. During the 2000 Jupiter observing season, the NEDFs and their associated festoons were very subdued and the EB was absent. However, following the 2006 apparition they persisted throughout 2007. Keep a close eye on the EZ for dramatic changes this year.

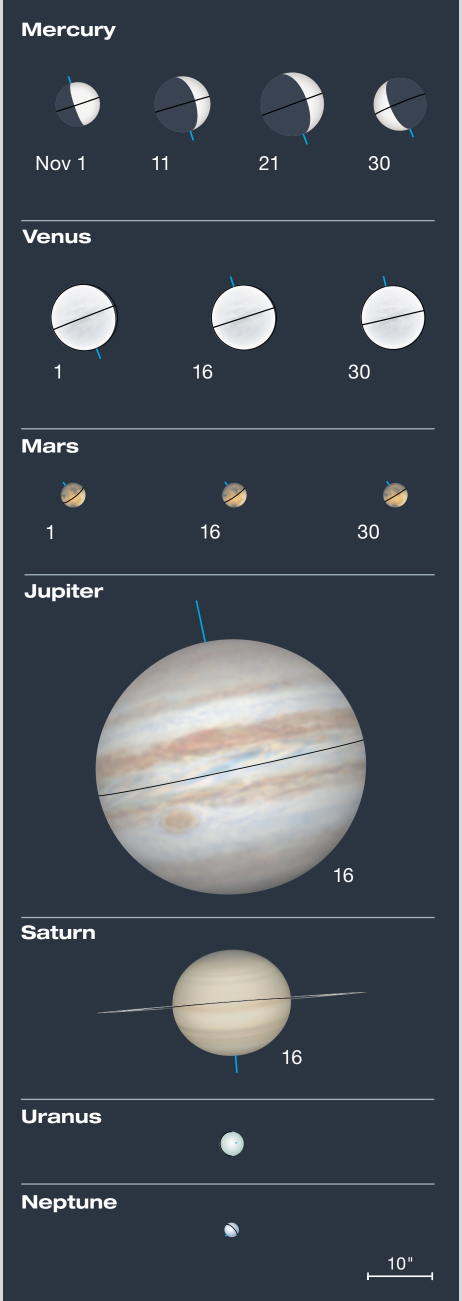
For observers at mid-northern latitudes, Jupiter rides high in the sky during the long winter nights of the 2025–2026 apparition. If you're willing to engage in a sleep-deprivation exercise, you'll even be able to take in a complete rotation of the planet during a single night. Hopefully the ever-changing King of the Planets will be as captivating as it was throughout its last observing season.

▶ Both the mid-SEB outbreak and the NTBs disturbance were well-developed by February 10, 2025. Blue festoons projecting from the NTBs are unusually prominent, merging to form a broad dusky band in the middle of the Equatorial Zone.

ERIC SUSSENBACH

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

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dawn starting on the 27th • **Venus** visible at dawn all month • **Mars** lost in the Sun's glare all month • **Jupiter** rises in the evening and visible to dawn • **Saturn** visible at dusk and transits in the early evening.



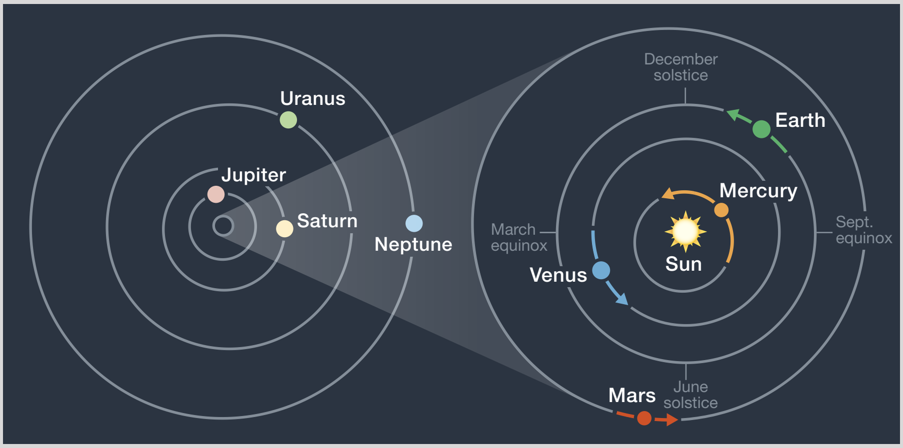
▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

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

November Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$14^h\ 24.4^m$	–14° 19′	—	–26.8	32′ 14″	—	0.993
	30	$16^h\ 23.5^m$	–21° 35′	—	–26.8	32′ 26″	—	0.986
Mercury	1	$15^h\ 57.4^m$	–23° 25′	24° Ev	–0.2	6.9″	58%	0.976
	11	$16^h\ 16.5^m$	–23° 30′	18° Ev	+0.6	8.7″	26%	0.774
	21	$15^h\ 40.1^m$	–18° 47′	2° Mo	—	9.9″	0%	0.679
	30	$15^h\ 14.5^m$	–15° 22′	18° Mo	+0.2	8.2″	31%	0.819
Venus	1	$13^h\ 24.3^m$	–7° 17′	16° Mo	–3.9	10.3″	96%	1.616
	11	$14^h\ 11.6^m$	–11° 52′	14° Mo	–3.9	10.2″	97%	1.643
	21	$15^h\ 00.5^m$	–15° 59′	11° Mo	–3.9	10.0″	98%	1.665
	30	$15^h\ 46.1^m$	–19° 07′	9° Mo	–3.9	9.9″	99%	1.681
Mars	1	$15^h\ 38.9^m$	–19° 54′	19° Ev	+1.5	3.9″	99%	2.409
	16	$16^h\ 24.2^m$	–22° 09′	14° Ev	+1.4	3.9″	99%	2.420
	30	$17^h\ 08.4^m$	–23° 34′	11° Ev	+1.3	3.9″	100%	2.424
Jupiter	1	$7^h\ 46.1^m$	+21° 17′	104° Mo	–2.3	40.6″	99%	4.862
	30	$7^h\ 44.6^m$	+21° 25′	133° Mo	–2.5	44.1″	100%	4.473
Saturn	1	$23^h\ 47.1^m$	–4° 05′	137° Ev	+0.9	18.9″	100%	8.788
	30	$23^h\ 44.7^m$	–4° 15′	107° Ev	+1.1	18.1″	100%	9.191
Uranus	16	$3^h\ 48.6^m$	+19° 48′	174° Mo	+5.6	3.8″	100%	18.514
Neptune	16	$23^h\ 59.1^m$	–1° 35′	126° Ev	+7.8	2.3″	100%	29.299

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



ALAN DYER

Way, Way North

These telescopic objects lie within 10° of Polaris, the famed North Star.

Picture a circle of sky 20° in diameter, centered on the north celestial pole (NCP). One evening earlier this year, I decided to find out how many objects in that confined circle are visible in my backyard telescopes.

The far north isn't blessed with bright targets. Happily, the NCP stands 49.2° above my north horizon, which also happens to be the darkest direction of my suburban environment since most of our relatively small burg's sprawl is south of me. On the night in question, I spotted six of the seven stars in the Little Dipper, meaning I could see down to about magnitude 4.5.

Aiming near the NCP is awkward for telescopes on equatorial mounts. My 4¼-inch f/6 Newtonian reflector rides on just such a mount. So, before poking around the pole that night, I aligned the polar axis east-west rather than north-south. The 90° switcheroo permitted me to easily capture the North Star, Polaris, then hop to objects close by. My other scope, a 10-inch f/6 Newtonian on a Dobsonian mount, was already well-suited to navigating the north.

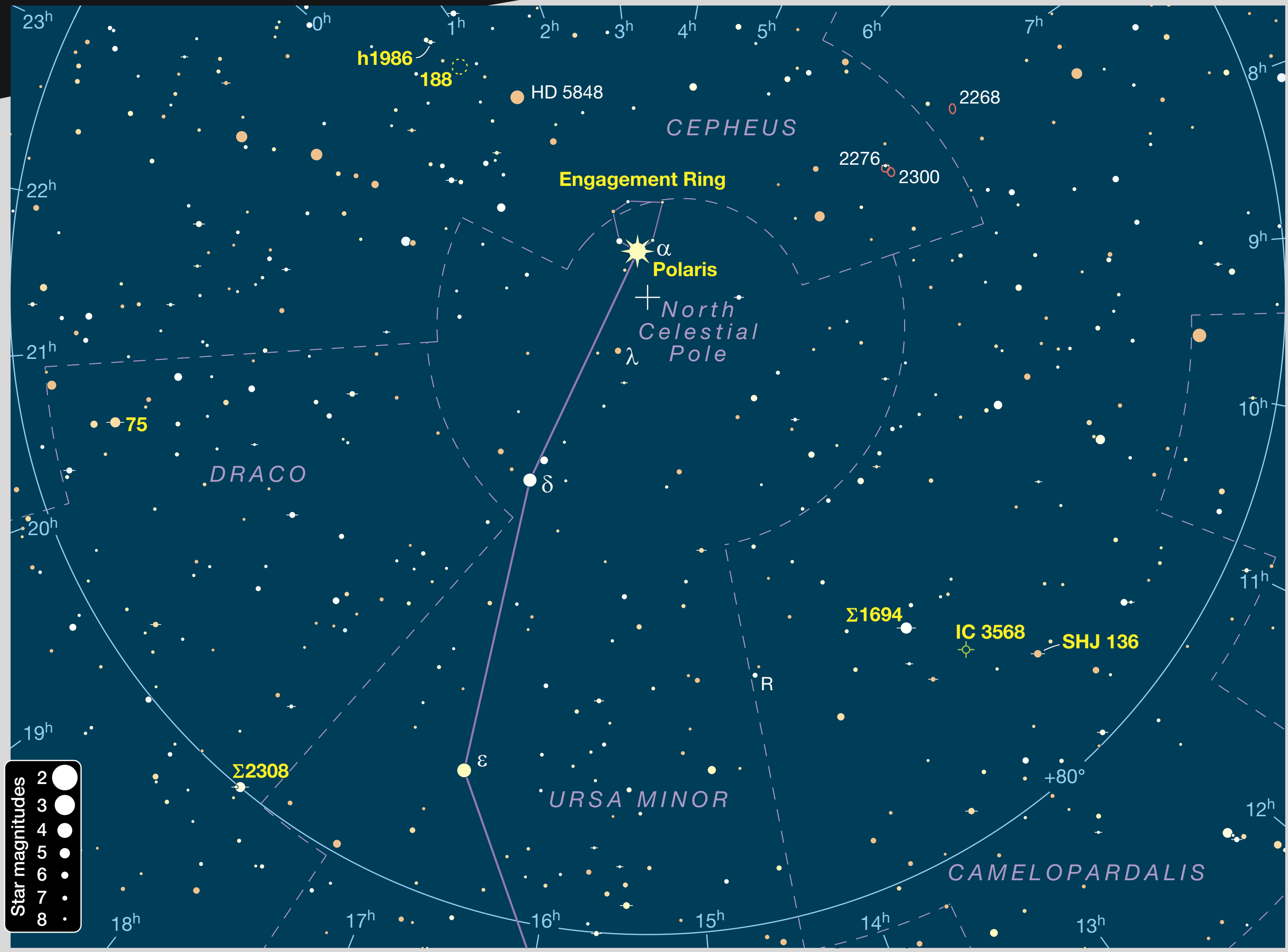
Engaging Polaris

Any decent star atlas, print or electronic, would have aided my North of 80 project, but I chose *Sky Atlas 2000.0* (2nd edition, Deluxe Version, 1998) by Wil Tirion and Roger Sinnott. Three charts of this venerable work cover the polar region. All the plotted objects (except galaxies) should be within range of my backyard gear. So, I opened the atlas and got to work.

My tour began at **Polaris**, the star officially labeled Alpha (α) Ursae Minoris. And it has one other important name: Struve 93. Yes, Polaris is indeed a binary system! The 2.0-magnitude, yellowish primary harbors a 9.1-magnitude secondary 18.4″ away. My 4¼-inch reflector operating at 40× caught the companion flickering feebly to one side of the brilliant primary. In my mind's eye, I beheld a hot sun illuminating a tiny planet. A nice start.

Polaris is also the gleaming diamond in a ragged circlet of stars called the **Engagement Ring**. First described 64 years ago by American amateur William Dutton, the Engagement Ring gives the

▲ **ANCIENT OPEN CLUSTER** The Polarissima Cluster, NGC 188, is about 5,400 light-years away. Because NGC 188 sits far above the galactic plane, it experiences little of the gravitational interactions that tend to break clusters apart. Indeed, the Polarissima Cluster has remained intact for nearly 7 billion years. Its oldest, visually dominant stars have been around long enough to evolve into cool giants. Even its most youthful members aren't much hotter than our Sun.



▲ **LONELY LIGHTS** The region around Polaris contains only two deep-sky objects within range of suburban telescopes — a small planetary nebula in Camelopardalis named IC 3568 and a faint open cluster in Cepheus called NGC 188. The latter, located less than 5° from the North Celestial Pole, is known as the Polarissima Cluster. Several fine double stars shine in the area as well.

famous Pole Star a suitably picturesque setting. In addition to Polaris, the Ring is outlined by at least 10 markers, one of them beaming at magnitude 6.5, the others ranging from 8th to 9th magnitude. The roughly ¾°-wide asterism is slightly elliptical, angles northeast-southwest, and Polaris fittingly adorns its northernmost point.

My little reflector, still working at 40×, gave me a fine view of the Ring. Polaris aside, I counted 10 jewels in all, though I was tempted to include several fainter bits of bling to help fill some gaps in the formation's irregular shape. The eyepiece truth is that the Engagement Ring is dim, dented, and distorted — yet it shows in any telescope and even binoculars.

Polarissima Cluster

Moving away from Polaris by about 4° and into neighboring Cepheus we find **NGC 188**, charmingly nicknamed the Polarissima Cluster. Polarissima is an alluring moniker, but the 8.1-magnitude, 15′-wide cluster is an obscure target for suburban stargazers. Residing well north of the galactic equator, NGC 188 is nowhere near its cluster kin along the Milky Way.

Two star-hops got me to NGC 188. After reducing the 4¼-inch to 20×, I swept from Polaris 3° to 4.2-magnitude HD 5848. Although this orangey naked-eye star possesses no Bayer letter or Flamsteed number, it twinkles helpfully 1° north-northeast of the elusive Polarissima. Doubling to 40×, I made a second, very short hop to a pair of 8th-magnitude stars ½° apart. Between those two stars was a triangle of 9th- and 10th-magnitude stars marking the cluster's location. I upped again to 72× hoping my averted vision would register something inside the triangle. No sale.

Simple numbers tell why. NGC 188 contains hundreds of suns; alas, none of them shine better than 12th magnitude. Harrumph! I turned to the 10-inch reflector and applied 95×. The Dobsonian produced a quadruplet of 11th-magnitude stars on or near the sides of the triangle. A handful of cluster members glimmered inside the figure. At 169×, the count grew to perhaps two dozen loosely scattered, exceedingly faint pinpricks of light.

Observing the dismal-abysmal Polarissima was like sipping lukewarm soup. But I'm happy to report that ½° south-southwest of NGC 188 is a slam-dunk double named **h1986**. Consisting of 8.0- and 8.5-magnitude stars 40.3″ apart, h1986 was beautifully clear in both scopes. An unrelated 7.1-magnitude beacon to the south-southwest morphed the double into a nice trio.

Polar Planetary

Employing the finderscope on my 10-inch Dob, I retreated to the Pole Star then marched onward for 7¼° to arrive at 5th-magnitude 32 Camelopardalis. It was quite a hike. Fortunately, 32 Cam lies in barren territory, so it shone prominently in the finder's field of view.

I wanted 32 Cam for two reasons. First, it's an exceptional binary cataloged as **Σ1694**, presenting 5.3- and 5.7-magnitude components 21.8″ apart. The almost equal headlights were bright 'n' tight at low power. Second, the double is a signpost to **IC 3568**, a challenging planetary nebula. A 1° nudge south-southwestward picked up the object — sort of. Struggling at magnitude 10.6 and just 10.2″ in diameter, the pee-wee planetary wasn't immediately identifiable.

The Dob operating at 48× revealed an 11.4-magnitude star situated 1.6′ south of an 11th-magnitude blur. Adding an O III nebula filter clarified everything. The filter obliterated the star, leaving a round nebula against a dark background. The disk of the planetary became more obvious with increasing magnification. At 218× (no filter), the disk was grayish and shiny-sharp in the middle — evidence of the planetary's 11.6-magnitude central star. Some photos of IC 3568 show a 13th-magnitude star hugging the nebula on its west-southwestern side. Doubling to (gulp) 436×, allowed me to glimpse the extremely dim neighbor.

The tiny planetary was a mere dot in the smaller scope. Thankfully, a consolation prize caught my eye 1° to the southwest. It was **SHJ 136**, a colorful double star. The 6.2- and 8.3-magnitude stars are separated by 71.9″. The brighter

ALAN DYER

▲ **ENGAGING CELESTIAL SIGHT** Polaris, the North Star, is a luminous diamond in the Engagement Ring, a roughly circular asterism of faint stars easily visible in small telescopes and even in 10×50 binoculars.

element glowed deep orange, the fainter one blue. Both SHJ 136 and Σ1694 looked great at low magnification.

Dragon Doubles

A near-clone of the Cam couple exists in the form of 40 and 41 Draconis, which reside at the tidy astral address of 18+80 (18.0 hours right ascension, +80.0° declination). Curiously, the Flamsteed numbers 40 and 41 appear to refer to a single, 6th-magnitude star. Only in a telescope does 40/41 become two.

I directed the 4¼-inch to the Flamsteed oddity by first locating 4.2-magnitude Epsilon (ε) Ursae Minoris in the handle of the Little Dipper. From Epsilon, a 3½° hop southeastward landed on 40/41 Draconis. It's also known as **Σ2308**, a superb double sporting 5.7- and 6.0-magnitude, yellowish stars 18.9″ apart. The delightful Draco duo was stunningly impressive at 20×.

My roundabout ramble ended 6° east-northeast of Σ2308 at **75 Draconis**, a yawning tandem whose 5.5- and 6.7-magnitude stars stand 196″ apart. Getting to 75 Draconis was quite a jump, but the super-wide set was an easy catch in the finderscope. Adding interest was 6.0-magnitude 74 Draconis 20′ to the south. Moreover, an 8.7-magnitude star was visible 3.5′ northeast of 74 Draconis. The airy quartet was picture-perfect at 20×.

This circumpolar project didn't focus on any particular constellation; it simply explored the celestial real estate north of declination +80°. Aside from double stars, the 314°-square area yielded just two deep-sky objects that my backyard equipment could detect. If your north sky is darker than mine, your views of both NGC 188 and IC 3568 might be genuinely satisfying. And you might even catch a few galaxies too!

■ Contributing Editor KEN HEWITT-WHITE occasionally escapes the city for dark skies. He surveyed faint galaxies near the NCP in the November 2012 issue.

Polar Pleasures

Object	Type	Mag	Size/Sep	RA	Dec.
Polaris	Double star	2.0, 9.1	18.4″	$2^h\ 31.8^m$	+89° 16′
Engagement Ring	Asterism	–	~45′	$2^h\ 46.0^m$	+88° 55′
NGC 188	Open cluster	8.1	15′	$0^h\ 47.5^m$	+85° 16′
h1986	Double star	8.0, 8.5	40.3″	$0^h\ 39.6^m$	+84° 45′
Σ1694	Double star	5.3, 5.7	21.8″	$12^h\ 49.2^m$	+83° 25′
IC 3568	Planetary nebula	10.6	10.2″	$12^h\ 33.1^m$	+82° 34′
SHJ 136	Double star	6.2, 8.3	71.9″	$12^h\ 11.0^m$	+81° 43′
Σ2308	Double star	5.7, 6.0	18.9″	$18^h\ 00.2^m$	+80° 00′
75 Draconis	Double star	5.5, 6.7	196″	$20^h\ 28.2^m$	+81° 25′

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

A Tapestry of Stellar Distances

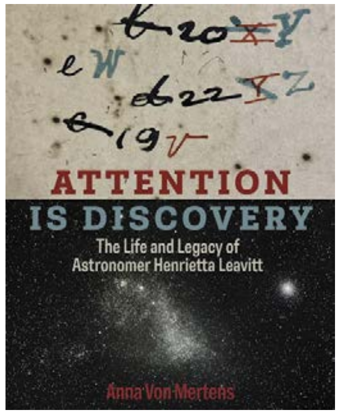
ATTENTION IS DISCOVERY: *The Life and Legacy of Astronomer Henrietta Leavitt*

Anna Von Mertens
The MIT Press, 2024
256 pages, ISBN 9780262049382
$34.95, hardcover

HENRIETTA LEAVITT (1868–1921) and the Harvard Computers have caught the attention of the world as some of the first modern female astronomers, but their story was nearly lost to time. *Attention Is Discovery: The Life and Legacy of Astronomer Henrietta Leavitt* is a series of essays that couch science and history in glorious illustrations to form a full picture of Leavitt and the impact of her work. Anna Von Mertens, an award-winning visual artist specializing in quilting and textiles, has used Leavitt's story to bridge the perceived gap between astronomy and art. Her book vividly displays her eye for detail and artistry as she finds inspiration in the stars and the people who studied them.

Von Mertens opens with a lyrical description of Henrietta's work — not the traditional image of her leaning over a desk at Harvard College Observatory in Cambridge, Massachusetts, but a simple retelling of her methodical study of each star on a photographic glass plate. Lauding the importance of the discovery that came from her dedication, this book highlights the slow, repetitive work of measuring and cataloging the positions and brightness of innumerable stars on hundreds of thousands of glass plates.

Since Leavitt didn't leave behind many personal notes, the author pieces together her daily life from writings and artifacts left behind by her coworkers and other astronomers of her time. Von Mertens even details techniques that Leavitt developed for capturing and estimating the magnitude of both very bright and dim stars after she published her discovery of the period-luminosity relationship in Cepheid variables. This relationship laid the foundation for modern cosmology, allowing astronomers to effectively calculate astronomical distances and understand the nature and scale of the visible universe.



After covering the development of the technology behind the glass plates and how our understanding of Cepheids has expanded since Leavitt's discovery, the book also takes a step forward into the modern day. A brief interlude by astrophysicist João Alves describes recent research that utilizes Leavitt's Law to map out the Milky Way and find new galactic structures like the Radcliffe Wave. The narrative then shifts to cosmologist Wendy Freedman's continued work with Cepheids and how researchers are looking to Leavitt's period-luminosity relation to untangle the Hubble tension, the discrepancy between model and data for the universe's expansion rate.

While Leavitt's contemporaries understood the significance of the Harvard Computers' work, Von Mertens explains how the technology of the time slowly eclipsed their story in the history books. She also portrays the persistence of the historic glass plate collection to the current day amid years of neglect and several disasters. Recently, in an effort to digitize their astronomical data, most of the Computers' ink notations on the glass were erased. Von Mertens praises the efforts of curator Lindsay Zrull, who prevented many historic plates from being "cleaned," as well as innovation scientist Peter Williams and software engineer Benjamin Sabath, who rescued the scans from a server crash and developed a more accessible website to display them on.

From full-page, face-on images to artful close-ups from interesting angles, this book swells with Jennifer Roberts's photographs of the glass plates and the Harvard Computers' logbooks, allowing the readers to fully immerse themselves in their hidden depths. Historical photos depict the daily activities of the observatory and its staff, as well as the tools and telescopes they used. It's uncanny to see the equipment, plates, and writings of these women, and even the protective sleeves of the glass plates, displayed like art. Von Mertens also exhibits some of the artwork she created while researching the Harvard Computers. Each sketch of the plates and hand-sewn quilt parades the depth and feeling of her investigation while demonstrating the deep connection she feels to Leavitt.

Von Mertens really takes the time to immerse herself in Leavitt's world and life. And she manages to glorify the process of research without glossing over its tedium. Anyone who enjoys reenactments and documentaries, as well as art and poetry, would relish submerging themselves in this book.

■ Editorial Assistant **SABRINA GARVIN** wishes she could travel back in time to meet the Harvard Computers.

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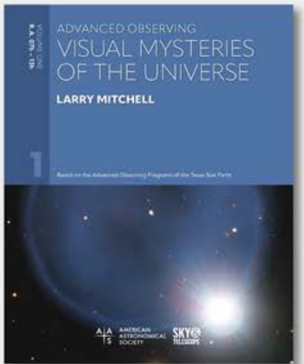

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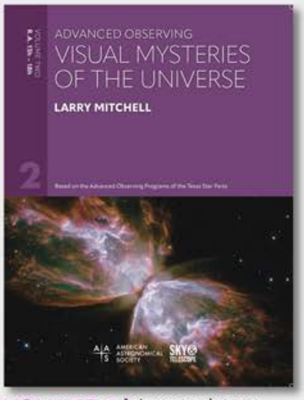

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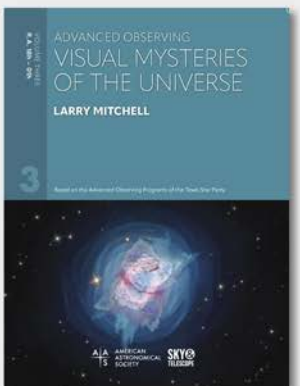

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ZWO SEESTAR S30

Telescopes are getting smarter and easier to use.

RISE OF THE SMART TELESCOPES

Artificial Intelligence and robots are coming for us all — including you, my fellow astro-imager. It wasn't that long ago I was describing the next big thing in astrophotography (*S&T:* August 2022, p. 60). The writing was on the wall then. Now, some three years later, "smart" technology is becoming mainstream, and from what I hear on the grapevine, smart telescopes are now a commodity and "selling like hotcakes," as my dad used to say. There's even a smart eyepiece on the market that can transform your Go To scope into a smartscope.

The Dawn of Digitized Astronomy

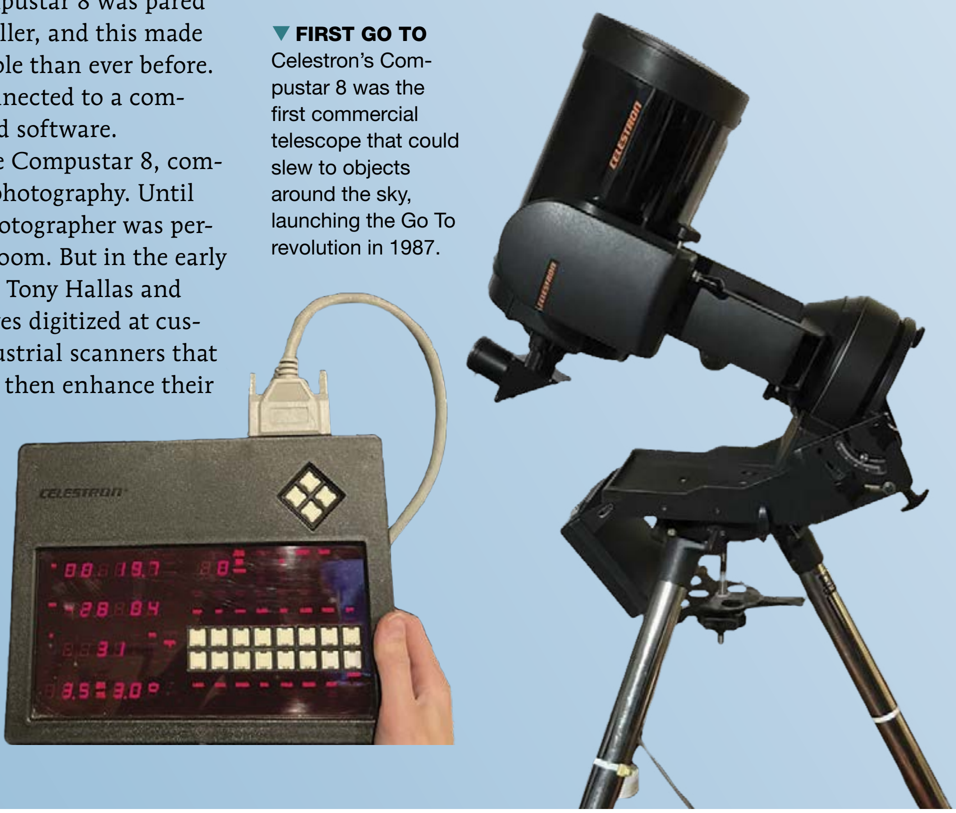
So, how did we get here? The seeds were planted long ago with the advent of computers and automation. Such electronics found their way into astronomy almost as soon as they came into existence. In the 1950s, astronomers were using basic computers to calculate the positions of objects, chart the heavens, and help point their instruments. By the mid-1980s they had become affordable (and shrank) enough to enter the consumer market.

A key development was the introduction of the Go To telescope. In 1987 Celestron (**celestron.com**) introduced the Compustar 8 — a computerized telescope that would automatically "go to" any object currently above the horizon using an internal database of celestial objects. This initial offering was later eclipsed by competitor Meade Telescopes in 1992 with the release of its LX200. With the LX200 system, the bulky box that commanded the Compustar 8 was pared down to a less cumbersome hand controller, and this made observing vastly easier and more accessible than ever before. These Go To telescopes could also be connected to a computer and controlled with more advanced software.

Not long after the introduction of the Compustar 8, computers began to enter the world of astrophotography. Until the 1990s, the main work of the astrophotographer was performed at the telescope and in the darkroom. But in the early '90s pioneering astro-imagers, including Tony Hallas and Jack Newton, began having their negatives digitized at custom labs with drum scanners (large industrial scanners that used photomultiplier tubes). They would then enhance their photo with early versions of image-processing programs like *PhotoStyler* and *Adobe Photoshop*. By the latter half of the decade consumer-grade scanners and image-processing software were must-have accessories for astrophotographers and the desktop computer began to displace the darkroom. By 1997 with the apparition of comet Hale-Bopp (C/1995 O1), astrophotography was making a big splash in online "bulletin boards" hosted by early internet providers like AOL and CompuServe.

The '90s also saw the introduction of specialized astronomical cameras designed around the charge-coupled device (CCD) that produced digital images directly. At first these sensors were tiny and very expensive, but by the turn of the 21st century their growth in the broader consumer photography market drove down the cost. Near the end of the '90s, CCDs began supplanting film as the medium of choice for advanced astrophotographers. The digital imaging revolution was underway.

Meanwhile, companies such as Santa Barbara Instrument Group or SBIG (**diffractionlimited.com**) and Software Bisque (**bisque.com**) paved the way toward automated astrophotography. In addition to introducing one of the earliest commercially successful CCD cameras, SBIG pioneered a technology that relieved astrophotographers of the tedious task of guiding a telescope. Early astrophotographers had to carefully monitor a star in a reticle eyepiece attached to a second scope or an off-axis guider and manually make small corrections to keep the star centered, thus avoiding trailed stars and blurred nebulae and galaxies in long-exposure photographs. This was a monumental breakthrough in the days when really good deep-sky astrophotos recorded on film required exposures of 60 minutes and longer. SBIG significantly simplified this process with the introduction of the first commercially successful autoguider, the ST-4, which used a computer to monitor



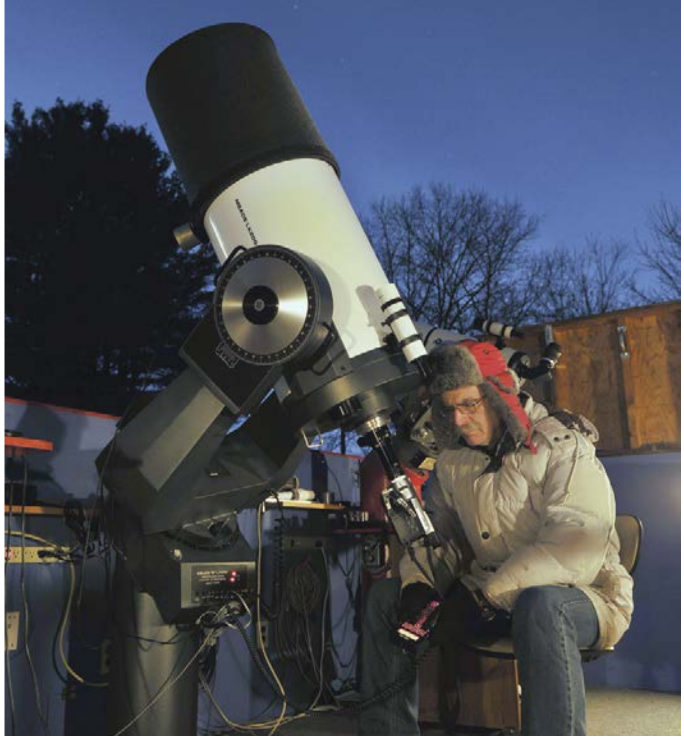
▼ **FIRST GO TO** Celestron's Compustar 8 was the first commercial telescope that could slew to objects around the sky, launching the Go To revolution in 1987.

ROBOT HAND AND ORB: SEANPRAI / SHUTTERSTOCK.COM; ZWO SEESTAR S30: ROD MOLLISE; FIRST GO TO: JORDANNE BRISBY (2) star drift on a small CCD detector and automatically make corresponding drive adjustments.

Computers continued their advance into astrophotography when SBIG collaborated with Software Bisque in the mid-1990s to produce the first fully functional digital astrophotography ensemble. Software Bisque's *CCDSoft* software worked closely with SBIG's CCD cameras as well as Go To mounts and telescope systems to automate image acquisition and perform basic image processing tasks, while its planetarium program, *TheSky*, managed telescope control. Amateur astronomers could now script an entire night's worth of imaging — automatically locate targets, focus, change filters, and autoguide. In the morning, they'd find a folder full of image data ready to be processed into astrophotography masterpieces. Today, this is all taken for granted and there are dozens of packages that perform these tasks. Some of them are even free.

One additional development that occurred in the 1990s had important ramifications some two decades later. With the release of version 4 of *TheSky*, a type of plate solving called "Image Link" was added to perform accurate astrometric measurements on imported FIT files. Plate solving is the act of identifying an area of sky by examining star patterns. The technique was originally performed manually on glass plates in the early 1900s.

On another front some years earlier, skilled tinkerers were attempting to mate CCD video cameras and closed-circuit televisions (CCTVs). The first successful commercial attempt at real-time observing with digital cameras (latered dubbed electronic-assisted astronomy, or EAA) came about in 1994 when, after years of experimentation, Rock Mallin introduced Mallincam I. This was with a monochrome 1/3-inch-format CCD sensor. Its ½-second exposures allowed amateurs to



▲ **IMPROVED ERGONOMICS** Five years after Celestron's Compustar 8, Meade's LX200 telescopes made Go To convenient. Its hand-paddle Go To controller became the template for all others for the next 20 years.

view faint deep-sky objects in near real-time on a CRT monitor. I remember well the first time I saw a color Mallincam in use on a large Dobsonian telescope at the Winter Star Party in the Florida Keys. It was quite impressive, and I knew it was the shape of things to come.

Techno-Evolution

As with all technology, things get smaller, better, faster, and (most significantly) less expensive when they become high-

VAONIS STELLINA

UNISTELLAR EVSCOPE

ZWO SEESTAR S50

LX200 AND ZWO SEESTAR S50: DENNIS DI CICCO (2); VAONIS STELLINA: SEAN WALKER / S&T; UNISTELLAR EVSCOPE: RICK FIENBERG

▲ *Left:* By the mid-1990s, CCD cameras controlled by a desktop computer began to supplant 35-mm film as the medium of choice for cutting-edge astrophotograpy. *Right:* By the middle of the first decade of the 21st century, laptop computers were the brains of most CCD-imaging systems, permitting more portable imaging setups.

demand commodities. Initially, CCD cameras were very expensive. For example, an SBIG ST-8 CCD camera, with its modest 1,530 × 1,020 pixel (1.5 megapixel) array cost a whopping $6,450 in January 1999. But as digital photography increased in popularity, prices fell and CCD cameras ruled the world for a while. By 2010, CCD detector sizes had grown larger than 35-mm film with the 16-megapixel Kodak KAF-16801E detector measuring 37 × 37 mm while costing not much more than the ST-8 did a decade earlier.

By 2000, a new approach to image-sensor manufacturing, the complementary metal-oxide-semiconductor (CMOS), began to overtake CCDs. These detectors are far less expensive to mass-produce because they use many of the same manufacturing processes as the computer semiconductor industry. They had other advantages including better power efficiency and faster readout. The consumer digital camera industry embraced this cheaper technology by the end of the first decade of the 2000s and within the span of a few years,

VAONIS VESPERA

MIRROSKY HX35

UNISTELLAR EVSCOPE V2

TELESCOPE CONTROL ROOM 1999 & 2010: DENNIS DI CICCO (2); VAONIS VESPERA AND UNISTELLAR EVSCOPE V2: SEAN WALKER / *S&T* (2); MIRROSKY HX35: SPECTRUM OPTICAL INSTRUMENTS

SEAN WALKER / *S&T* (2)

AI in Amateur Astronomy

There are four general types of artificial intelligence (AI). The oldest are rules-based algorithms called *expert systems*, a subset of a broader form called "symbolic AI" where programmers code specific logic rules. I worked on one in the early 1990s for a health-insurance company. Most modern scheduling and automation software for astrophotography use these.

A more sophisticated form of AI, *neural networks*, has also been around for decades, but only recently entered the mainstream as computer processing has greatly increased. These kinds of AI models use machine learning, where computers "study" large data sets. Modern graphics processors (GPUs) were key in making these easier to produce. Neural networks can outperform humans in many respects but occasionally can behave unpredictably and give weird results. Russ Croman's popular AI-based *PixInsight* and *Photoshop* plug-ins rely heavily on neural networks to determine when and how to apply various image-processing techniques (like star removal as seen above) to improve astrophotos.

Neural networks are also used in another AI process called *generative AI*. This is the type of AI that, based on prompts or input imagery, synthesizes media — pictures, video, music, etc. Some early noise-reduction plug-ins use generative AI to fill in the gaps for noisy or incomplete images. These often did more harm than good on astrophotos. For example, Samsung was embroiled in controversy for artificially enhancing images of the Moon with source images found online. This gave the false impression that their smartphone cameras were taking far better lunar photos than was actually the case. Some noise-reduction plug-ins aren't as egregious as the Samsung controversy, but they've left a mark on the reputation of AI for image enhancement.

Finally, *large language models* (LLM) are a specific subset of generative AI focused on language or text-based content. These AI models can appear to be capable of advanced reasoning and even hold conversations much like a person. These LLMs are the type of AI that made the news recently — the kind that can greatly enhance productivity or even eliminate certain jobs.

There's no fear that AI is going to replace astrophotography. Rather, it's already enhancing it in several ways. Smart telescopes can and do use all of the kinds of AI I've outlined here. An LLM in your control app may talk to you and accepts instructions for the next target to photograph. Expert systems can find and center your target and refine your focus, and machine-learning-trained neural networks can perform noise reduction or sharpening on your picture.

These tools aren't much different than, say, using a spreadsheet to help with accounting. They refine existing data, and can be over-applied like other processing tools. The real concern is generative AI being used excessively to create results promoted as real but aren't backed up by the raw, unaltered data.

all DSLRs and pocket cameras (as well as cellphones) included CMOS rather than CCD technology.

The switch to CMOS, however, was much slower for the astronomy community primarily due to the pesky problem of a glow caused by electronics within the cameras (*S&T:* May 2020, p. 30). But the issue was surmounted around 2020, and today CCDs are thought of as technological dinosaurs by many in the amateur community.

The current generation of CMOS cameras have broken new ground in terms of sensitivity and noise control, allowing astrophotographers to take increasingly shorter individual exposures, which greatly relaxes the constraints on guiding and tracking of the telescope mounts (*S&T:* April 2022, p. 54). In fact, the low noise from CMOS sensors has enabled a new form of EAA called "live stacking," in which very short exposures are aligned and combined on a computer as you watch in real time (*S&T:* May 2023, p. 58). The barriers to digitally observing faint deep-sky objects continued to fall. Indeed, this is one of the main processes at the core of smartscopes today.

Of course, computers continued shrinking while becoming more powerful. In the '90s, CCD imagers used desktop computers to control their gear in home observatories. Then laptops became lighter, faster, and more power efficient, which enabled a more portable rig. For the next decade laptops became an integral part of astrophotography setups. But, in the early 2010s another computer phenomenon took the world by storm. Computers were getting as small as the size of a deck of playing cards. Such machines were easily portable, lightweight, and drew much less power than typical laptops. The most recognizable hobbyist-centered product here was the Raspberry Pi, first released in February 2012. These small computers had been used in industrial applications all over the world and astro-imagers immediately took notice. Astronomy software and scripts for these devices soon began to appear. I recall that in late 2013, while working as a consultant for Software Bisque, I modified *TheSky* to run on a Raspberry Pi to control a telescope mount and CCD camera. Using a tablet or a laptop to remotely control the setup was promising, because I could power this small computer all night at a remote location much more easily than I could a laptop computer. We showed this off at the 2014 Northeast Astro-Imaging Conference and I began imaging with it at the Riverside Telescope Making Conference in May of that same year.

When the Raspberry Pi 2 was released in 2015 it was a huge leap in performance and really opened the floodgates. It was

▲ **TINY COMPUTER** The Raspberry Pi computer loaded with a modified copy of *TheSky* is seen atop the author's Officina Stellare RH200 astrograph. *Inset:* The author showing just how small the Raspberry Pi is.

MIRROSKY SPI53

UNISTELLAR ODYSSEY PRO

DWARF II

DWARF III

RASPBERRY PI COMPUTER: RICHARD S. WRIGHT, JR. (2); MIRROSKY SPI53: SPECTRUM OPTICAL INSTRUMENTS; UNISTELLAR ODYSSEY PRO: UNISTELLAR; DWARF II: ALAN DYER; DWARF III: DWARFLABS

▲ **DIALING IT IN** The ZWO ASIair that entered the scene in mid-2018 was the first commercial ride-along control computer that users interface with using a smartphone app.

JOHNNY HORNE

around this time that *Astroberry* (**www.astroberry.io**) was born — the first integrated astrophotography control system designed to run on a Raspberry Pi. It was followed in 2017 by *StellarMate* (**stellarmate.com**), which was a bit more polished.

Then in July of 2018 the first commercially successful product based on the mini-computer was introduced by Chinese camera manufacturer ZWO (**zwoastro.com**), the ASIair (*S&T:* Sept. 2019, p. 66). This device offered a complete automation package in a small, portable setup with multiple ports to power and control specific types of astrophotography gear. The ASIair proved that a small computer with smart software could work with a complex astrophotography setup and do it well.

Thinking Outside the Box

Using a compact computer for astro-imaging control was an obvious evolutionary path. Many thought of doing it, and some executed it successfully. Concurrently, a more innovative approach was born in France when Cyril Dupuy founded the company Vaonis (**vaonis.com**) in 2014. Dupuy's experience in public outreach led him to understand the potential of a small, integrated computer inside a Go To telescope with built-in camera that could send images to a tablet or smartphone.

Dupuy wasn't so much targeting traditional astrophotography — he wanted to make astronomy more accessible for everyone by using a camera to display far more than what could be seen through an eyepiece (EAA). Using a built-in camera and a completely automated pointing system, he could also eliminate the often-challenging task of getting a target into view. The way the telescope would find its way around the sky was through the use of automated plate solving instead of aligning a Go To mount on multiple stars across the sky. Tiny computers were now so powerful they could handle performing millions (billions?) of measurements per second and quickly identify the exact area of the sky that the telescope and camera were pointed at. With all the pieces in place, the project came to fruition with the release of the Stellina 80-mm "observation station" in late 2018 (*S&T:* March 2020, p. 68). The Stellina combined all the various technologies into one convenient package: Go To, plate solving, live-stacking, EAA, and a convenient way to deliver the results to devices most everyone already owns.

Vaonis wasn't the only company working to release an integrated plate-solving imaging system. At the same time Unistellar (**unistellar.com**), an investment company founded in 2015, began a Kickstarter campaign to finance the development of the eVscope, a 4-inch f/5 reflector with an eye on the science such a system could achieve. Although the company showcased a prototype at the 2017 Consumer Electronics Show in Las Vegas, its product didn't reach the market until late 2020. Still, the eVscope made a huge impact. It functions similarly to the Stellina, though it includes one feature that makes it feel more like a telescope: an electronic "eyepiece" containing a tiny color screen that displays the image being recorded.

The commercial success of smartscopes is evident as these companies continue to improve on their original designs. There are several models of smartscopes from these early leaders today, as well as several new companies. DwarfLab (**dwarflab.com**) released its DWARF I smartscope in mid-2020 while ZWO, capitalizing on its ASIair technology, announced the SeeStar S50 in April of 2023. The Seestar S50 immediately began to dominate the smartscope market for two reasons: it works extremely well and because it was initially priced at $499 — far less expensive than any of its competition. More recently, in January of 2024, Celestron entered the field with the largest smartscope in production, the 6-inch f/2.2 Origin. This Row-Ackermann Schmidt Astrograph is designed to produce poster-quality astrophotos. And at this year's Northeast Astronomy Forum, a new company, Spectrum Optical Instruments (**spectrumoi.com**), unveiled its Mirrosky line of modular smartscopes designed to allow both imaging and visual use.

There's even a smart eyepiece that can make your own Go To telescope perform much like a smartscope. The

SMART ENABLER The SmartEye adds many of the hallmarks of smartscopes to your own Go To system, including field recognition by plate solving, live-stacking, and even a tiny "eyepiece" screen.

PegasusAstro SmartEye (**pegasusastro.com**) includes an "eyepiece" monitor that displays live-stacked images of the system's targets. (Full disclosure: Together with Simulation Curriculum, I played a leading role in development of this product.)

Pictures as a Gateway

Smart telescopes are making astronomy and astro-imaging more accessible than they have been at any other time. Instead of a niche hobby aimed at people who love to tinker and solve problems, these devices are making astronomy a mainstream pursuit. While some may discount the value of astrophotography, there's no doubt that imaging is a great way to get people's attention and perhaps expose them to unfamiliar scientific concepts. Anyone with a smartscope can get a photo of a deep-sky object in just minutes from their driveway.

Smartscopes even offer the potential to do "real" science. These robotic, self-aligning devices make it trivially easy to get data on a target at short notice. There are programs for doing variable-star photometry, spectroscopy, compiling light-pollution data, recording exoplanet transits, and tracking newly discovered near-Earth asteroids or even interstellar comets (see page 48). While amateurs have always been involved in these kinds of projects, removing technological barriers should make doing so much easier for more people. High marks on this front go to Unistellar. Through its association with the SETI Institute, it is active in promoting citizen-science projects with their products.

The book *Crossing the Chasm: Marketing and Selling Disruptive Products to Mainstream Customers* by Geoffrey A. Moore describes how new technology grows from an awkward, early adopter "techie" phase to finally "cross the chasm" and become a mainstream phenomenon. In just the last two or three years, it's apparent that smart telescopes have done just that. They're here to stay, they're going to be disruptive, and it's going to be great for amateur astronomy.

Contributing Editor **RICHARD WRIGHT** first started writing code on a home computer more than 40 years ago. He has since contributed to multiple astronomy and astrophotography software products.

CELESTRON ORIGIN

MIRROSKY 127

PEGASUS: RICHARD S. WRIGHT, JR.; CELESTRON ORIGIN: DENNIS DI CICCO; MIRROSKY 127: SPECTRUM OPTICAL INSTRUMENTS

Astro-Tech AT150EDL Refractor

Color-free performance and quality construction make this refractor a superb choice for visual observers.

▲ Astro-Tech's AT150EDL is a 150-mm f/8 refractor that delivers apochromatic-like performance from a two-element objective. The main tube assembly is finished with handsome pearl-white paint. It's pictured here with the author's Telescope Engineering Company eyepiece turret.

AT150EDL Refractor

U.S. Price: $3,395.00*
astronomics.com

What We Like

Excellent optics

High-quality focuser

Robust storage case

What We Don't Like

Storage case is difficult for one person to handle

**Prices subject to change*

EVEN EQUIPMENT GEEKS relatively new to the astronomy hobby are likely marveling at the current rate new gear is entering the market. And it's not just the volume of new products that's noteworthy but also their novelty. Just a few years ago, who had heard of strain-wave mounts or smart telescopes? (See page 60.) But amid this flurry of new astronomy hardware, at least one thing has remained notably constant — when it comes to telescopes for observers, a 6-inch refractor remains a big telescope. And it has been for a long time. Admiral William H. Smyth's *Bedford Catalogue,* the 19th-century genesis for virtually all future amateur observing guides, was compiled more than 180 years ago based on observations he made with a 5.9-inch refractor.

Today, one of the newest refractors of this caliber is the Astro-Tech AT150EDL, a 150-mm (5.9-inch) f/8 with a doublet objective made with FCD-100 ED (extra-low dispersion) and lanthanum glass elements. We borrowed one for this review from Astro-Tech's parent company Astronomics in Norman, Oklahoma. This telescope held a num-

▶ *Right:* Although the scope is sold without a finder or eyepieces, there is a Synta-standard shoe for a finder mounted on the 3.2-inch, dual-speed focuser. The 2-inch eyepiece adapter can be rotated 360° to aid with eyepiece and camera positioning.

▶ *Far Right:* The focuser drawtube extends up to 98 mm and is solidly driven by helical rack-and-pinion gears with adjustable tension for the focus knobs. The focuser body can rotate 360° on the telescope tube, which allows the focuser knobs to be comfortably located.

ALL IMAGES ARE BY THE AUTHOR

ber of pleasant surprises that began even before I had the shipping carton fully opened.

In the lead up to the telescope's availability, Astronomics's Mike Bieler sent email updates explaining how he had worked extensively with the scope's Chinese manufacturer to bring the AT150EDL to market for less than $3,000 (a price that has now risen to $3,395 because of recently imposed tariffs on Chinese products). This was $1,400 less than the list price at the time for Astro-Tech's flagship AT152EDT 6-inch f/8 APO refractor with a triplet objective. That seemed like a big difference given that on paper the two scopes shared many mechanical specifications, and the doublet comes with a bonus storage case. Subliminally, I was set up for the AT150EDL to be pared down by more than the virtually meaningless 2-millimeter difference in aperture between the two scopes.

As it turns out, it wasn't. My first indication of that came as I began unpacking the scope. The storage case, which was pictured but not described on the Astronomics website, is exceptionally robust and well made. It also helps explain why the shipping weight of 33 kg (72 pounds) is more than double the scope's 11.3-kg weight, including its two mounting rings, 33-cm (13-inch) Losmandy-style dovetail mounting plate, and carrying handle, which also doubles as an 18-cm-long Vixen-style mounting bar.

The 131-cm-long foam-lined case could accommodate a telescope a bit larger than the AT150EDL, which is only 108 cm long with its sliding dew shield and focuser both retracted. There's room (and some foam cutouts) for eyepieces, a star diagonal, and similar accessories. Despite three strong handles, the case is an awkward load for one person, and it's better carried by two people.

Everything about the scope's optical tube assembly (OTA) behind the AT150EDL's objective is the same as the pricier AT152EDT. The dual-speed focuser is impressive — its 3.2-inch-

▲ The fully multi-coated objective has air-spaced elements made of FCD-100 ED (extra-low dispersion) and lanthanum glasses. Several of the six internal light baffles are visible within the tube assembly. The front of the 170-mm diameter dew shield (shown retracted here) can extend 22 cm beyond the front of the objective.

▲ The scope comes with machined tube rings, which have numerous threaded holes for attaching accessories on the top half, and there's an 18-cm-long Vixen-style mounting bar that doubles as a carrying handle. The rings are attached to a 33-cm-long Losmandy-style mounting plate.

diameter drawtube has 98 mm of travel and is solidly driven by helical rack-and-pinion gears.

The focuser accepts conventional 2-inch accessories held in place with a brass compression ring and three locking thumbscrews (it comes with a 1¼-inch adapter as well). This assembly can be rotated 360° to aid in orienting star diagonals and cameras. Furthermore, the whole focuser can be smoothly rotated 360° on the OTA, which makes it easy to keep the focusing knobs at a comfortable position regardless of where the scope is aimed when paired with an equatorial mount. I really like this feature, since there's enough friction on the rotation mechanism to keep the focuser in place without having to deal with its locking thumbscrew.

The scope's focus falls 160 mm outside the 2-inch mounting ring when the focuser drawtube is fully retracted. This generous back focus easily accommodates a 2-inch star diagonal and

The 20-kg, foam-lined storage case is very robust, and it's nearly double the weight of the scope, even with its tube rings and mounting plate attached. While there is one carrying handle on the side of the case, handles on each end acknowledge that transporting the fully loaded case is really better suited for two people.

all the eyepieces I used with the scope. It's also enough room for most imaging setups. If you need more for, say, a binoviewer, you can gain another 100 mm of back focus by removing the extension sleeve that connects the focuser to the main telescope.

The Optics

Before taking the AT150EDL outside and under the stars, I did a quick test of the objective on my optical bench. Using a double-pass autocollimation test with a Ronchi grating and green laser light source, the Ronchi bands appeared straight across the whole lens aperture and showed no sign of zones. This was certainly a good start.

Observing tests were done with the scope mounted on an iOptron CEM120 equatorial mount in my backyard observatory in the MetroWest suburbs of Boston. It took only moments after turning the scope skyward to realize this was indeed an optically superb telescope. Even at moderately high magnifications stars snapped into focus. The sweet spot for focus was so precise that just a touch of the fine-focus knob moving the eyepiece either inside or outside of focus visibly softened the images. And the same was true when focusing various cameras that I attached to the scope.

Focused star images were remarkably crisp with no hint of mushiness.

Observing Sirius B

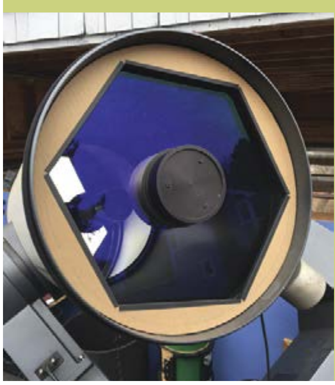
If your observing bucket list includes getting a glimpse of Sirius B, the 8th-magnitude white dwarf companion of the night sky's brightest star, now is a good time to have a look. Also known as "the Pup," Sirius B is currently near its 11.3″ maximum separation from Sirius in its 50.1-year orbit. But the problem with seeing Sirius's companion isn't so much the separation as it is the overpowering brilliance of the primary star, which outshines the Pup by 10 magnitudes, or about 10,000 times. If these were a pair of, say, 4th-magnitude stars, even the smallest telescope could follow them throughout the entire orbit.

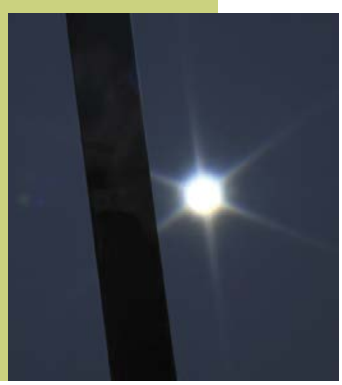
Over the years I've used several tactics well-known among observers for catching sight of Sirius B — a hexagonal aperture mask and an eyepiece occulting bar. The mask helps channel Sirius's glare into diffraction spikes that can be positioned away from the companion by rotating the mask on the telescope's aperture. Covering Sirius with an occulting bar further suppresses the distraction of its glare in the eyepiece. But it can be difficult to know if the bar's edge extends too far beyond Sirius and covers the companion as well. To help with that, I tried a technique a few years ago that I've not seen mentioned before — that is, to make the occulting bar out of a suitable filter material rather than something completely opaque. This allows me to reduce Sirius's brilliance but still lets me keep track of its position behind the bar.

The first material I used for an occulting bar was the now-discontinued "photographic" version of Baader's AstroSolar Safety Film, which transmitted too much light for safe visual solar observing but was fine for photography. It worked well for dimming Sirius's brilliance in a 16-inch telescope, but for smaller apertures, it's better to have an even-more-transmissive filter material. Since optical quality isn't critical for the occulting bar, I experimented with metallized plastic food wrappers and found the wrapper for Kellogg's Pop Tarts to be just about ideal. It's cheap, readily available at just about any grocery store, and easy to cut into thin strips with sharp scissors or a razor blade.

The occulting bar needs to be positioned at the location of the field stop in an eyepiece. Many modern eyepieces are designed with field stops between the lens elements and are thus not accessible. But older designs, especially Plössl and Orthoscopic eyepieces, have field-stop locations in front of the lenses and within the eyepiece barrels. You can easily check if an eyepiece is suitable by looking through it while inserting the tip of a pencil into the barrel. If you find a point where the tip is seen in focus, this is where the occulting bar needs to be placed.

▼ Pictured here are the hexagonal aperture mask and occulting bar made from filter material described in the sidebar. They were used for the photos of Sirius and its companion, the Pup, with the author's 16-inch telescope in March 2019.





Likewise, the images of stars inside and outside of focus showed classic textbook examples of similar, perfectly round diffraction patterns that indicated the objective was free of spherical aberration and properly mounted in its lens cell without being stressed or pinched.

There were no apparent color halos around even very bright stars. Indeed, the only flickers of color that I ever noted around star images were due to seeing-induced refraction. It's remarkable how much modern optical glass types and lens designs have been able to reduce the chromatic aberrations of an f/8 doublet objective to levels typically ascribed to multi-element apochromats.

My sky testing began in early March, when Jupiter and Mars were decently placed near the meridian during the evening. As I focused on Jupiter, I realized that the astronomical seeing was somewhat above average (a rare occurrence for me), so I immediately turned to one of my favorite winter quests — trying to catch a glimpse of Sirius B, the elusive companion of Sirius, which is also known as "the Pup."

Using a 24-mm Tele Vue Panoptic eyepiece fitted with the "Pop Tart" occulting bar (explained in the sidebar on the facing page) and a 3× Barlow yielding 150× on the AT150EDL, it took only moments for me to spot the companion just 11″ northwest of Sirius. I was thrilled, since this was now the smallest aperture I've used to see the Pup (others have used smaller refractors), and timing played a big role. Less than 20 minutes later, the seeing deteriorated, and I lost sight of the companion. Several later attempts in March were all foiled by the seeing as well.

Turning back to Jupiter, which was much higher in my sky than Sirius, I was rewarded with very nice views of the planet and its four Galilean moons. At 400× there were even a few moments when I could convince myself that Ganymede appeared as a tiny disk rather than its usual starlike point of light.

Mars was equally high in the sky, but the Red Planet was two months past opposition and only about 10″ in diameter. Still, there were times when albedo features were clearly seen.

▲ Although there is no dedicated field-flattener for the AT150EDL, the scope still delivers quality star images for many of today's popular astronomy cameras. This stack of three 10-minute exposures of the Ring Nebula, M57, was made with a QHYCCD Minicam 8. It shows the full field of the camera's 11.2-by-6.3-mm CMOS detector that covers a 32′-wide field on this scope. A stack of five 3-minute exposures made with a full-frame Nikon D850 camera *(bottom)* covers a 1.7°-wide field but shows noticeable distortion of the star images at the edges.

In the weeks that followed, I spent a lot of evenings observing double stars. The AT150EDL's sharp and very contrasty images made it especially easy to distinguish subtle color differences between many of the stellar pairs. There was never a night when I didn't truly enjoy using the scope.

Today, it seems like apochromatic refractors are the ones getting lots of accolades, especially from astro-imagers. But in my opinion, when it comes to visual observing, the performance difference between a refractor with a three-element apochromatic objective and the AT150EDL doesn't justify the typical cost difference. And when you factor in the excellent mechanical features of the AT150EDL, it makes it a very sweet deal. I highly recommend the scope.

■ If he didn't already have his own 8-inch refractor, **DENNIS DI CICCO** would certainly be tempted by the AT150EDL.

What Is Guiding?

TO CAPTURE SHARP, pinpoint star images during long-exposure photographs, astro-imagers use motorized equatorial tracking mounts to compensate for Earth's rotation. However, these devices can suffer from small, periodic tracking errors. So, if you're serious about obtaining the best astrophotos possible, then accurate *guiding* is a must. Guiding can correct for periodic errors and atmospheric effects as well as slight telescope imbalance, sagging, or polar misalignment.

The goal of guiding is to keep the target centered (and stationary) within the camera frame by making small corrections to the mount's tracking rate — that is, adjusting the telescope's right ascension and declination throughout the exposure to prevent stars from appearing elongated, trailed, or even squiggly.

One way to guide is to use a *guidescope*, a small auxiliary telescope that's mounted securely to, and precisely aligned with, the main imaging telescope. Decades ago, guiding was done manually — that is, you looked through the guidescope's eyepiece (usually equipped with an illuminated crosshair), and you did your best to keep the magnified image of your chosen guide star perfectly centered on the crosshair while your camera shutter is open. Careful polar alignment, practice, and lots of patience were required. The drawback to this approach is that the guidescope adds extra load on the telescope's mount and motor drive, and any flexure or wobble in the setup can throw the guidescope out of alignment.

Another method is to use a device called an *off-axis guider* (OAG). This accessory is mounted between the imaging telescope's focuser and your camera body. The OAG uses a small pickoff prism or mirror to divert light from a suitable guide star near your target into your guiding eyepiece.

▲ **TO GUIDE OR NOT TO GUIDE** Compare these 12-minute exposures of the Cocoon Nebula in Cygnus (see page 26) captured by Contributing Editor Alan Dyer with a SharpStar 76-mm refractor and Canon EOS Ra camera. Guiding helps keep star images sharp and perfectly round. A slight drift in the telescope mount's right ascension caused the trailed stars in the top image.

Today, most astrophotographers avoid the tedium of continuously monitoring a star visually by utilizing an *autoguider* — a small electronic camera that automatically performs the necessary corrections for you. An autoguider connects directly to your telescope mount's drive system. Not all mounts are capable of autoguiding, but most new ones are. The autoguider is fitted to either guidescope or OAG, effectively replacing your eye with a mini camera and computer/guide software combination.

Some dedicated astronomical imaging cameras, such as the ZWO ASI2600MC/MM Duo and Air models, feature dual sensors — one to capture the image and another to perform the autoguiding function. Such an integrated design eliminates the need for a separate guidescope or OAG and simplifies the setup. So, you can sit back, relax, and enjoy a hot cup of coffee, either next to your telescope or from a remote site, as the camera captures portraits of your favorite celestial targets.

Happy imaging! ■

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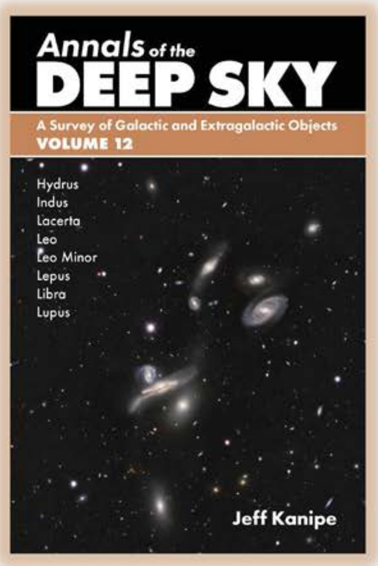

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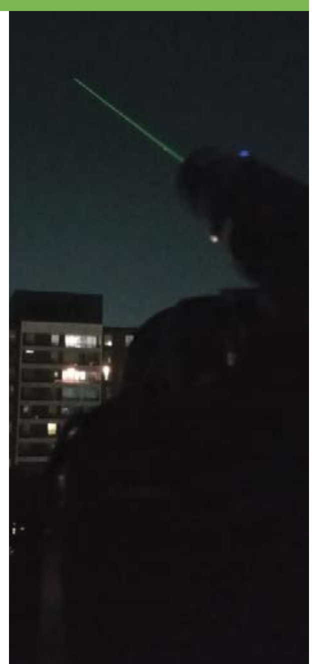

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A Polar Telescope in the Spirit of Porter

This periscoping planet-viewer packs a punch.

ON THE HEELS OF the Stellafane Convention — the world's oldest annual gathering of amateur telescope makers in Springfield, Vermont — it feels appropriate to discuss a project close to Russell W. Porter's heart. Wisconsin amateur Jordan Marché has taken a classic design and improved upon it: Here's a reflecting telescope in which the viewer looks into a fixed eyepiece right on the polar axis, staring down into the objective. How on Earth? First, some ATM history:

Porter, the founder of the Springfield Telescope Makers, the Stellafane Convention, and the amateur telescope-making movement at large — isn't who this story is about. But it does begin with one of his innovative designs from more than a century ago. Here, starlight first hits a large optical flat angled at 45° to the polar axis, called a *coelostat*, or polar-tracked mirror. Light is sent by this into a polar-aligned, parabolic primary mirror and then reflected back along the same axis. As the light cone narrows, it passes through a center perforation in the flat and into an eyepiece (enclosed in a cozy room below the instrument).

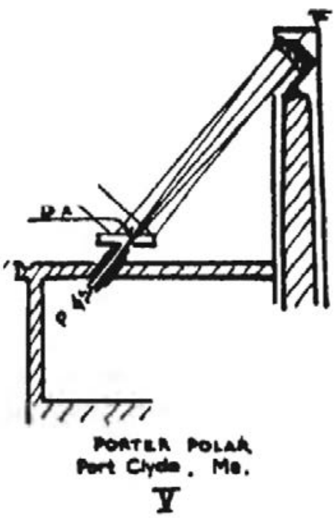
Porter eventually wrote this design off as "not recommended on account of the inconvenience of looking up the polar axis," which in northern latitudes is "very trying to the neck muscles after long periods of observing." Jordan, a retired astronomy educator, wondered why Porter never introduced a third reflection. It seemed like a star diagonal would've fixed this problem handily: "Was the third reflection, which produces a mirror-reversed view of celestial objects, seen as a major drawback to its usage?" he asked.

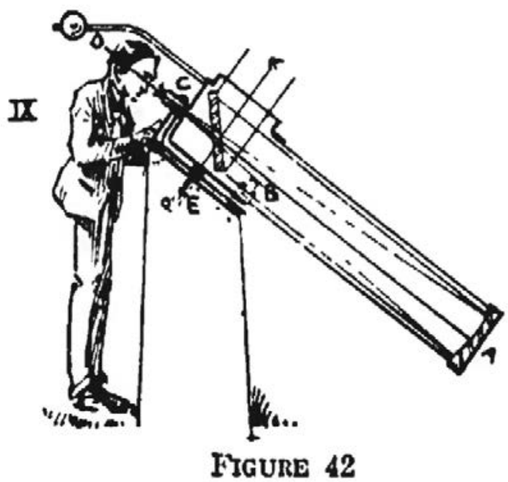
Jordan sketched his own ideas: "While studying Porter's original design, it occurred to me that if I turned the building (and the instrument) 90° onto its side, then it would allow the observer to look comfortably down the polar axis and solve Porter's chief difficulty. No additional reflections would be introduced." While his neck would be spared, he notes one limitation: "Viewing becomes restricted to the southern half of the sky." Since he intended this solely as a lunar and planetary instrument, he was only concerned with that slice of sky where the planets and Moon live, within 23.5° of the celestial equator. So the limited angle wasn't a drawback, and this had benefits. If the telescope is restricted to this band of the ecliptic, the large flat could get away with a much smaller hole (due to the minimal ±11.75° pivots from this axis needed to reach its intended targets).

The instrument uses two mirrors, both hand-figured by Jordan — a 152-mm (6-inch) f/11 parabolic primary ground and polished as an ordinary Newtonian and a 203-mm flat, with the

▲ Jordan Marché in his home observatory, next to the eyepiece end of his polar telescope.

MARCHÉ: JORDAN MARCHÉ; SKETCHES: RUSSEL PORTER (2)





◀▶ Two of Russell W. Porter's coelostat telescopes as illustrated in *Amateur Telescope Making*. The one described in this column is similar to the version seen at left, while the drawing at right is optically identical to Jordan's, though it rotates differently.

▲ *Left:* On the left side of the fork, a lag screw interfaces with a modified hose clamp to provide declination axis slow-motion control. *Right:* An angled mirror on the fork acts as a 1×-power finder in right ascension, allowing Jordan to chase down objects with the slow-motion controls once he located them on the crosshairs.

center cored at 45° to the mirror plane.

There are tricks to getting a perforated flat right. If one drills through a finished mirror, it will change shape in ways meaningful to its use as an optic — but less important to its future as a paperweight.

To avoid released strain causing problems, it's preferable to core the mirror *before* figuring it. Jordan did so, plugging the core back into place with beeswax to figure it. "Retaining the core in this manner made the disk behave more like an uncored blank," he said.

The novel features of his polar instrument go on, as does its impressive workmanship. He built the inverted fork for the mirror with sandwiched plywood, glued and clamped. The right ascension and declination axes rest on enormous pillow-block bearings, and their slow-motion controls are built in.

Just as impressive, the entire instrument also sits on a telescoping pier. This scope spent years on the drawing board for one reason: The fixed eyepiece must remain at eye level. Jordan's roll-off-roof backyard observatory has walls at roughly shoulder level, meaning the top of this permanent assembly would be head-and-shoulders into the roof. While there were ways around this, none of the compromises were appealing — he wasn't about to rebuild the observatory. So, he found an old pneumatic cylinder and turned that into a manually operated lift. A register system with detachable struts ensures polar alignment remains consistently accurate.

The result is as delightful as it is anachronistic. Though not in a warmed observing room (as Porter titled the ATM book chapter on such coelostat designs), Jordan enjoys the fixed-position eyepiece, comfortable viewing angle, and right-reading image orientation.

Once I wrapped my head around the telescope's light path, I wondered how the instrument performed, starwise. The central doughnut hole would certainly be apparent in defocused stars, like a hand waved in front of any telescope. But as a void, rather than a physical obstruction, would it cause nearly as much diffraction? Or is the image going to be sharp, nearly unobstructed in behavior? Jordan answers: "In looking at the planets, it seems as if the telescope does function more like an unobstructed reflector; surface contrast seems to be enhanced rather than reduced."

■ Contributing Editor **JONATHAN KISSNER** considers building things not designed to fit in his hatchback.

▲ *Left:* Jordan's 6-inch primary mirror on its three-axis, adjustable mounting. *Right:* When not in use, the primary mirror is covered with a wooden box.

JORDAN MARCHÉ (4)

GALACTIC CANNIBAL

Vikas Chander

The dusty outer shells surrounding the flocculent spiral galaxy NGC 3521 in Leo are likely tidal debris resulting from several ancient galactic mergers. Loosely ordered patches of dust and stars in this galaxy's discontinuous spiral arms make it appear a bit woolly.

DETAILS: *PlaneWave CDK600 Corrected Dall-Kirkham telescope and Moravian C5A-100M camera. Total exposure: 28¾ hours through hydrogen-alpha and LRGB filters.*

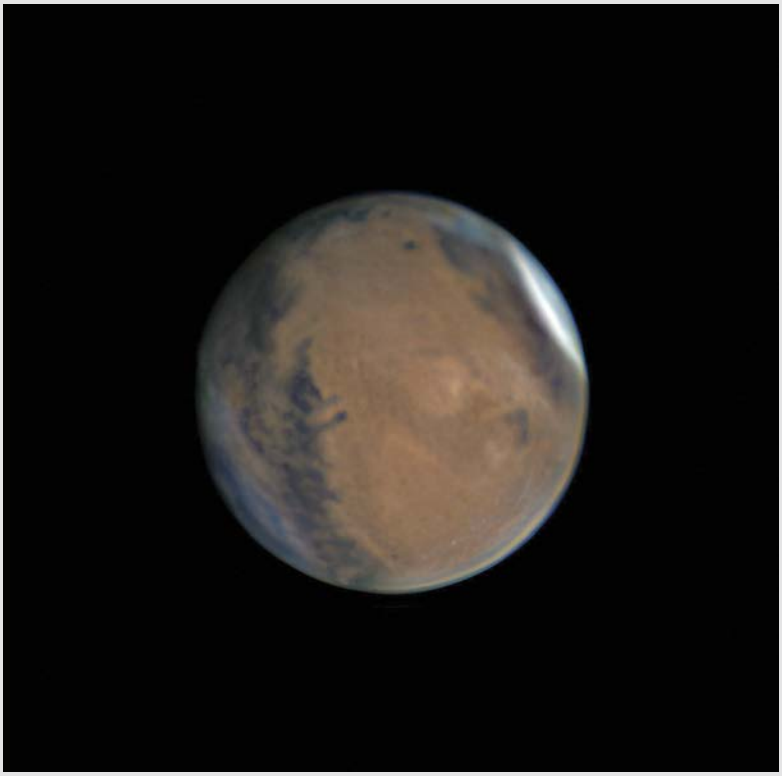
TERRIFIC TRIFID
Francis Bozon and Cecil Navick
Dark dust lanes trisect the bright inner regions of M20, the Trifid Nebula, in Sagittarius. Intense radiation from the group of bright O-type stars at its center has cleared three large gaps in the surrounding nebulosity, producing the dusty silhouetted lanes.
DETAILS: *PlaneWave CDK14 Corrected Dall-Kirkham telescope and ZWO ASI6200MM camera. Total exposure: 213 hours through narrowband filters.*

▷ RUSTY MARS

Dan Llewellyn

Mars displayed a bright whitish Northern Polar Cap on the morning of February 2nd as dawn broke over Syrtis Major. The lighter area in Amazonis Planitia to the right of center is the large volcano Elysium Mons.

DETAILS: *Celestron C14 Schmidt-Cassegrain and Player One Mars-C II planetary camera. Stack of 7,700 video frames.*



▽ A DIAMOND RING

Dan Crowson

Abell 33 in Hydra is a planetary nebula that formed when an aging star shed its outermost layers during the late stages of its lifespan. The 7th-magnitude star HD 83535 aligning perfectly with the nebula's edge lies in the foreground.

DETAILS: *PlaneWave CDK24 Corrected Dall-Kirkham telescope and QHY600M camera. Total exposure: 8 hours through LRGB filters.*

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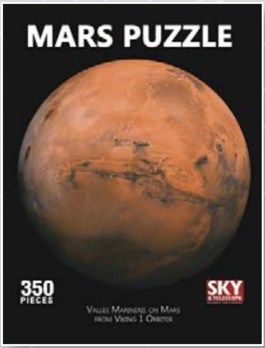

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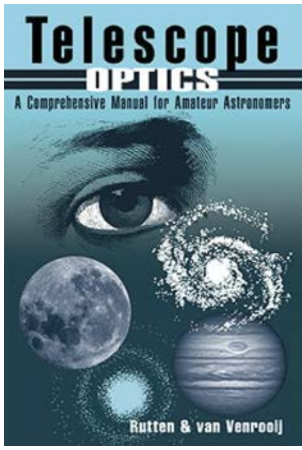

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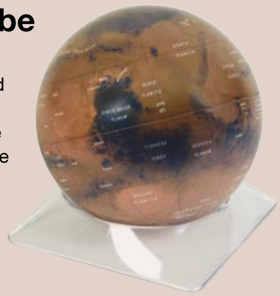

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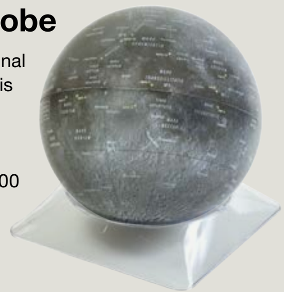

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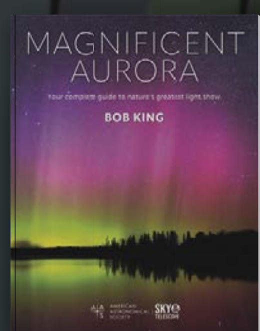

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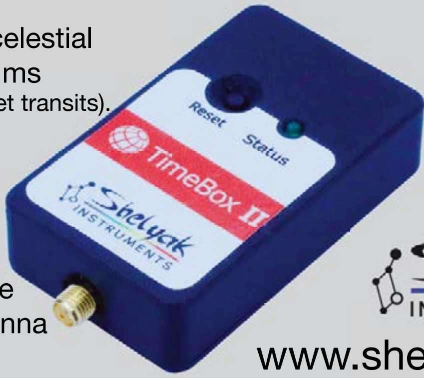

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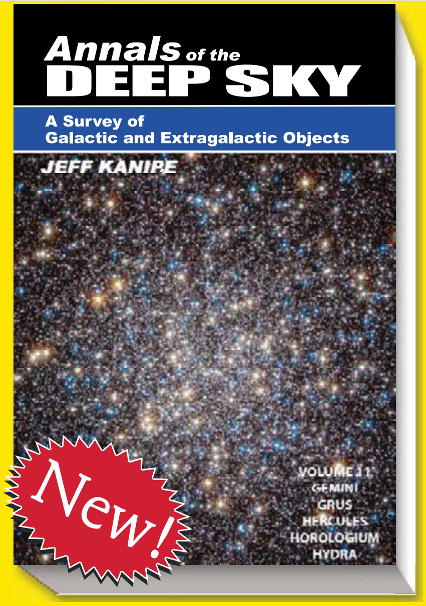

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Event Calendar

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

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October 20–25
ELDORADO STAR PARTY
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October 23–26
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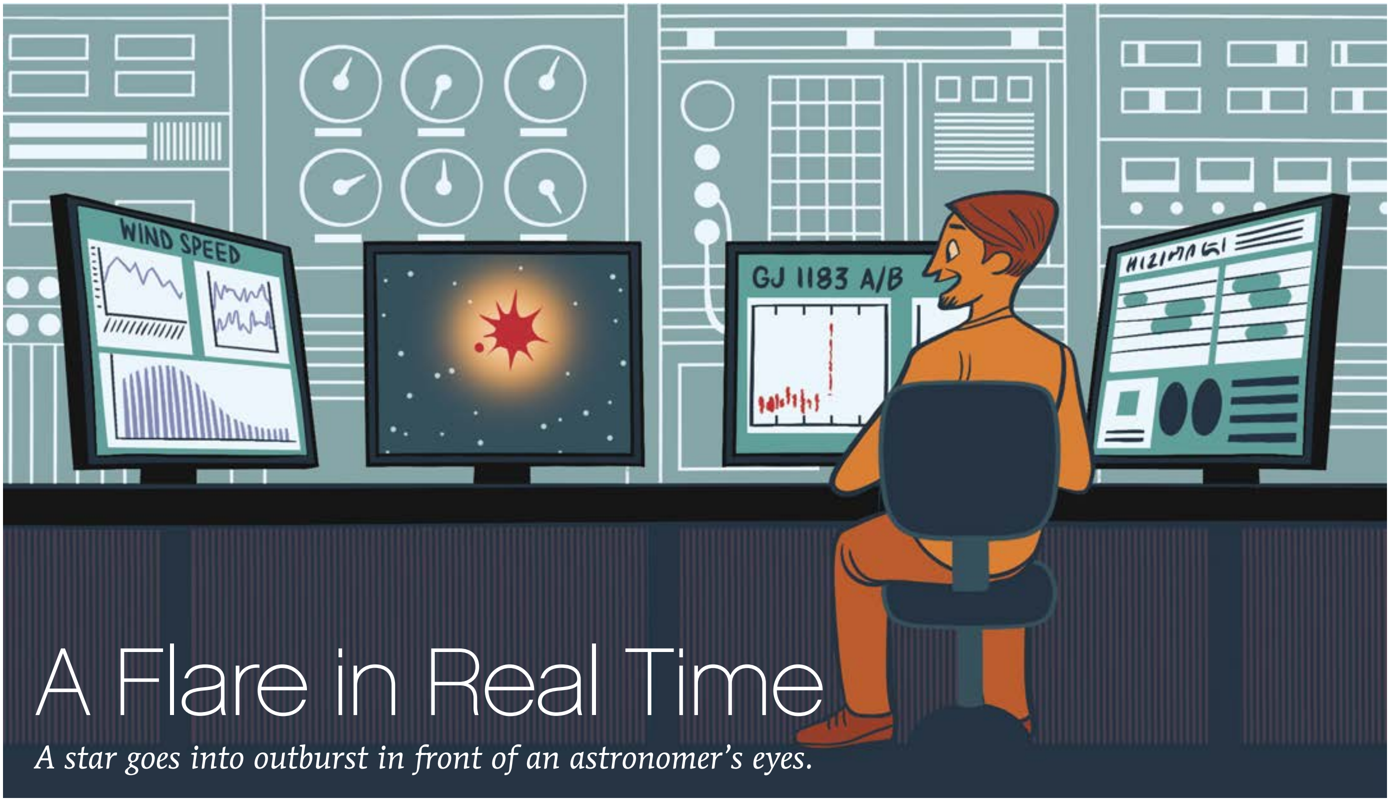

A Flare in Real Time

A star goes into outburst in front of an astronomer's eyes.

I WAS STUFFED INSIDE a lonely control room for the final time in a 20-night observing run at a telescope on a mountain in the remote foothills of the Chilean Andes. One of my targets was a pair of two nearby, small, red stars in a binary system called GJ 1183. I'd been studying the duo for years as part of a broader project to see how the brightness of such "twin" stars, which otherwise have similar properties, behaves over time. During my three weeks in Chile, I would routinely point the telescope at the pair and collect a few images — a procedure I repeated several times each night.

On that last night, at 4 a.m. local time, I was contemplating the 24 hours of travel I'd be facing later in the day. I'd been staring at these tiny dots on the screen for weeks now, pointing the telescope at them, taking a few images, checking their brightness, and repeating the process. Over and over, nearly 70 times throughout those 20 nights.

It was time for the final visit. I blearily punched in the coordinates and pointed the telescope once again. I took my usual test image to ensure I had my target in view. I blinked twice. One of the dots was MUCH brighter than the other one! But how could that be? I'd just checked them a few hours earlier!

I quickly realized what was happening: One of the stars was flaring. These small, red stars are known to be magnetically active and sometimes release short-lived, massive eruptions of energy, which occasionally shine brighter than the rest of the star. Most flares aren't so large, but my intuition told me this one had to be *big* to explain what I was seeing. I immediately started taking quick-fire images. Flares are very short, typically lasting only about 30 to 60 minutes, so I knew time was of the essence if I wanted to capture this event. Over the next half an hour, I stared in amazement as I watched the star dim rapidly in real time.

While collecting the images, I did some quick pen-and-paper math and realized the star wasn't just a lot brighter when I took that first image — it was a full *10 times* brighter than normal. By the time the binary was setting on the horizon, the flaring star still outshone its companion. It was still about twice as bright as normal when I reluctantly had to let it go. Later analysis confirmed that I'd indeed watched the star brighten an order of magnitude from its usual faint existence — such enormous flares occur quite rarely, making them hard to catch in observations. But I'd just lucked into a beautiful display before my very eyes. I sealed it into my memory for the long trip home, which I embarked on with a huge grin on my face.

It's easy to feel small and alone, staring at the vast universe night after night, sometimes while tired and bored. The universe itself can appear unchanging from our perspective on Earth. But occasionally — if you're looking at just the right place, with just the right equipment, at just the right time — you can see the universe wink at you.

■ **ANDREW COUPERUS** is a Visiting Assistant Professor of Astronomy at Smith College in Northampton, Massachusetts. He researches nearby stars to better understand how their astrophysical behaviors might impact the potential habitability of orbiting exoplanets.

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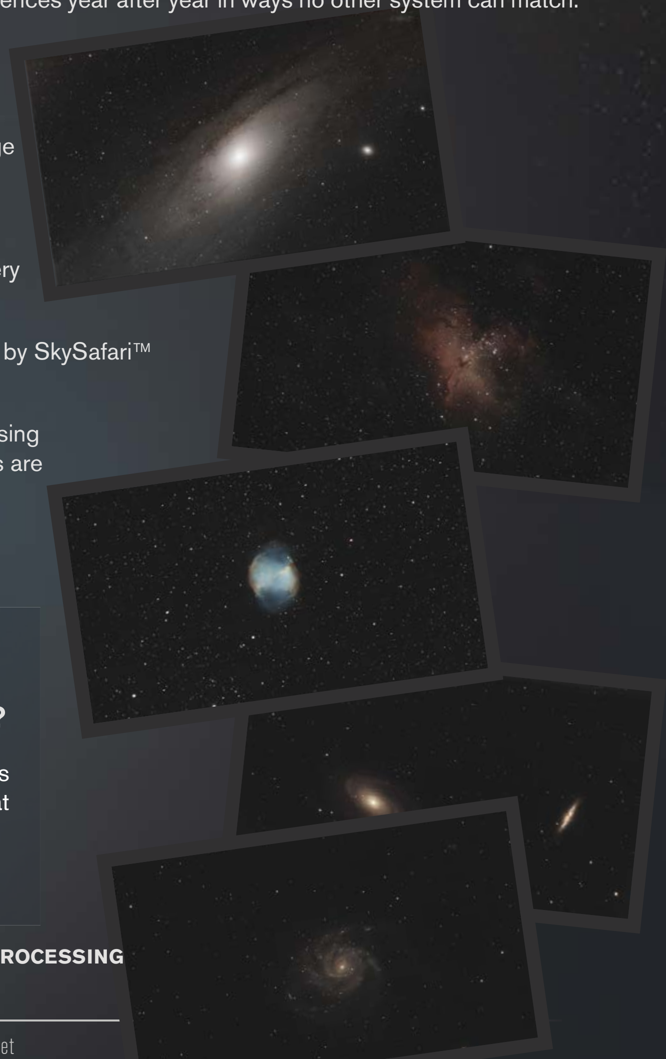

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