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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

OCTOBER 2025

Capture the Sun's STUNNING Eruptions

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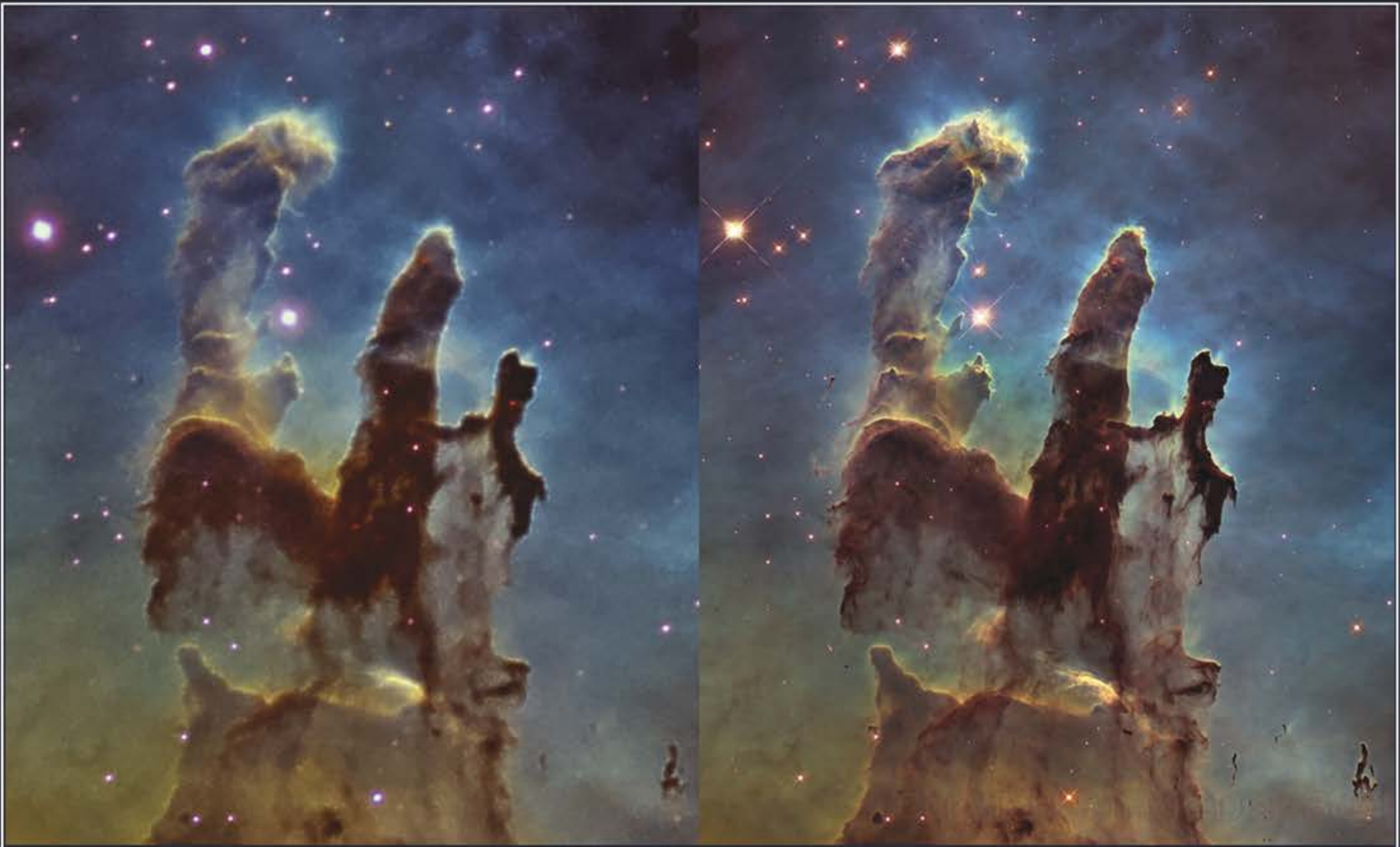

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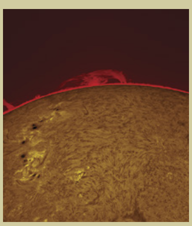

A massive solar prominence rises over the Sun's limb.
PHOTO: CHRIS SCHUR

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Let's Keep Looking Up

AS I SIT HERE at Saint George Regional Airport in southwestern Utah, I can't help but reflect on my experiences this past week. At the Astronomical League's annual convention, I've been lucky to be in the inspiring company of more than 400 amateur and professional astronomers. From June 25th through the 28th, enthusiasts from across the country gathered to celebrate all things celestial in stunning Bryce Canyon.

The raging France Canyon wildfire spewed a lot of ash and smoke into the air, somewhat scuppering observing opportunities. Nevertheless, attendees resolutely set up scopes and imaging equipment, and as always, the star-party atmosphere was infectious. In those moments when the smoke cleared, the views of the Milky Way from more than 9,100 feet at the Park's Rainbow Point were breathtaking. A few meteors even streaked across the sky, as we were there during the peak of the Boötids!

▲ Setting up at Bryce Canyon's Rainbow Point.

DIANA HANNIKAINEN

Smoky conditions didn't dampen enthusiasm as participants attended a variety of talks and workshops. Some of the latter were led by people associated with *S&T*, such as Contributing Editor Scott Harrington and sketcher extraordinaire Cindy Krach. As always, the convention concluded with an awards ceremony, where the Astronomical League recognizes observers' dedication, tenacity, and countless hours at the telescope. Perhaps the most inspiring moment was witnessing the National Young Astronomer Award and Horkheimer Awards granted to talented, young people already fully dedicated to the science and hobby of astronomy.

These past few days were a powerful reminder of the passion that drives and unites us. Despite the state of science funding in the U.S. today (see pages 10–11), we share the same sky, and together we can navigate these turbulent times.

Speaking of awards, we recently learned that the AAS's High-Energy Astrophysics Division recognized Contributing Editor Govert Schilling with its most distinguished prize, the David N. Schramm award, for his article "Catching Cosmic Neutrinos" in the May 2023 issue of *Sky & Telescope*! Please join us in congratulating Govert for this stellar recognition. It's a fitting honor to mark Govert's 25th year as a contributing editor!

This issue also marks the debut column by our newest contributing editor, Jonathan Kissner. He has big shoes to fill, as he succeeds longtime Astronomer's Workbench author, Jerry Oltion. But I have no doubt he will soon be leaving outsize footprints of his own. Welcome to the *S&T* family, Jonathan!

Diana

Editor in Chief

SKY & TELESCOPE
The Essential Guide to Astronomy

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

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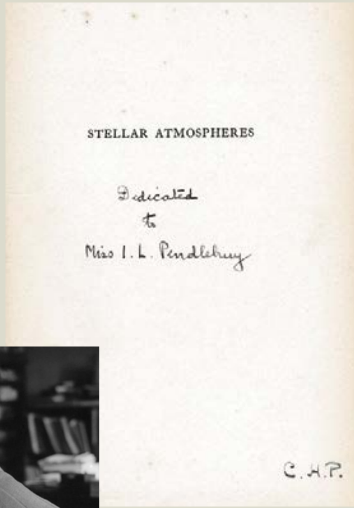
Payne at St. Paul's

To complete the excellent article "A Stellar Revolution Turns 100" by Douglas MacDougal (*S&T:* May 2025, p. 22), it should be noted that Cecilia Payne dedicated this copy (at right) of her PhD thesis to Ivy L. Pendlebury. Payne attended St. Paul's School for Girls. At the time, composer Gustav Holst was the music teacher there. He almost convinced her to become a professional conductor or pianist. However, luckily for astronomy, her physics teacher, Ivy Pendlebury, inspired her to stick to science.

Lisa Budd
London, England



◀ Cecilia Payne at Harvard College Observatory

Sharp Vision

Regarding Govert Schilling's "Sharp Vision" (*S&T:* May 2025, p. 14), I would like to promote the Infrared Spatial Interferometer (ISI) as one of the significant contributions to interferometry.

The ISI was the brainchild of Charles Townes (University of California, Berkeley). It's currently inactive but it was groundbreaking at the time of first light. Operating at 10.6 microns and comprising three large Pfund telescopes, it demonstrated the utility of lasers and mobile vans to create a variable, interferometer baseline. In its time, it performed highly accurate measurements of the sizes and shapes of red giant stars and their dust envelopes.

Meanwhile, I wish a hearty congratulations to Diana Hannikainen on her appointment as our new Editor in Chief. I have subscribed to *S&T* since October 1947 and have enjoyed a great career designing, building, and using several hundred optical systems for a variety of tasks. Throughout all these activities, *S&T* has been my lodestar.

Joe Houston
Saratoga, California

Visual Homonym

While reading Govert Schilling's article "Sharp Vision," I couldn't help but notice the similarity between the Atacama Large Millimeter/submillimeter Array (ALMA) image of the protoplanetary disk of the young star HL Tauri and the diffraction patterns astronomers see when star-testing telescopes. The ALMA image looks surprisingly like some of the diffraction patterns in Harold Suiter's book *Star Testing Astronomical Telescopes,* Second Edition; although, the ALMA image looks more elliptical, as if it were tilted at an oblique angle compared to the examples in Suiter's book. Given the interference nature of diffraction patterns, could the ALMA photo be exhibiting some kind of artifact of the processes used to produce it? Hopefully, I'm way off the mark here, because the image of the protoplanetary disk is pretty remarkable and something I never thought I'd see a photograph of in my lifetime.

Jeff Bland
Monroe, Washington

Camille M. Carlisle replies: *What we have here is the visual equivalent of a homonym: two things that look alike but have different origins and meanings. Astronomers have used ALMA to study dozens of protoplanetary disks (see this collection of 20* **https://is.gd/ALMA_20Protoplanetdisk**, *and this new result studying 73* **https://is.gd/ALMA_73Protoplanetdisk**). *While there is often similarity in the patterns, there is also wide variety, with some disks not showing rings at all. If these rings were an artifact of the observing process, we'd expect far more uniformity.*

An Enchanting Wreath

I really enjoyed reading Stephen J. O'Meara's new Enchanted Skies column "Webb's Wreath" (*S&T:* May 2025, p. 12) and was happy it included a target that offers something for observers with both large and small scopes. I don't think I've seen Webb's Wreath before and will take up the challenge to see if I can spot PGC 61289 on a good night with my Celestron 11-inch Schmidt-Cassegrain.

What made it extra fun to read was looking up more info on Webb's Wreath right after. I found the Cloudy Nights thread that led up to the article (**https://is.gd/CN_WebbWreath**) and has the people and observations mentioned in the column as they were taking place just last year. It made me almost feel like I was there, and I can't wait to get out there and see the Wreath myself now!

Nils Walter
Garrison, New York

Stephen James O'Meara replies: *What a pleasure to read your letter. I am not a member of Cloudy Nights group, so I was not aware of the thread. But I now know how it came about. In July 2024, I alerted Roger Ivester to the galaxies in Webb's Wreath after seeing a Digitized Sky Survey image of it. I suggested to Roger that this would make a good challenge for observers with large telescopes and asked Mario Motta to image the field. In September 2024, Roger alerted members of Cloudy Nights of the galaxy challenge, which inspired Larry Mitchell and Keith Rivich to search for the galaxies. When Roger told me that Larry and Keith had success in seeing several of them, I contacted Larry directly for the scoop, as he is a close friend.*

By the way, it may interest you that last April, Larry Mitchell, Keith Rivich, Jimi Lowrey, Steve Gottlieb, Doug McCormick, and I observed all the galaxies in and around Webb's Wreath through Lowrey's 48-inch telescope in Fort Davis, Texas. What's interesting is that I and others found

PAGE: COURTESY LISA BUDD; PAYNE: SMITHSONIAN INSTITUTION / SCIENCE SERVICE, RESTORATION: ADAM CUERDEN *the unnamed galaxy easier to see than PGC 1772537; surprises never cease.*

Dipper Dilemma

On reading Stephen James O'Meara's "Origins of the Big Dipper" (*S&T:* May 2025, p. 45), I was reminded that, in my youth in Britain, the seven-star asterism in Ursa Major was called the Plough and was never referred to by any other name. Indeed, when I came to Canada in the early 1960s, I admitted to my class that not only was I unfamiliar with the name "Dipper" for the asterism, but I had no idea what a dipper was. My class responded by kindly presenting me with a "big dipper," which I still possess.

That was a long time ago. Can any reader say whether the Plough is still the name used for the asterism in Britain?

Jeremy B. Tatum
Victoria, Canada

I read Stephen James O'Meara's "Origins of the Big Dipper" in the May issue with great interest. The last paragraph turned out to be very special for me. The names Big Wagon and Little Wagon were the names I knew for the asterisms long before I switched from Czech to English and learned to call them Big Dipper and Little Dipper. The roots of the Wagon asterism names seem so much deeper than the roots of the Dipper names. Now I would really like to find out which cultures and nations call them Dippers and which call them Wagons.

Pavel (Paul) Otavsky
Golden, Colorado

Thanks For Being a Friend

S&T has been a part of my family's life for well over 50 years. As a Cumberland Presbyterian minister my father was fascinated with science, the stars in particular. He loved reading about the universe. I well remember in my childhood those freezing February nights (those clear, dry nights) looking through his telescope at a dot in the sky. He was excited, and I was cold. He would explain the distances of those points of light, sharing the names and shapes of the constellations, and tell us that we were looking millions of years back in time.

My father is now 92 and living in a nursing home nearing the end of his journey. He can no longer enjoy the magazine. Sadly, we will not be renewing his subscription this year. As the stars well illustrate, sparkles of time are all around us to remind us of eternity. Thanks, *S&T*, for being a friend to my father, Reverend Don Thomas. After 70 years of service in the church, who knows how many of his sermon illustrations came out of this magazine?

Lynndon Thomas
Scottsboro, Alabama

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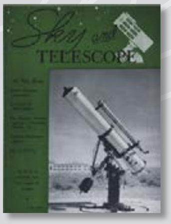
75, 50 & 25 YEARS AGO by Roger W. Sinnott

1950



1975

2000

◖ October 1950

Ring of Stars "On a 75-minute exposure with Harvard's Jewett Schmidt telescope a slightly fuzzy object surrounded by an almost perfect halo has been found in the constellation Serpens. . . . Arthur Hoag, of Harvard Observatory, pointed out that at first sight it seems to be a strikingly symmetrical planetary nebula.

"But most planetaries are near the Milky Way plane, whereas this object is far from it; central stars of planetaries are, with one exception, among the bluest objects known, yet the nucleus in this case is reddish. In fact, the color is more like that of a galaxy, but there is no evidence of structure between the nucleus and the halo."

Studies have ruled out a planetary nebula and an odd case of gravitational lensing. It seems Hoag's Object is a rare, pole-on "ring galaxy," created by collision with another galaxy. Hubble Telescope images have resolved the ring's blue supergiant stars.

◖ October 1975

Caught on the Rise "During the last days of August, amateurs all over the world were startled to see a brilliant strange star in the constellation Cygnus [that] distorted the familiar pattern of the Northern Cross. The independent discoverers of the spectacular Nova Cygni 1975 must number many hundreds. . . .

"By good fortune, Ben Mayer of Los Angeles, California, was taking repeated photographs of this part of the sky on the nights of August 27–28 and 28–29, using the automatic meteor camera he described in this magazine for July, 1974, page 54. On the first night, the nova was too faint to register, but his all-night series of 17 exposures on the following date shows clearly the spectacular hour-by-hour brightening. [The last has] the new star nearly at maximum light, almost equal to Deneb."

Ben Mayer used a lawn-sprinkler control and an Erector-set pulley in his home-brew project.

◖ October 2000

Universe's Age "Uranium decays at a very slow, precisely known rate, producing thorium. Therefore, the ratio of uranium to thorium in a very old rock can be used to determine the rock's age. These heavy elements are extremely sparse in stars and produce extremely weak spectral lines. But a new ultraviolet spectrograph attached to one of the four new 8.2-meter reflectors of the European Southern Observatory's Very Large Telescope in Chile has recorded their signatures. Bengt Gustafsson (Uppsala University, Sweden) and six colleagues recently measured the amount of thorium, and set an upper limit to the uranium, in a faint . . . old star in the Milky Way's halo. They find that the star formed at least 12 billion years ago — ruling out any models of cosmology in which the Big Bang happened more recently."

◀ This image combines 678 exposures, totaling more than seven hours of observing time, to reveal faint details in the Lagoon Nebula (center) and Trifid Nebula (top right).

ASTRONOMY & SOCIETY

Vera C. Rubin Observatory Releases Long-Awaited First Images

AT THE SUMMIT of Cerro Pachón, the Chilean mountain home of the newly constructed Vera C. Rubin Observatory, fatigued yet focused scientists gather in the observatory's control room. They're monitoring the systems around the 8.4-meter telescope in an effort to troubleshoot a serious issue: The camera is overheating. That's a problem because it's already May — just a few weeks before the observatory is set to release its first images to the public.

That first look is just the beginning. Every three or four nights for the next 10 years, the fast-slewing and unprecedentedly sensitive telescope will complete a scan of the Southern Hemisphere sky. The full set of 3.5°-wide images, which will be taken through six filters to cover the full visible range and into the near-infrared (338 to 1,010 nanometers), will ultimately take up some 60 million gigabytes. Stitched together, they will become a time-lapse "movie" of the universe known as the Legacy Survey of Space and Time (LSST).

The goals for the observatory, named for the trailblazing astronomer who found conclusive evidence of dark matter, include mapping galaxies to demystify dark matter and dark energy, catching fast-moving asteroids as well as fast-changing events like supernovae, and mapping the universe around us.

But even taking the initial images is no small feat. Since construction began in 2015, highly customized components built in labs around the world have been coming together on the remote mountaintop, with engineers solving technical problems on-site.

MILKY WAY

Andromeda and the Milky Way Might Not Collide

A NEW STUDY suggests that our galaxy might survive an upcoming encounter with the Andromeda Galaxy unscathed.

Astronomers have long known that Andromeda and the Milky Way are heading toward each other; however, to determine whether the two galaxies will someday merge, they also need to know each galaxy's mass as well as Andromeda's movement across the sky, called its *proper motion*. To be really sure, they need to determine those same properties for two galactic sidekicks: M33 (Andromeda's buddy, the Triangulum Galaxy) and the Large Magellanic Cloud, companion to the Milky Way.

In 2012, astronomers used the Hubble Space Telescope and the Very Long Baseline Array to precisely measure Andromeda's proper motion, concluding that it would hit the Milky Way, potentially head-on (*S&T:* Oct. 2014, p. 20). A subsequent study added Gaia data and found the first encounter was more likely to be a glancing blow but would still result in a merger (*S&T:* June 2019, p. 12).

But the new study, led by Till Sawala (University of Helsinki, Finland), calls that fate into question. The team combined Gaia and Hubble data on all four galaxies, then ran 100,000 simulations following the group's evolution 10 billion years into the future. (The large number of simulations are necessary to evaluate the range of possible values in all of the parameters.)

The team reports June 2nd in *Nature Astronomy* that in about half of their simulations, Andromeda and the Milky Way fly past each other in the first round, swinging back and colliding later on. In the other half, the two galaxies escape each other for at least the next 10 billion years.

Sangmo Tony Sohn (Space Telescope Science Institute), who worked on the previous studies but wasn't involved in the new one, agrees with the researchers' methods but is skeptical of the

NSF / DOE / VERA C. RUBIN OBSERVATORY

One of those problems has to do with the cooling systems for the Rubin digital camera, the largest in the world. The cooling systems have always been "the big pickle" for engineers working on the LSST Camera, says research engineer Claire Juramy (French National Institute of Nuclear and Particle Physics). Different parts of the camera need to be kept at different temperatures and, if any of their separate cooling systems malfunction, the camera can overheat relatively quickly.

So when on-site scientists see the camera's temperature climbing in May, even as the air temperature drops in the middle of the night, they are quick to shut it down and start problem-solving. "It's definitely stressful, but I love these days," says Kevin Fanning (Stanford).

The next night, the team decides to wait until outside temperatures drop again before operating the camera, to determine if cold air causes the cooling system to malfunction. But the outside temperature isn't falling at all — it's getting warmer, thanks to notoriously fickle mountain weather. The following morning, the team reconvenes and forms a new plan.

Over the next weeks, the team further insulates the cooling systems and explores heating parts of the camera on cold nights. (It turns out the cool night air *was* involved.) The fixes bring the observatory a few steps closer to the first-look images, released June 23rd.

Now, crystal-clear views of the the Lagoon and Trifid nebulae (left) and the Virgo Cluster (right) showcase the observatory's true potential. Not only do these images demonstrate just how deeply the camera can gaze into the universe, but they also show how much there still is to discover and understand. The full survey (and movie) of the Southern Hemisphere sky is slated to begin later this year.

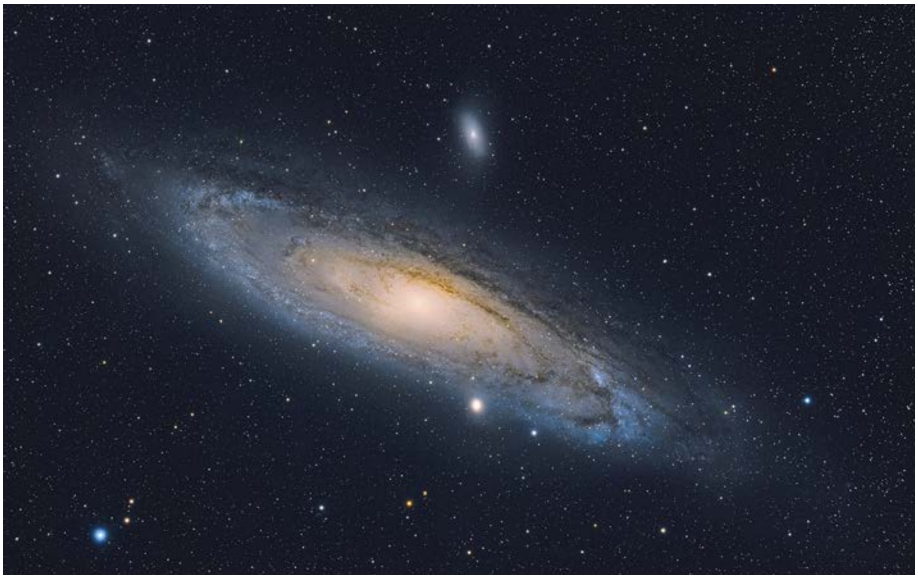
■ K. R. CALLAWAY

▲ This image shows a small section of the Virgo galaxy cluster, about 55 million light-years away. Foreground stars and much more distant background galaxies are also visible.

conclusion. That's because Sawala's team favors lower masses for Andromeda and the Milky Way than Sohn and his colleagues did in 2012, when they concluded that a merger would be inevitable. Lower masses shrink the probability of collision.

To pin down mass estimates, Sohn and his colleagues are obtaining more precise proper motion measurements with Hubble — something that becomes easier as the years pass and the galaxies move further across the sky. Those observations will dispel some of the fog in astronomers' crystal ball.

■ CAMILLE M. CARLISLE



▶ New simulations show that the Andromeda Galaxy (pictured) may not hit the Milky Way.

VIRGO GALAXY CLUSTER: NSF / DOE / VERA C. RUBIN OBSERVATORY; ANDROMEDA: LUC VIATOUR / HTTPS://LUCNIX.BE / CC BY-SA 2.5

SCIENCE POLICY

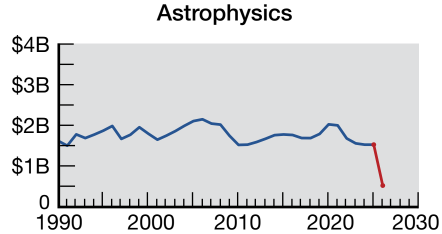
Proposed Budget Would Gut NASA Science, Jobs

ON MAY 30TH, the White House released its proposed 2026 budget for NASA, the detailed version of a "skinny budget" published earlier that month. For many in the space science community, it confirmed their worst fears.

"Were we prepared? A little bit," says Paul Byrne (Washington University in St. Louis). "But when you actually see the visceral specifics of it, it's a whole new level of horror."

With total spending set at $18.8 billion, NASA spending would reach its lowest level since 1961, adjusted for inflation — despite making up less than half a percent of the government's spending. The otherwise unrelated tax and spending bill that Congress passed on July 3rd made $10 billion available to NASA over the next seven years for human exploration, including additional Space Launch System rockets, the Gateway lunar station, and spaceflight infrastructure improvements. No additions were made to support science.

President Trump signed the spending bill into law on July 4th, but the fate of



▲ Each of NASA's four major science divisions is facing a steep cut to its budget. Shown here is the budget for the astrophysics division. Values are adjusted for inflation.

NASA's science, technology, and education programs is still uncertain. At press time, the White House budget request provides the best information about how the funding might be distributed.

Under that proposed budget, 41 NASA missions would be defunded, including the Chandra X-ray Observatory and the Fermi Gamma-ray Space Telescope — two of NASA's oldest continuous astrophysics missions and unique in the wavelengths they study.

The Nancy Grace Roman Telescope, NASA's next flagship mission, isn't canceled, but it's only funded at less than 40% of its asking price, jeopardizing its ability to launch on time in 2026.

Also on the chopping block are highly anticipated programs, including the Mars Sample Return, which aimed to bring home the first samples of Martian rocks. (A Mars orbiter in support of the Mars Sample Return will receive funding, however.) The DAVINCI and VERITAS missions, slated to explore Venus in detail for the first time since the 1990s, would be canceled, and numerous Earth-observing satellites would cease operations.

NASA contributions to European missions are also proposed to be rescinded, including Euclid, which studies dark matter and dark energy; the Laser Interferometer Space Antenna (LISA), which aims to measure gravitational waves from space; and the ExoMars Rosalind Franklin rover mission, which NASA rejoined last year after pulling out in 2012.

Meredith MacGregor (Johns Hopkins University) isn't just worried about existing missions, but future ones. The budget essentially turns off the tap for new proposals, which would create a "huge gap" in new science, she says.

SCIENCE POLICY

"Shattering" NSF Budget Proposal Threatens Gravitational Wave Science

IN 2015, the two giant detectors that make up the Laser Interferometer Gravitational-Wave Observatory (LIGO) enabled astronomers to detect subtle ripples in spacetime. The discovery confirmed Einstein's theory of gravity, garnered a Nobel Prize, and launched a new way of studying the cosmos. Now, one decade later, the Trump administration has proposed shuttering one of the detectors as part of its National Science Foundation (NSF) budget request, stunning the scientific community.

Closing one facility would be a "senseless, irrational thing to do," says Maya Fishbach (University of Toronto). "It's like trying to fly a plane with only one wing."

LIGO's two facilities each work the same way: A mirror splits a laser beam in half, sending the beams ping-ponging through separate vacuum-pressured arms four kilometers in length. Detectors then check to see if gravitational waves shortened one arm relative to the other by as little as 10^{-19} meter.

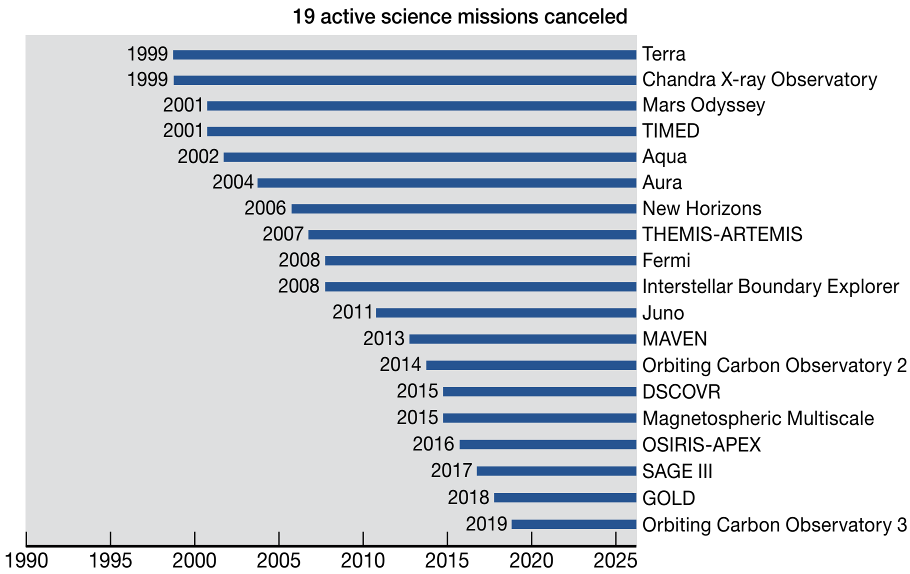
While one site can detect a gravitational wave on its own, the signal is fuzzy and not well triangulated. Two sites of the same sensitivity enable astronomers to determine where the waves came from and what kind of cosmic event created them.

This unparalleled physics and engineering experiment may now come undone: The White House's 2026 NSF budget proposal calls for a 40% funding reduction, down to $29 million; an accompanying line specifies the funding will support only a single site.

LIGO works in partnership with three other facilities: Virgo, a gravitational wave detector in Italy; KAGRA, a detector in Japan; and GEO600 in Germany. However, the others aren't powerful enough to record any but the

GRAPH: THE PLANETARY SOCIETY; LIGO HANFORD: CALTECH / MIT / LIGO LAB

▶ The White House budget request has proposed cutting one of the sites of the LIGO gravitational-wave detector.



▲ The proposed FY 2026 budget would cancel 19 NASA science missions that are currently active, healthy, and producing valuable science. These represent a cumulative investment of more than $12 billion and years of work to design and build.

In addition to cutting science, the proposed budget also guts personnel; more than 5,000 civil servants and many thousands of contract workers would lose their jobs.

The document is "a narrowing of ambition and a narrowing of vision . . . that will fundamentally damage U.S. leadership in scientific exploration," says Casey Dreier (Planetary Society).

As one mid-career scientist puts it, scientists often rally around one or two threats to missions during budget season, but this year the message is simpler: "Save NASA."

■ **HANNAH RICHTER**

loudest signals on their own.

"It's going to be near-impossible to carry out our mission at any kind of high productivity level with the budget that's coming down," says LIGO director David Reitze (Caltech).

As with the NASA budget, exactly how the NSF budget is divvied up isn't yet final; at press time, both budgets await congressional appropriations. But since LIGO receives all of its funding from the NSF, its leaders have already begun thinking about how to keep both sites open — at the cost of significant job losses across each facility. Such a move might be critical, because a single LIGO facility would only detect the most dramatic of gravitational waves.

Combined with the president's request for NASA to pull out of the Laser Interferometer Space Antenna (LISA), the European-led gravitational-wave observatory in space, scientists worry the U.S. isn't just ceding leadership but stifling the whole field.

"We're still at the tip of the iceberg of the potential that gravitational waves have to teach us about our universe," Fishbach says. The signals carry information about a variety of physics, from why and how often black holes merge, to what makes the heaviest elements in the universe, to how galaxies evolve.

But the LIGO team hasn't given up yet. Reitze says they are in talks with members of Congress, as well as collaborating with larger campaigns by the American Astronomical Society and the American Physical Society.

"I've heard that there is sympathy and support for science on both sides of the aisle in Congress," Reitze says. If not, though, LIGO is preparing to ask private donors for support: "Desperate times call for desperate measures."

■ **HANNAH RICHTER**

THE PLANETARY SOCIETY, SOURCE: FY 2026 WHITE HOUSE NASA REQUEST

IN BRIEF

China Launches Asteroid Sample-Return Mission

On May 28th, China launched the Tianwen 2 asteroid sample-return mission. The primary target is 469219 Kamoʻoalewa, a near-Earth asteroid discovered in 2016 that resembles weathered lunar rocks and might hail from the Moon. The asteroid presents challenges for the Tianwen 2 team, being the smallest asteroid and fastest rotator yet visited, at 46 to 58 meters (150 to 190 feet) across, and with a rotation period less than 30 minutes long. Starting in July 2026, the mission will not only circle the quasi-moon but land on it and collect a sample. "The sample returned to Earth would help clarify the origin of Kamoʻoalewa and in particular it should give an answer to whether it originated as lunar ejecta or not," says Marco Fenucci (European Space Agency). ESA is not involved with the mission itself, he notes, but China will most likely share pieces of the sample return with international institutions. After its visit to Kamoʻoalewa, the mission has a second target set for 2035: Comet 311P/PanSTARRS, an active asteroid (*S&T:* June 2023, p. 12) in a 3.23-year orbit around the Sun that spends most of its time in the main asteroid belt.

■ **DAVID DICKINSON**

New U.S. Coin Honors Astronomer Vera Rubin

The late astronomer Vera Rubin has an observatory named for her (page 8); now she has a U.S. quarter-dollar coin, too, minted as part of the American Women Quarters series. The series honors "extraordinary women whose achievements, triumphs, and legacies reflect the strength and resilience" of the United States, according to the U.S. Mint's May 27th press release. The Mint chose Rubin due to the crucial data she collected in support of dark matter's existence. As with all U.S. quarter coins, George Washington's profile appears on the front side. The back side's design features a profile of a smiling Rubin gazing upward with stars and a spiral galaxy in the background. "By positioning her portrait off-center and toward the upper right," explains artist Christina Hess, "I aimed to move the audience's gaze upward, symbolizing exploration beyond the coin's boundaries, evoking a sense of infinite possibility and continuous motion."

■ **RICHARD TRESCH FIENBERG**

SPACE EXPLORATION

Japanese Resilience Lander Crashes on the Moon


Resilience took this earthrise photo while in orbit around the Moon on May 27th.

ON JUNE 6TH, Japanese company ispace attempted to land its Resilience spacecraft on the lunar nearside. All seemed to be going well until, about 90 seconds before touching down, Resilience suddenly fell silent. The mission has now joined the ranks of probes littering the lunar surface.

After mission control in Tokyo issued the command for the lander to begin its terminal approach to a site in Mare Frigoris, Resilience descended from about 100 to 20 kilometers (60 to 10 miles) above the lunar surface. The lander fired its main engine to slow its approach, when sensors showed the vehicle to be nearly verticle as expected, but contact was lost shortly thereafter.

Controllers confirmed in a press conference several hours later that the laser rangefinder had experienced delays upon approach, which likely resulted in the hard landing. The cause of the delays remains unknown.

This landing is the company's second failed attempt, after a first spacecraft crashed near Atlas Crater two years ago (*S&T:* Aug. 2023, p. 11). That crash happened because a software problem led to incorrect altimeter data. Now, the company has acknowledged that there are more lessons to learn.

Resilience carried a number of scientific instruments, including a probe designed to measure the radiation environment at the site as well as an electrolyzer that would have attempted to produce hydrogen and oxygen from an onboard supply of water. A third experiment would have tried to grow algae as a potential food source for future missions. Another notable payload lost was Tenacious: a four-wheeled, solar-powered micro-rover that would have explored and dug into the surface.

It's possible some artifacts onboard, including a commemorative alloy plate and a UNESCO "Memory Disc," might have survived the 42 meters per second (94 mph) impact.

Despite the setbacks so far, ispace is still moving forward with a third mission to the Moon with a new lander; launch is currently set for 2027.

■ DAVID DICKINSON

RESILIENCE'S VIEW OF MOON AND EARTH: ISPACE; SUN'S CORONA: SCHMIDT ET AL. / NJIT / NSO / AURA / NSF


Hot plasma falls back down toward the Sun in this image of coronal rain.

New Views of the Sun

This summer, solar missions and telescopes have been releasing images and videos with unprecedented detail and coverage of the Sun's visible surface, corona, and the broader space environment.

On June 11th, the European Space Agency's **Solar Orbiter** released views of the Sun's turbulent south pole. The spacecraft's orbit, tilted at 17° relative to the ecliptic, revealed the pole's messy magnetic fields, which should start becoming more ordered as the Sun's activity wanes (*S&T:* Apr. 2025, p. 72).

Another new view of the Sun comes from closer to home: NASA's **Polarimeter to Unify the Corona and Heliosphere (PUNCH)** mission consists of four spacecraft in Sun-synchronous Earth orbits. The data from their four cameras are combined into a single image that captures solar activity as it passes out into the wider solar system.

Context for this widest-yet view of space weather comes from another instrument that started operations on the International Space Station in December 2024. The **Coronal Diagnostic Experiment (CODEX)** takes detailed temperature and velocity measurements of hot gusts of solar wind as it emerges from the Sun.

On the ground, the **Daniel K. Inouye Solar Telescope** in Hawaiʻi continues to provide stunningly detailed views of the convective cells on the Sun known as *granules*. Also on the ground is the **Goode Solar Telescope** in California, which released the sharpest views yet of plasma dancing and raining down in the corona near the Sun's visible surface, as seen in the image at left. Read more about these missions' accomplishments and watch the videos at **skyandtelescope.org/sunviews1** and **skyandtelescope.org/sunviews2**.

■ MONICA YOUNG

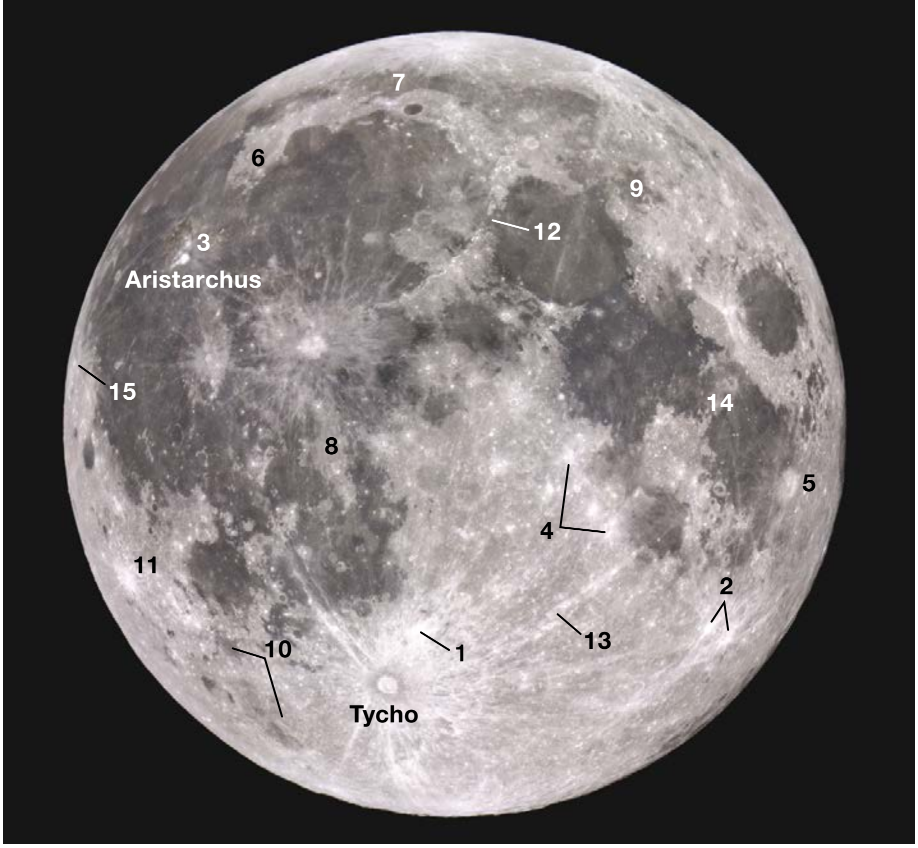
Test Your Vision on the Moon

What's the finest lunar detail your unaided eye can see?

AS DETAILED IN OUR September issue (page 52), American astronomer William Henry Pickering (1858–1938) created a list of 12 features on the Moon to test the acuity of naked-eye vision, from easiest (1) to hardest (12).

I've enjoyed Pickering's challenge for years, and I've observed additional details that I believe add to his vision test. Listed here is my selection of 15 naked-eye lunar features. They're also identified in the accompanying photo. I've compiled these targets, which are not arranged in any particular order of observing difficulty, based on my decades of pushing the limits of what my unaided eyes can see on the Moon.

Generally, the best time to look is either from about 15 minutes before sunrise to shortly after sunset, when the contrast between the Moon and the background sky is reduced. Look for the most challenging objects around *perigee*, when the Moon is closest to Earth. You can observe during full Moon, which occurs this month on October 6th at 11:48 p.m. EDT. The Moon achieves perigee on October 8th at 8:37 a.m. EDT (see the Lunar Almanac on page 42.)



▲ **LUNAR EYE CHART** Try to see if you can spot the author's proposed 15 new lunar features.

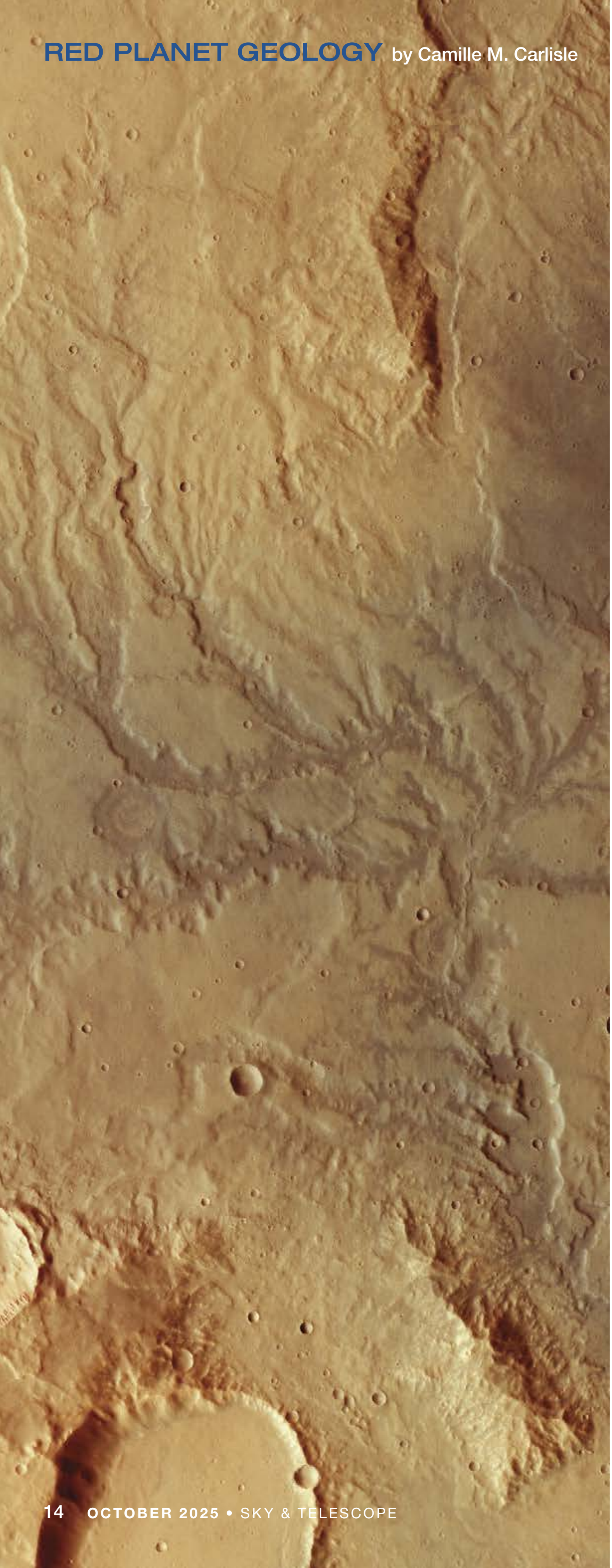
GARY SERONIK

15 New Test Features

1. **Cassini's Bright Spot.** Commonly mistaken for the crater Tycho. Around full Moon, Cassini's Bright Spot combines with Tycho's ejecta to form a large arrowhead of light that includes the crater Clavius at its tip.
2. **Stevinus A** and **Furnerius A.** These bright ray craters are also known as the Lunar Headlights.
3. The ejecta blanket around the crater **Aristarchus.**
4. Brightening in the Moon's southern highlands from **Alfraganus** to the **Cyrillus** and **Beaumont** crater regions.
5. The interior of **Langrenus** crater has a higher *albedo* (reflectivity) than its surroundings. It's best seen when the Moon is waxing, and the lunar disk is 20% to 50% illuminated.
6. The highland region around the crater **Mairan**, near the northern edge of Oceanus Procellarum.
7. **Mare Frigoris** (Sea of Cold). A long, narrow, east-west-oriented lava plain in the far north of the Moon.
8. The north-south-oriented island of lunar highland in the **Fra Mauro** crater region.
9. **Lacus Somniorum** (Lake of Dreams). Its eastern part is darkest.
10. A sizeable dullness in the southern highlands, especially from **Lacus Excellentiae** (Lake of Excellence) toward the crater **Schiller**. It's best viewed when the waning Moon is about 70% to 30% illuminated.
11. The ejecta blanket around the crater **Byrgius**. It's best seen during favorable *librations* (see page 42) and around sunrise. It's most visible when the waning Moon is about 23% to 18% illuminated.
12. This dark gap between **Montes Caucasus** and **Montes Apenninus** is best observed around perigee, when the waxing Moon is 55% to 60% illuminated, or when the waning Moon is 67% illuminated.
13. **Tycho's ray**. It's most conspicuous when the waxing Moon is roughly 65% to 70% illuminated.
14. **Montes Secchi** region. This narrow brightening separating Mare Tranquillitatis (Sea of Tranquility) from Mare Fecunditatis (Sea of Fertility) is best seen around perigee and when the Moon is 30% illuminated.
15. The ejecta from the rayed crater **Olbers** is easiest to see during favorable librations and when the Moon is about 75% to 65% illuminated.

If you don't succeed on your first or second attempt, don't give up. Try again on another night. Good luck!

■ Eagle-eyed Contributing Editor **STEPHEN JAMES O'MEARA** was the first to visually detect the spokes on the B ring of Saturn in 1976 and recover Halley's Comet in 1985, among his many feats.



When Rive

Water carved the terrain of ancient Mars in sporadic bouts of activity that scientists are striving to explain.

Mars today is a frozen wasteland. Countless craters pockmark the terrain, including scars from some of the heftiest planet pummelers the early solar system let fly. More than half the surface is at least 3 billion years old, preserving the Red Planet's geologic history like a rare book.

This ancient landscape tells the story of a different Mars than the one we see today. Scientists have found roughly 70,000 valleys splayed across the surface, some linked in networks that meander for thousands of kilometers. Valleys play connect-the-dots with craters, flowing over rims in ways that suggest lakes once filled — and sometimes spilled out of — the basins. One network stretches all the way from the impact-beaten highlands near the south pole to the smoother equatorial lowlands, some 8,000 km (5,000 miles) away.

Since their discovery in the 1970s, these valley networks have provided abundant evidence that water once flowed on Mars's surface. (For various reasons, the liquid had to be water.) But poor little Mars can't sustain liquid water today: It has lost nearly all of its atmosphere. That's due at least in part to the solar wind, which stripped the planet's gaseous shroud away like dandelion fluff caught in a child's breath. The carbon dioxide air is now so thin that the atmospheric pressure is less than 1% that of Earth's, and average surface temperatures are far below freezing. What water remains lies trapped in polar ice caps or in the ground.

To explain the valleys crisscrossing its terrain, Mars must have had a radically different climate between 3 and 4 billion years ago. For decades, scientists have debated what that environment looked like and what enabled its existence, a debate sometimes summed up as "warm and wet versus cold and icy."

Now, however, better observations and calculations have transformed the conversation. Scientists are increasingly seeing ancient Mars as a world that suffered climate whiplash, bouncing time and again between clement and frigid conditions. Glaciers, rivers, rain — the planet seems to have had them all. Yet how water's many manifestations worked together to sculpt the landscape, and what mix of causes spurred the climatic swerves, remain half-exposed enigmas.

◀▶ **ANCIENT WATERWAYS** *Left:* This composite image from the Mars Express orbiter shows an eroded valley system in the planet's southern highlands. The topography suggests water flowed downhill from north (top) to south, carving valleys up to 2 km (1 mile) wide and 200 meters (650 feet) deep. *Right:* A simulated side view, based on terrain data.

rs Ran Through It

Mixed Messages

The valleys stretch primarily across the southern highlands, the primeval, rugged land that covers two-thirds of the planet. Some networks branch like great carved trees. In many cases, the tributaries start near the peaks of topographic divides, just as watersheds do on Earth. Their appearance suggests that the water that made them often came from rain or snowmelt.

But although the valleys are widespread, they don't carve as deeply or as extensively as researchers would expect if they had formed during prolonged warm and wet conditions.

Surface minerals also suggest liquid water had a limited presence. Although there's evidence of erosion by water, and there are clays created by water's interaction with rocks, the mineralogy doesn't match what we'd see if water cavorted across the planet for hundreds of millions of years. The mineral olivine, for instance, alters quickly in contact with water, transforming into other things. Yet olivine is all over Mars.

Long-lasting liquid water would also have created vast deposits of carbonate rock, through the interaction of minerals and carbon dioxide both dissolved in the water. The lack of ubiquitous carbonates has long been one line of evidence indicating that Mars lost its CO_2-rich atmosphere to space, instead of by chemically stuffing it into the crust (*S&T:* July 2018, p. 14). Researchers have recently found far more carbonates than they once thought existed, and they are currently debating the implications. Yet they still see nothing like the marine deposits on Earth.

Thus, although scientists have no doubt that there was lots of liquid water on Mars between 3 and 4 billion years ago — enough to cut valleys into rock and fill crater lakes and maybe even an ocean in the northern lowlands (still an open question) — that water wasn't active for very long. "Nobody that I know of thinks it was warm for a billion years," says Briony Horgan (Purdue University).

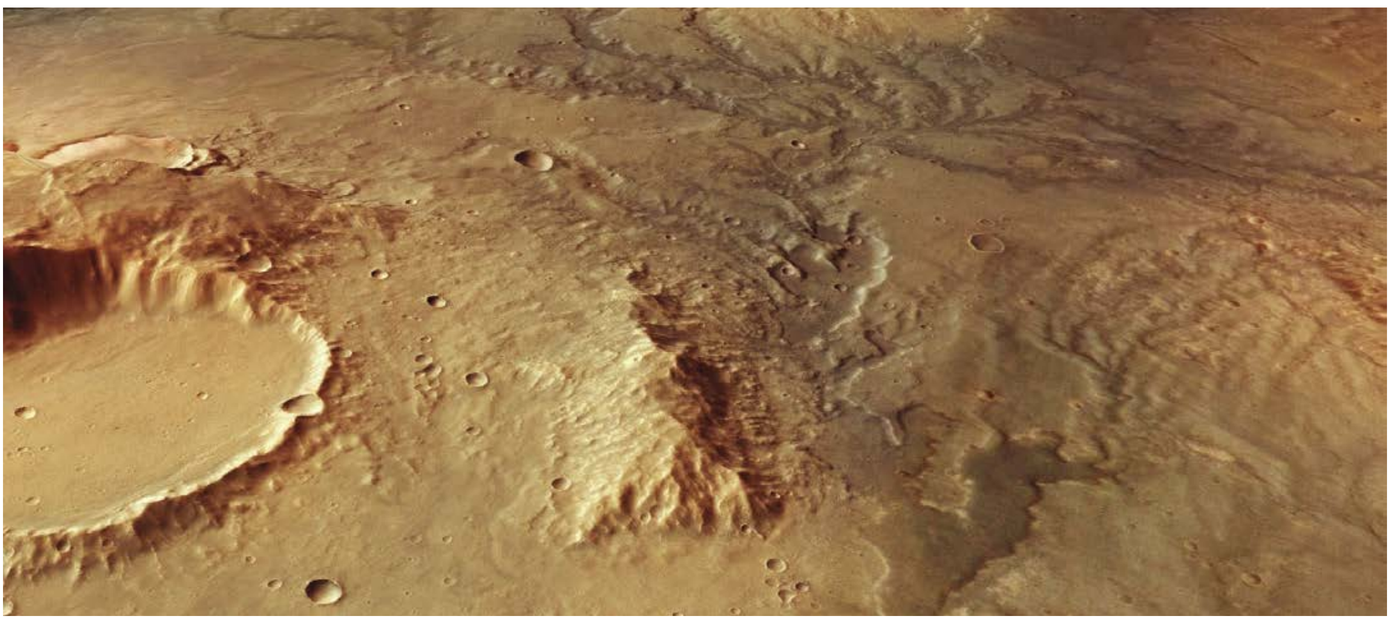
Instead, much of the Mars scientific community has converged on an episodic scenario, in which the planet was on-again, off-again habitable. Estimates vary, but clement conditions might have lasted between 100,000 and 10 million years cumulatively, with each interval stretching for some 10,000 to 1 million years. There might have been up to 100 different eras during which water flowed.

It's Cold Outside

Mars lies half again as far from the Sun as Earth does, and the early Sun was fainter than today's. So in order to sustain liquid water, ancient Mars would have needed a boost of more than 60 kelvin (110°F) in greenhouse warming — around double the greenhouse effect on present-day Earth, and nine times greater than the effect on present-day Mars.

Awash in Riddles

The peak of valley formation occurred 3.7 billion years ago, at the transition between an older geologic period known as the Noachian and the more recent Hesperian period. There should have been widespread ice sheets in the southern high-



lands around this time. The highlands' terrain rises several kilometers above the younger northern plains, a stark contrast that makes the planet look two-faced.

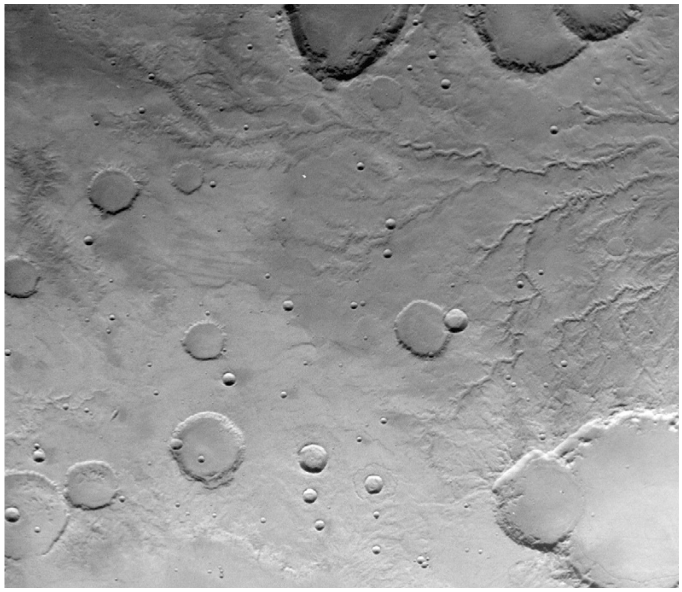
During the Late Noachian, when the valley networks were forming in earnest, the planet's atmosphere was thicker, with a surface pressure of perhaps half a bar to a full bar (where 1 bar is the pressure at sea level on Earth). In a thick enough atmosphere, air will cool with elevation, as it does on Earth. The coldest places become "traps" where water vapor in the air freezes out as ice and snow.

"If you have an active water cycle, water is always going to want to travel to cold-trap regions," says Robin Wordsworth (Harvard University). Water would inevitably accumulate in the southern highlands as ice. "Then when you combine that with melting events driven by climatic warming, there's just a natural feedback that will allow water to cycle through the system." The water would flow down to lower elevations, carving valleys and filling lakes as it went, then evaporate and travel back to the highlands to reset the cycle.

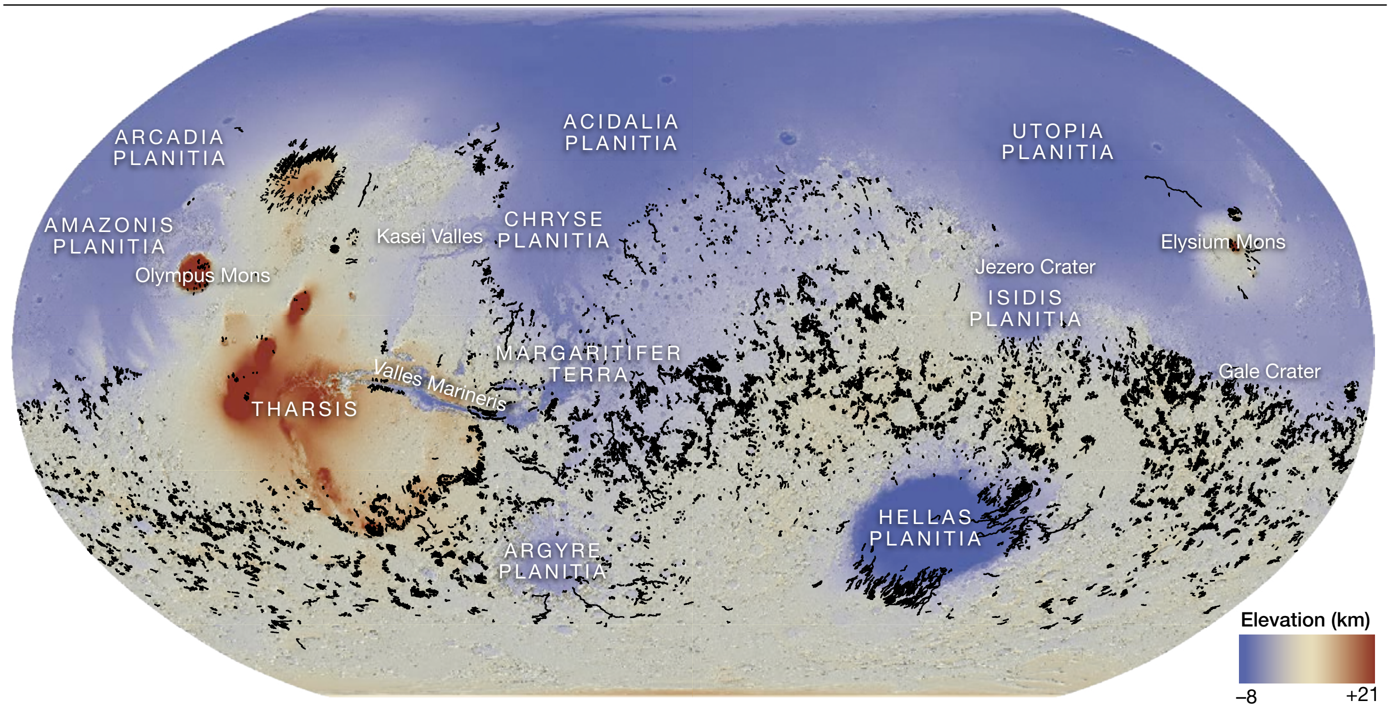
We see signs of ancient ice sheets on Mars, such as the Dorsa Argentea Formation at the south pole. This geologic feature includes *eskers*, sediment ridges that build up within subglacial drainage channels. Other glacial features appear at mid-latitudes and even in some places near the equator, along the boundary between highlands and lowlands.

The ice sheets would have played their own role in sculpting valleys. Some valleys appear to have been carved not by rivers but by meltwater flowing beneath glaciers, where it cut channels into the underlying rock. These features indicate that Mars did not have to be warm to make every valley; water wielded a variety of chisels.

But scientists disagree about the impact glaciers had on Mars during this era. There's no sign of large-scale glacial landscapes like those we see on Earth, where long-gone



▲ **EARLY SIGNS** This Viking 1 image from 1976 shows the Paraná Valles, a valley network in Margaritifer Terra. The image spans about 250 km. North is lower right, higher terrain is to the south.



▲ **VALLEYS GALORE** Scientists have so far found tens of thousands of valleys across Mars. They lie primarily in the southern highlands, which rise several kilometers above the northern plains. The volcanic Tharsis plateau also reaches to high elevations; it was likely already in place during the era of valley formation (debate continues). Like the southern highlands, Tharsis experienced glaciers. Mars's dramatic topography would have influenced climates on multiple scales, making it difficult for researchers to disentangle what the ancient environment looked like.

1970S NETWORK: JPL / NASA; GLOBAL MAP: ANNA GRAU GALOFRE ice sheets scoured and eroded the ground, leaving distinct mounds of debris.

"Even at the rover scale, we just haven't seen any deposits or anything that we would associate with glaciation, with icy environments," Horgan explains. "Everything we see looks like there was just liquid water on the surface."

Perhaps, some argue, that's because the highlands were never covered in ice, and early Mars was persistently warm. Others have suggested that the glaciers' bases were so cold that they froze to the rock instead of melting and sliding.

A third possibility is that Mars's weaker gravity changed how meltwater drained from beneath its glaciers. Mars is a much smaller planet, and its surface gravity is only one-third that of Earth. Martian glaciers should thus sit less heavily on the landscape, enabling stable drainage channels to form beneath the ice and reducing friction between the ice and ground, Anna Grau Galofre (Laboratory of Planetology and Geosciences, Nantes, France) and others have suggested.

These channels would siphon water away, preventing sliding and erosion. As a result, the team concluded, glacial erosion on Mars should be much lower than on Earth — perhaps anywhere from 20 to 400 times slower. Martian glaciers' primary fingerprints would be the remnants of this drainage system, including channel networks and eskers much like the valleys and ridges found in the southern highlands. That could explain why on Mars we don't see the same glacial landscapes we find on Earth.

Think Indiana, Not Antarctica

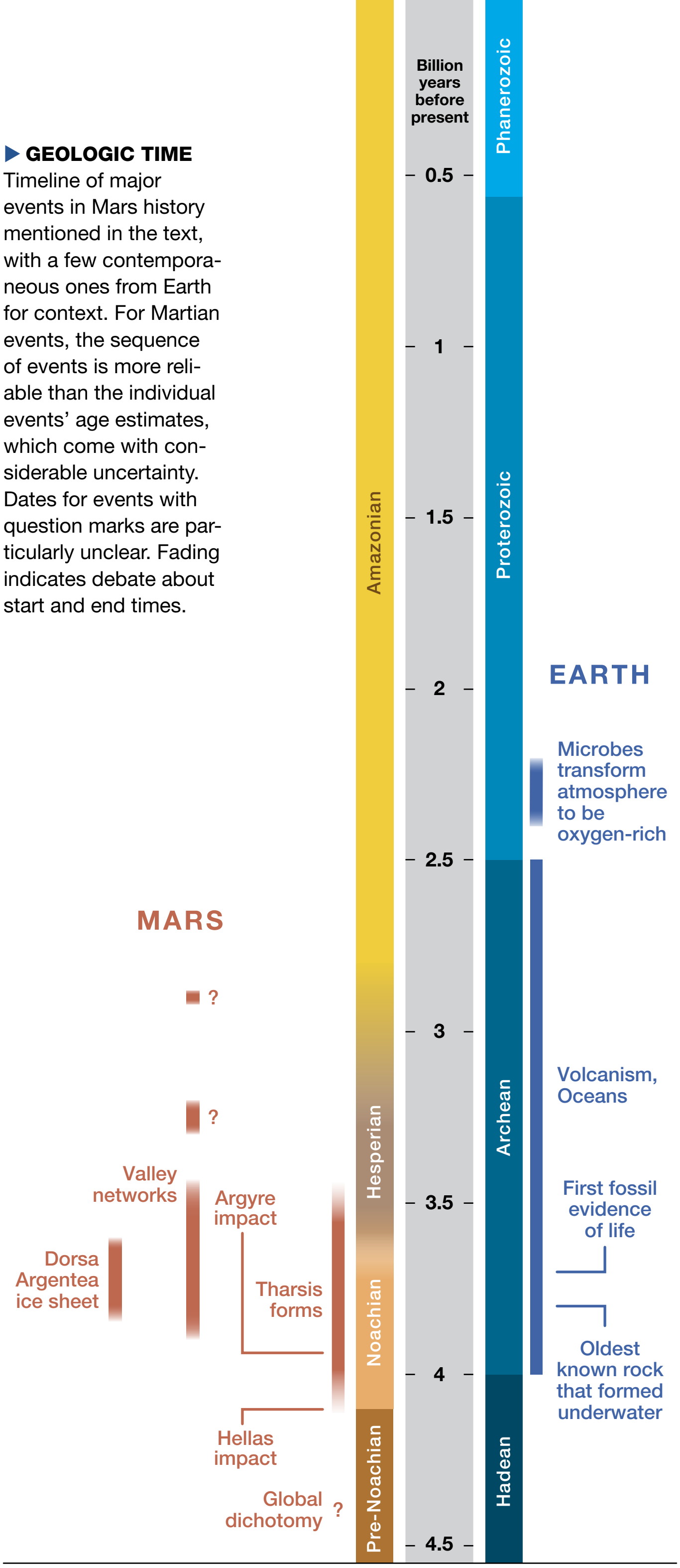
Still, ancient Mars cannot have always been icy. Mineral evidence favors the presence of warm, rainy conditions at least some of the time.

Scientists have found more than 100 outcrops of clay-rich rock that date from roughly the same era as the valley networks. These *weathering profiles* can be 200 meters (700 feet) thick. On Earth, deposits like these form when rain seeps down into the soil and breaks up minerals. The water drags the resulting clays downward with it as it slowly leeches through the ground.

Such clay stacks require lots of water to develop. We usually see terrestrial ones in tropical climates where the ground is tectonically stable and stays in place long enough for water to sit and act. But with no tectonic activity or quick erosion to erase these outcrops on Mars, a semi-arid climate would suffice to create them — something like the U.S. Midwest and its rainstorms, says Horgan.

The clay outcrops cluster in the mid-latitudes, and they appear at lower elevations and closer to lakes than valleys do. Whereas the valleys would have formed where the ground was susceptible to erosion, the clay stacks formed where it wasn't and where water could pool.

"The big takeaway we have right now on the geology side is, I don't know the way to produce both the valley networks and the weathering profiles that we see with just snow and ice," Horgan says. "It really does have to be warm and raining."



▶ **GEOLOGIC TIME** Timeline of major events in Mars history mentioned in the text, with a few contemporaneous ones from Earth for context. For Martian events, the sequence of events is more reliable than the individual events' age estimates, which come with considerable uncertainty. Dates for events with question marks are particularly unclear. Fading indicates debate about start and end times.

These clay stacks couldn't have formed beneath glaciers, she adds. On Earth, glaciers' daily and seasonal melt cycles unleash intense amounts of water, which create a silica goo very different from the minerals in the outcrops.

NASA's Curiosity rover has also seen signs that ice-free water once existed on the Red Planet. For more than a decade now, the rover has been climbing a towering sediment mound in Gale Crater near the equator, trundling through the planet's geologic history as it travels upward. The rover has

BEATRIZ INGLESSIS / S&T, SOURCES: W. K. HARTMANN / *ICARUS* 2005, C. I. FASSETT & J. W. HEAD III / *ICARUS* 2008, R. D. WORDSWORTH / *ANNUAL REVIEW OF EARTH AND PLANETARY SCIENCES* 2016, A. GRAU GALOFRE ET AL. / *ICES IN THE SOLAR SYSTEM* 2024, R. D. WORDSWORTH ET AL. / *NATURE GEOSCIENCE* 2021

▲ **WEATHERED ROCK** Over time, surface water leached down through this basaltic ash deposit in Madagascar, transforming the bedrock (gray) into oxidized rock (red). On Mars, we don't see as much evidence for oxidation, so the weathering profiles don't look quite as red.

found evidence for multiple lakes, each at a different geologic time and lasting for an uncertain duration.

Recently, the rover drove over a lake deposit with wave-created ripples. The only way for wind-spurred waves to have stirred ripples in the lakebed is if the lake was at most 2 meters deep and its surface was ice free.

"That rules out a whole class of scenarios that are loosely Antarctica-like," says Edwin Kite (University of Chicago). Antarctica has some 600 lakes beneath its ice sheets, and Kite had previously thought such ice-covered lakes might be a possibility for Mars. This new result eliminates that option, at least for Gale. "You have to have open water."

NASA's Perseverance rover, meanwhile, has been exploring a shallower crater called Jezero, in which lakes came and went. Scientists chose Jezero in part because it's the end point for the area's valley networks, which flowed into the crater, dropped their entrained sediment, and created a large delta. As the rover has climbed to higher elevations, the rocks around it have transformed from those seen in deep lakes to rivers to big flood deposits. It's unclear whether the latter would be from glacial melting or larger climatic change.

The confusing lines of evidence make it difficult to assemble a clear picture of the ancient Martian environment. "It's closer to the feeling a few years before all the puzzle pieces fit together," says Kite. "All these hard-to-explain observations are piling up."

The confusion is compounded by the fact that conditions would have changed with time and from place to place. "It's a *planet*, right?" says Horgan. "It should have had many different things going on at different times, and you can imagine ice sheets coming and going. . . . The question is, why?"

Chicken Little Was from Mars

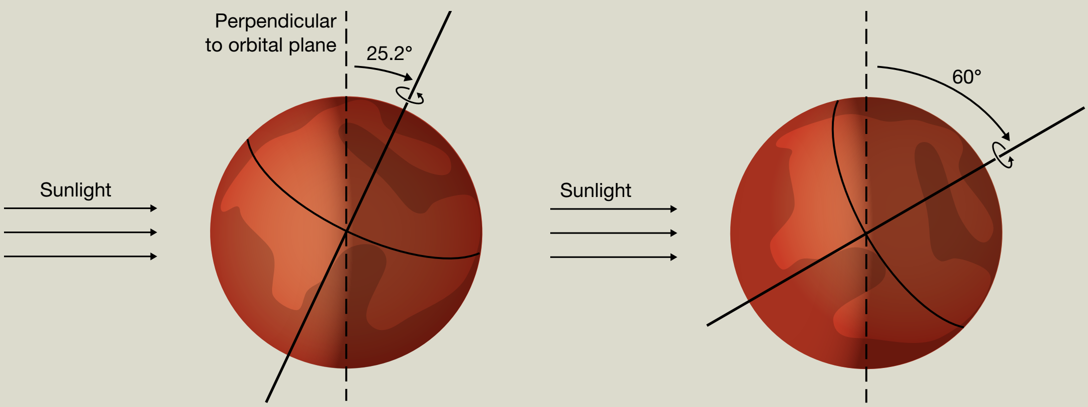
One driver of worldwide climate change is variations in the tilt of a planet's spin axis. These changes happen because the planets tug on one another as they revolve around the Sun. Thanks to the stabilizing presence of our large moon, Earth's rotation axis holds pretty steady, with an *obliquity* (tilt) of about 23° with respect to the plane of its orbit.

Mars has no such guardrail. The tilt of its rotation axis swings over hundreds of thousands of years, ranging from 0° to 60°, perhaps more. Although Mars's current obliquity is similar to Earth's, the average is likely around 40°.

When the obliquity is low, like now, the Red Planet's poles stay cold and icy. But at angles greater than about 40°, summer finds sunlight beating down on those same regions. The resulting heat wave melts the ice. Carbon dioxide releases into the air, raising the atmospheric pressure, and water migrates toward the now-colder equator, where it freezes. This climate transition happened as recently as a few million years ago, when mountain glaciers formed in the tropics.

Because the obliquity seesaw is a chaotic process, scientists can only trace the behavior back some 20 million years into the past. More distant forecasts must rely on statistics and geologic evidence. It's therefore unclear how obliquity played with (or contributed to) bouts of clement climate during the era of valley formation. Strong seasonal changes might have enabled water to melt even when the yearly average temperature was ostensibly far too cold for liquid water, for instance.

▶ **LEANING PLANET** Mars's spin axis is currently tilted about 25° from being perpendicular to its solar orbit *(left)*. But this angle, called obliquity, oscillates over time and may reach 60° *(right)*. The obliquity variations change which regions receive the most intense sunlight and where ice collects on the planet's surface. The diagram shows southern summer.



The variations would also have cast Mars into and out of ice ages. "Landscapes that carried water early in Mars's history may have been glaciated later on during one of these ice ages," Grau Galofre explains. "Some regions of the mid-latitudes most likely have seen both glacial and [river] processes throughout Mars's history." The giant Hellas Basin, for instance, likely contained a glacier during periods when Mars's tilt was severe, but the ice sheet disappeared when the planet reoriented to a lower angle. Areas near the south pole, meanwhile, may have had glaciers, rivers, and water flowing beneath ice sheets, all at the same time.

But the chaotic obliquity wasn't the only factor shaping the ancient climate. Back when the valley networks were forming, the Sun was fainter. At that time, Mars received only one-third as much sunlight as Earth does today. Although the Red Planet had a thicker atmosphere back then, even a full bar (or more) of carbon dioxide wouldn't have been enough to warm the planet. Too much CO_2 can, ironically, have a chilling effect.

The atmosphere can even collapse. Cool the planet a little at lower obliquities, and the carbon dioxide gas will begin to condense as surface ice at the poles — particularly the southern one, which rises to a much higher elevation than the northern one. A thinner atmosphere transports heat less effectively, and so the pole cools more, creating a runaway effect in which the sky literally falls. And it happens *fast*, within a few hundred years.

Counterintuitively, atmospheric collapse might have helped create some valley networks. The carbon-dioxide ice cap would have formed on top of a pre-existing water-ice cap. Last year, Peter Buhler (Planetary Science Institute) suggested that the thick, CO_2-ice sheet could have served as a thermal blanket, helping warm the water ice beneath it. The resulting meltwater would have snuck out from beneath the cap as ice-encrusted rivers, flowing like oozing lava into the gigantic basin Argyre and filling it with an ice-topped sea as voluminous as the Mediterranean. From there, the water spilled out again and wound its way equatorward until finally draining into the Margaritifer Terra plains, thousands of kilometers from the south pole (*S&T:* Apr. 2025, p. 11). The innovative scenario could explain the extensive valley system branching across that part of Mars.

But given the evidence for intermittent warm and wet conditions, one or more greenhouse gases besides carbon dioxide and water likely helped Mars out at least some of the time.

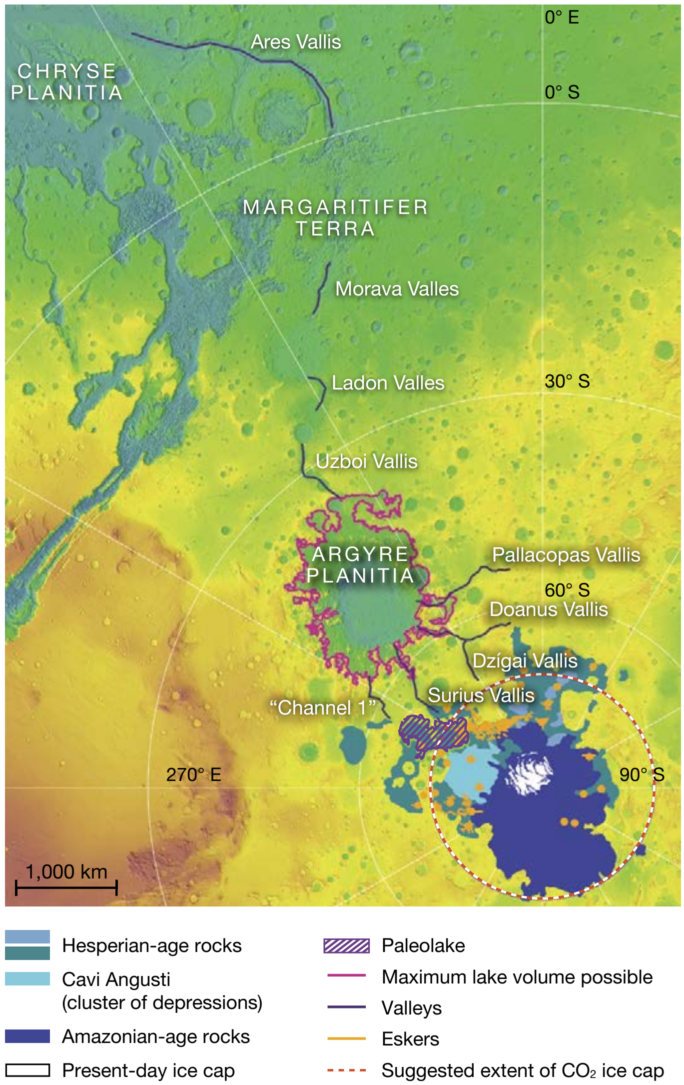
One solution is hydrogen. Mars's crust is basalt, a type of volcanic rock that's also the most common rock type in Earth's crust. If you throw a bunch of water at basalt, it'll chemically modify the rock and create hydrogen gas. The planet's lower gravity means the crust should be more porous, too, enabling water to infiltrate the ground and interact with minerals there to make hydrogen.

Hydrogen would also come from volcanism itself. Ancient Mars had plenty: Widespread lava flows cover terrain from the Noachian and Hesperian periods. As it wells up from below, molten rock carries with it gases, trapped as bubbles, that escape as the magma reaches the surface. Scientists think the Martian mantle contains a higher fraction of hydrogen than Earth's does, meaning the gases spewed out would contain a higher proportion of hydrogen.

It's possible that multiple sources of hydrogen would be enough to temporarily boost the greenhouse effect and create warm, humid climates, Danica Adams (Harvard), Wordsworth, and others recently proposed. It remains unclear whether other molecules that contain hydrogen, such as methane, could also contribute.

Cold Storage

The era of valley-network formation marks the beginning of Mars's transition to a cold, arid climate. Over time, liquid



▲ **GIANT RIVER SYSTEM?** A vast valley network connects Mars's south pole to the lowland plains of Margaritifer Terra and Chryse Planitia. Recent research suggests this network might have formed when a sheet of carbon-dioxide ice built up over the pole, helping to melt underlying water ice that then snuck out and meandered, ice-encrusted, for thousands of kilometers. The underlying topography map spans elevations of several kilometers.

P. B. BUHLER / *JOURNAL OF GEOPHYSICAL RESEARCH: PLANETS* 2024

JEZERO Ancient waterways spilled into Jezero Crater, leaving evidence like the delta at the center of this image. The Perseverance rover climbed up this delta to reach the crater's rim. The inset below is a simulated side view, created by draping camera data over a terrain model. Jezero itself is about 45 km wide.

JEZERO FLOW: ESA / DLR / FU-BERLIN / NASA / JPL-CALTECH; B&W: NASA / JPL-CALTECH / USGS

water huddled at lower and lower elevations, likely due to a dwindling greenhouse effect that left the high places too cold for water to move and carve the terrain. The planet experienced several major climate transitions. Rivers and lakes appeared and disappeared with increasing scarcity.

Eventually, the planet dried out. Today, besides the occasional asteroid impact, the only thing notably shaping Mars's surface is wind. It sweeps across parched terrains, kicking up grains left by long-gone glaciers, rivers, and volcanoes. Dust storms shroud the sky and kill solar-powered craft. As the Sun traverses butterscotch-hued heavens, the wind and its dust devils are the only things scouring the landscape — a landscape with its past freeze-dried on its surface, waiting for us to decipher it.

Reading that history is a slow process. Scientists have barely had time to dig into Perseverance's data, Horgan says. And over the next couple of years, both Curiosity and Perseverance will traverse terrains with ages we've never explored on the ground before — Curiosity to younger deposits, Perseverance to older ones. Perseverance is now atop Jezero's rim and ambling among extremely old rocks, including fragments of pre-Noachian crust that were scooped out by impacts and dropped there. "They really do date from the dawn of Mars geology, which is wild," Horgan says.

Scientists have precious little information about this period. "It could be the first few hundred million years of Mars history are the most habitable," Kite says. "But we just don't have a good surface record, because that record's been buried." These chunks of ancient crust might preserve evidence of that early time.

So far, Perseverance has collected more than two dozen samples, from a variety of rock types, and is leaving them in tubes on the ground for future pickup and return to Earth. On Earth, scientists can see and handle rocks and run tests with a host of sophisticated lab equipment. They can determine things like the atmospheric composition and ambient temperature when the minerals formed. They can't load all those capabilities on a rover.

"Sample return is really, really, really important," Wordsworth says. "It's absolutely vital."

Yet NASA has struggled to devise a workable sample-return strategy, and as of press time the Trump administration's proposed budget would nix funding for a mission. For now, there's no plan for reclaiming the tubes of rock and air.

Mars scientists hope that changes. "If we can actually get the samples back, [it] would be just absolutely phenomenal," Horgan says. "Those samples piece together how the atmosphere degraded."

When the samples finally make it home, the Red Planet's history won't just sit preserved on a surface some 200 million kilometers away — it'll sit in the palm of our hands.

■ Science Editor **CAMILLE CARLISLE** would never, ever, ever want to live on Mars, but she'd love to hold a Martian rock nabbed by a robot and brought back to Earth.

A 17th-Century Pale Blue Dot

Christiaan Huygens showed extraordinary vision in his prescient 1698 masterwork, *Cosmotheoros*.

CHRISTIANI HUGENII
ΚΟΣΜΟΘΕΩΡΟΣ,
SIVE
De Terris Cœleſtibus, earumque ornatu,
CONJECTURÆ.
AD
CONSTANTINUM HUGENIUM,
Fratrem:
GULIELMO III. MAGNÆ BRITANNIÆ REGI,
A SECRETIS.

HAGÆ-COMITUM,
Apud ADRIANUM MOETJENS, Bibliopolam.
M. DC. XCVIII.

VOYAGER PALE BLUE DOT PHOTO: NASA / JPL-CALTECH; HUYGENS PAINTING: CASPAR NETSCHER / WIKIMEDIA COMMONS / PUBLIC DOMAIN; TITLE PAGE FROM *COSMOTHEOROS*: COURTESY ROB VAN GENT / UNIVERSITY OF UTRECHT / PUBLIC DOMAIN

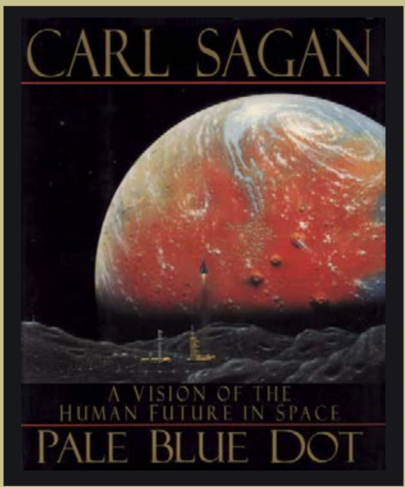
"Look again at that dot. That's here. That's home. That's us." Many of this magazine's readers will recognize this quote as the start of a moving and inspiring passage from Carl Sagan's 1994 book, *Pale Blue Dot: A Vision of the Human Future in Space*. Referring to the famous 1990 Voyager 1 photo of our home planet as "a mote of dust suspended in a sunbeam," Sagan reflected on humanity's place in the wider universe. "Our posturings, our imagined self-importance, the delusion that we have some privileged position in the Universe, are challenged by this point of pale light," he wrote.

What most people don't know is that a very similar vision was outlined almost three centuries earlier in a wonderful book by Dutch polymath Christiaan Huygens. In fact, when he wrote his famous *Pale Blue Dot* passage, Sagan may well have been inspired by Huygens's writings, which he featured in the sixth episode of the momentous 1980 PBS television series, *Cosmos: A Personal Voyage*. In his book *Cosmotheoros*, Huygens also pondered the smallness of Earth in the vastness of space and scientifically considered the existence of extrasolar planets and extraterrestrial life.

A Man of Many Talents

Christiaan Huygens (1629–1695) was the second son of Dutch poet, composer, and diplomat Constantijn Huygens. Among many other accomplishments, Christiaan was the first to have observed dark markings on the surface of Mars; discovered Titan (Saturn's largest satellite) as well as the true nature of Saturn's rings; invented the pendulum clock; and formulated the wave theory of light. Together

SINGLE-PIXEL WORLD
On February 14, 1990, from a distance of 6 billion kilometers (4 billion miles), Voyager 1 captured this mind-boggling photo of our home planet reduced to a mere "mote of dust, suspended in a sunbeam," as described by Carl Sagan in his 1994 book *Pale Blue Dot*.



with his older brother (also named Constantijn), he built the best telescopes of his time. A mountain on the Moon, an asteroid, a huge impact basin on Mars, a basic telescope eyepiece design, and the European space probe that touched down on Titan in 2005 have all been named after him.

It wasn't until he was in his early sixties that Huygens started writing *Cosmotheoros*, which he dedicated to his brother. The manuscript was completed in January 1695, about six months before Huygens's death, but the book wasn't published until 1698, after Constantijn, who had been charged with overseeing the publishing process, had also passed away. Christiaan had decided to write the book in Latin, possibly to enable rapid translations into various languages. An English version (with the convoluted title *The Celestial Worlds Discover'd: or, Conjectures Concerning the Inhabitants, Plants and Productions of the Worlds in the Planets*) appeared shortly after the original Latin edition. A Dutch translation was published in 1699

▲ **SELF-MADE SCIENTIST** *Left:* Christiaan Huygens was a little more than 40 years old and already famous for his astronomical discoveries when he sat for this portrait by Dutch painter Caspar Netscher.

▲ **ECHOES ACROSS TIME** *Middle pair:* Despite being published almost three centuries apart, Christiaan Huygens's 1698 book *Cosmotheoros* (left) covers some of the same philosophical topics as *Pale Blue Dot*, written by Carl Sagan in 1994.

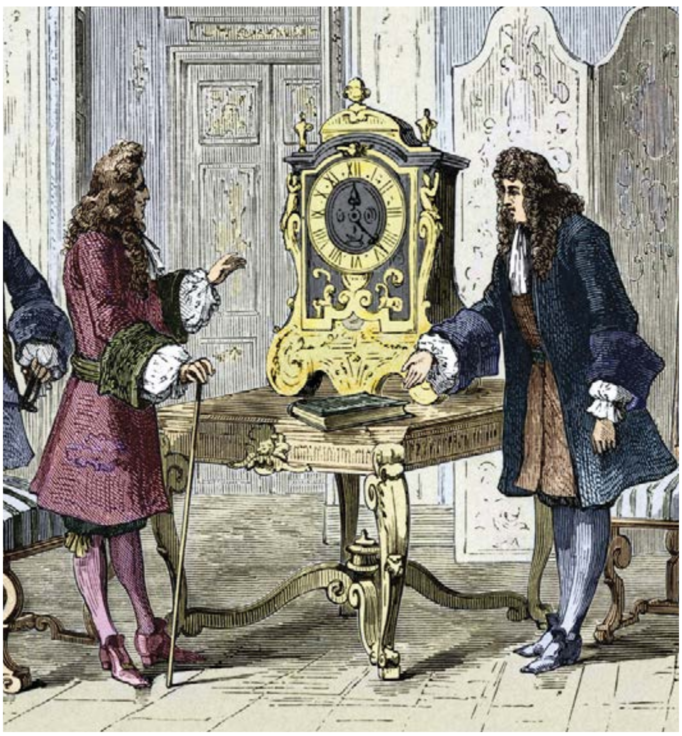
▲ **OUTREACH CHAMPION** *Right:* Known and admired for his influential 1980 PBS television series Cosmos, which he co-wrote with his wife, Ann Druyan, and his many popular science books, Carl Sagan was also a respected planetary scientist and a member of the Voyager science team.

PALE BLUE DOT COVER: PENGUIN RANDOM HOUSE; CARL SAGAN AND ANN DRUYAN: TONY KORODY, COURTESY ANN DRUYAN and French, German, Russian, and Swedish editions followed in the 18th century.

"The book was quite popular and well-received," says Daphne Stam, a planetary scientist who retranslated *Cosmotheoros* to Dutch in 2024. Stam happens to live a stone's throw from Hofwijck, the Huygens's family mansion in Voorburg, a suburb of The Hague. "The original Dutch translation of 1699 is really hard to read," she noted. "With the recent developments in the field of exoplanets, and the scientific search for life beyond Earth, I believe that Huygens's book deserves to be much better known." In fact, strange as it may seem, many Dutch people hardly know of Christiaan Huygens, let alone his work and scientific importance.

A Universe in a Book

Even today, reading *Cosmotheoros* is a wonderful experience. It's as if Huygens is sitting across from you, talking out loud, and trying to win you over with the sheer strength of his arguments. The book consists of two parts, and the very first sentence of Book I immediately grabs the reader's attention: "A Man that is of Copernicus's Opinion, that this Earth of ours is a Planet, carry'd round and enlighten'd by the Sun, like the rest of them, cannot but sometimes have a fancy, that it's not improbable that the rest of the Planets have their Dress and Furniture, nay and their Inhabitants too as well as this Earth of ours."



▲ **ROYAL CLOCKWORK** Besides discovering Saturn's largest moon, Titan, and the true nature of the planet's rings, Christiaan Huygens also formulated the wave theory of light and invented the pendulum clock, among many other achievements. In this 17th-century engraving, he is depicted (figure at right) presenting his accurate timekeeping device to King Louis XIV of France in 1659.

More than three centuries later, this remains a very familiar thought — if you know there are other worlds out there, you can't help thinking about extraterrestrial life.

In Book I, Huygens invokes a version of what is now known as the *Copernican principle*, which states that our place in space and time cannot be special or unique in any possible way. That's why Huygens argues that other worlds must also harbor plants, animals, and intelligent inhabitants, in addition to lifeless natural beauty. He wrote, "Now should we allow the Planets nothing but vast Deserts, lifeless and inanimate Stocks and Stones, and deprive them of all those Creatures that more plainly speak their Divine Architect, we should sink them below the Earth in Beauty and Dignity; a thing that no Reason will permit."

Book II delves deeper into the circumstances on the various planets in our own solar system, including a fascinating account of how "Saturnians" would see their home planet's ring system from various locations and throughout their days and seasons. This second part of *Cosmotheoros* also takes the reader into deep space, by discussing the distances to the stars and the likely existence of other planetary systems. It is here that Huygens shares his almost boyish astonishment at the wonders of the cosmos: "What a wonderful and amazing Scheme have we here of the magnificent Vastness of the Universe! So many Suns, so many Earths, and every one of them stock'd with so many Herbs, Trees and Animals, and adorn'd with so many Seas and Mountains!"

Obviously, at the end of the 17th century little was known about the true nature of stars and planets (for instance, Huygens deemed it likely that the Sun was a ball of liquid), let alone about the existence of other galaxies. Still, says Stam, "the book is much more scientific than I had expected." Huygens uses observations and logical arguments to draw his conclusions, and more often than not he acknowledges a lack of trustworthy facts, in phrases like "these are mere guesses, or rather doubts, but yet they are the best we can make of this," or (about the remote possibility of life on the Sun) "we have no Idea . . . which is as much as to say, that truly we have nothing at all to say."

Finding Fault

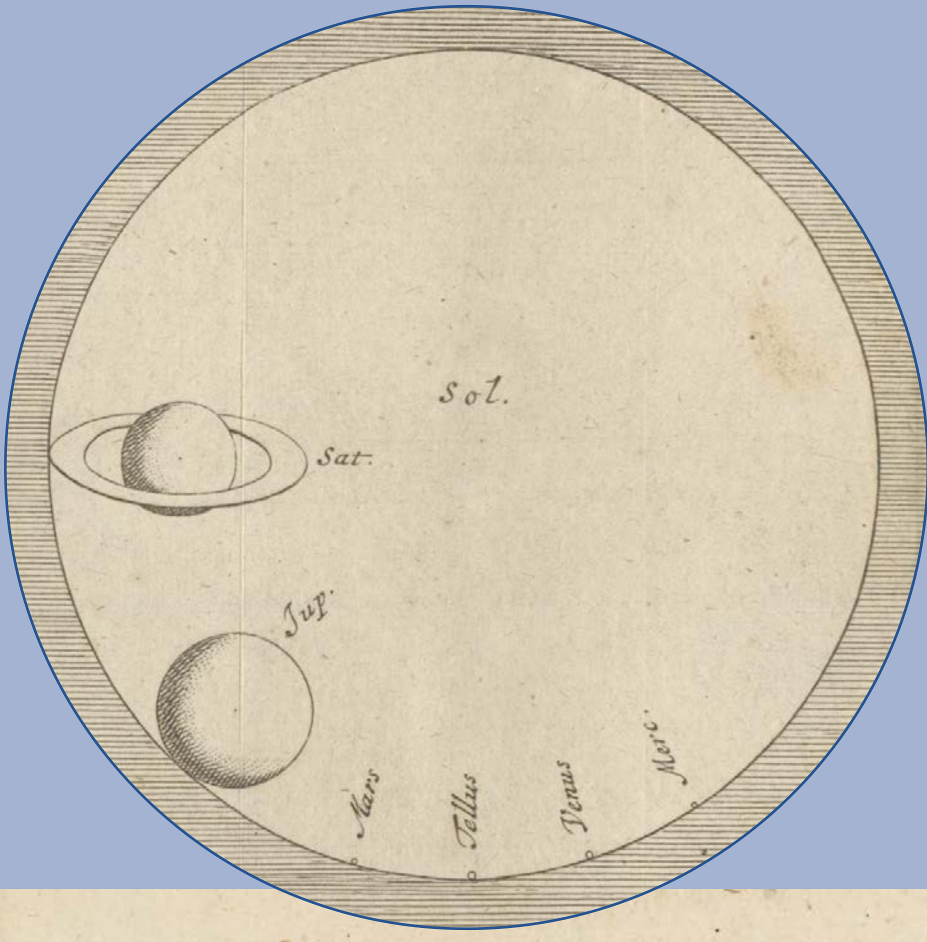
In contrast to *Cosmotheoros*, earlier books that dealt with extraterrestrial life were much more speculative, or even fantasy-like. Huygens mentions and criticizes three examples: Johannes Kepler's 1608 book *Somnium* (sometimes described as the first science-fiction novel); Bernard Le Bovier de Fontenelle's popular book *Conversations on the Plurality of Worlds* (1686); and the 1656 book *Iter Exstaticum* (*Journey in Ecstasy*) by German Jesuit scholar Athanasius Kircher, who worked astrology and angels into his spiritual narrative.

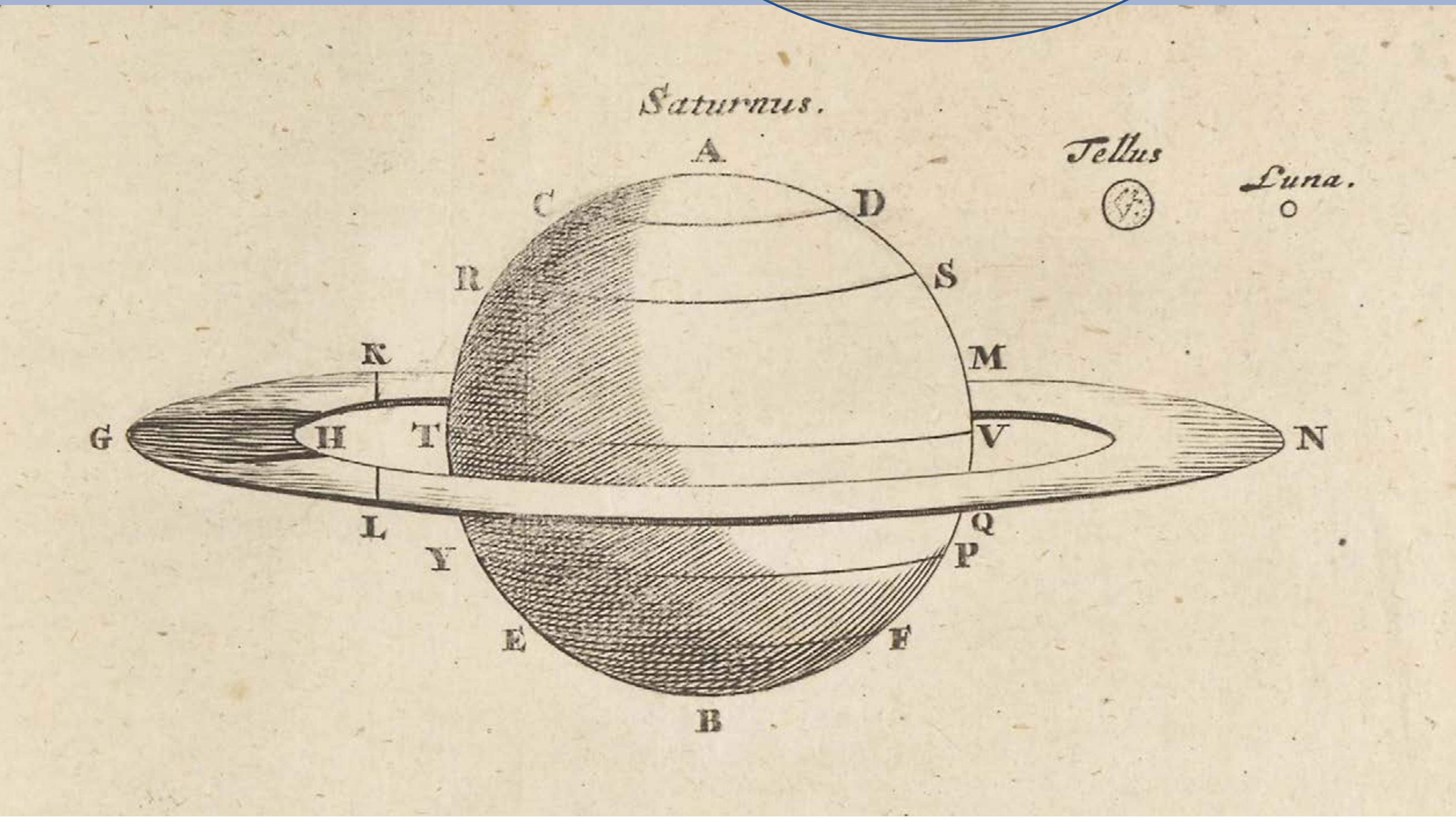
Huygens strongly disagreed with Kepler's earlier belief that there are seas and oceans on the Moon, and that lunar craters are, as he tells it "some vast work of the rational Inhabitants." Commenting on Kepler's erroneous idea that the "fixed stars" are all at the same, relatively small distance

Cosmotheoros Engravings

▶ **SIZE MATTERS** *Cosmotheoros* contains this engraving showing the relative sizes of the Sun and the planets. Remarkably, Jupiter and Saturn are depicted much too large.

▼ **FANTASTIC RINGWORLD** While Galileo Galilei had already noticed that Saturn sported mysterious "appendages," Christiaan Huygens was the first to realize that the planet is surrounded by a flat ring, thanks to the high quality of his homemade telescope. This engraving from *Cosmotheoros* also shows Earth and Moon to scale.





from the Sun, Huygens wrote, "I cannot but wonder how such things as these could fall from so ingenious a Man, and so great an Astronomer." And he takes issue with the belief of the great French philosopher (and one-time family friend) René Descartes that animals are mere machines, commenting ". . . it [is] an absurdity even to think of their being thus haply jumbled together by a chance Motion of I don't know what little Particles."

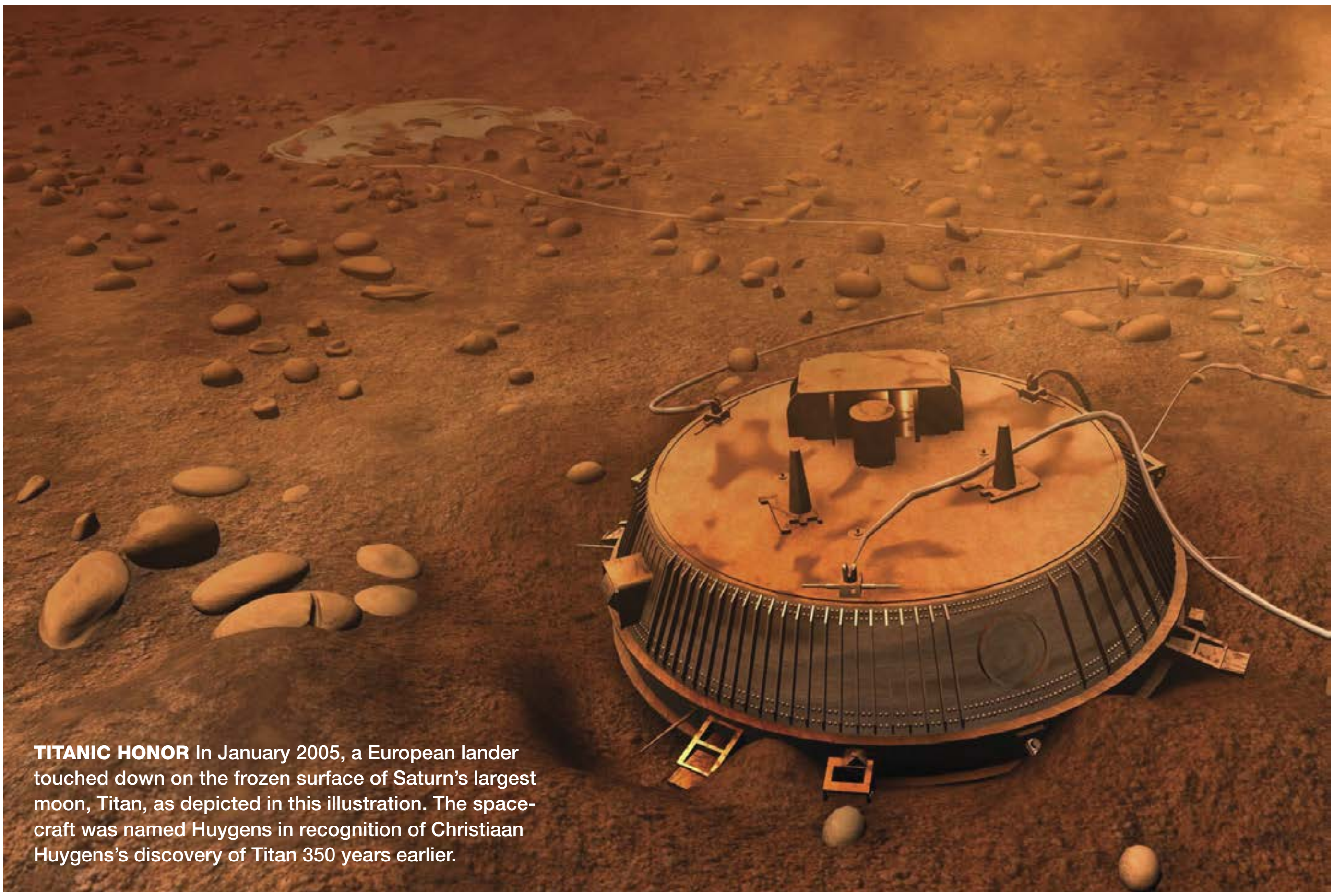
Given his sharp criticisms, it's notable that Huygens also got some things badly wrong. As Stam says, "*Cosmotheoros* itself contains a few blatant errors, which I came across when working on my new Dutch translation." For instance, in writing about Mars, Huygens states that "the Inhabitants have no perceivable difference between Summer and Winter, the Axis of that Planet having very little or no inclination to his Orbit, as has bin discover'd by the Motion of his Spots." In fact, the axial tilt of Mars is even a bit larger than the Earth's — something that should have been evident from Huygens's own observations and those of his contemporaries, especially after Giovanni Cassini discovered the planet's polar caps in 1666.

Even more surprising is Huygens's huge overestimation of the sizes of Jupiter and Saturn: ". . . the Diameter of Jupiter is above twenty times bigger than that of the Earth," he wrote. And, in another part of his book he states, ". . . the Diameter of the Ring round Saturn is to that of the Sun as 11 is to 37; that of Saturn himself about as 5 to 37; that of Jupiter as 2 to 11." The actual ratios are 7.2 to 37, 3.2 to 37, and 1.1 to 11, respectively. The same error is present in the line drawing showing the relative scale of the Sun and planets, reproduced on the preceding page. As for the four Galilean moons of Jupiter, Huygens derived their diameters from observing their shadows transiting across the Jovian disk. No surprise, then, that these estimates are also wrong: ". . . each of these Moons, by the shadow they make upon Jupiter, cannot be less than our Earth," he wrote.

According to Stam, it's a mystery how Huygens could have been so wrong. If you know a planet's distance and apparent size, it's easy to calculate the true diameter. Thanks to Kepler's laws of planetary motion, the dimensions of the solar system and the sizes of each planet's orbit were pretty well known at the time. Moreover, Huygens was a meticulous observer, who used thin metal blades or rods at the focal plane of his telescope to measure angular sizes — a technique he preferred above the use of micrometers. "It's all very strange," says Stam.

Distant Worlds

What is not so strange is that Christiaan Huygens speculated about planets orbiting other stars, and, consequently, about possible life forms on those planets. "I must give my



TITANIC HONOR In January 2005, a European lander touched down on the frozen surface of Saturn's largest moon, Titan, as depicted in this illustration. The spacecraft was named Huygens in recognition of Christiaan Huygens's discovery of Titan 350 years earlier.

ESA

▶ **SCIENTIFIC VALUE** In 1955, the Central Bank of the Netherlands issued this banknote of 25 Dutch guilders, designed by Eppo Doeve and showing Christiaan Huygens, the family home Hofwijck, and the planet Saturn.

Vote, with all the greatest Philosophers of our Age, to have the Sun of the same nature with the fix'd Stars," he wrote. "And this will give us a greater Idea of the World. . . . For then why may not every one of these Stars or Suns have as great a Retinue as our Sun, of Planets, with their Moons, to wait upon them? . . . They must have their Plants and Animals, nay and their rational ones too, and those as great Admirers, and as diligent Observers of the Heavens as our selves."

Huygens realized, however, that it would be impossible to directly observe planets orbiting other stars. By assuming that the stars in the night sky are as luminous as our own Sun, he estimated that the brightest one, Sirius, had to be 27,664 times more distant than the Sun (it's actually much farther away), and at such large distances planets become invisible. As Huygens explained, "For let us fancy our selves placed at an equal distance from the Sun and fix'd Stars; we should then perceive no difference between them. For, as for all the Planets that we now see attend the Sun, we should not have the least glimpse of them, either that their Light would be too weak to affect us, or that all the Orbs in which they move would make up one lucid point with the Sun."

According to Huygens, we live in a tremendously vast universe, in which our tiny home planet is dwarfed by the number, the distances and the dimensions of other celestial worlds. "This shows us," he wrote, ". . . how inconsiderable this Earth, the Theatre upon which all our mighty Designs, all our Navigations, and all our Wars are transacted, is when compared to them. A very fit Consideration, and matter of Reflection, for those Kings and Princes who sacrifice the Lives of so many People, only to flatter their Ambition in being Masters of some pitiful corner of this small Spot."

When reading those sentences, written one third of a millennium ago, it's hard not to think of Carl Sagan's remarks in *Pale Blue Dot*. "Look again at that dot," he wrote. "That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. . . . The Earth is a very small stage in a vast cosmic arena. Think of the rivers of blood spilled by all those generals and emperors so that, in glory and triumph, they could become the momentary masters of a fraction of a dot."

Sagan died in 1996, two years after those words were published. As Ann Druyan (Sagan's widow and co-creator of *Cosmos*) told me, it's "very likely that the Huygens insight resided somewhere in both of us. We both read *Cosmotheoros* when we were writing the sixth episode of our original *Cosmos* series. Some ten years later, when Carl was writing *Pale Blue Dot*, it may have provided an unconscious inspiration."

Druyan explained that if Sagan had been thinking of the Huygens quote consciously, he would have referred to it in the text. The *Pale Blue Dot* passage came about the day the Voyager 1 image of our planet arrived, she says. "We stared at the one-pixel Earth and I said, 'Everyone you ever loved lived there.' Carl grabbed one of his ever-present small dictation machines and began crafting the entire passage. It poured out of him."

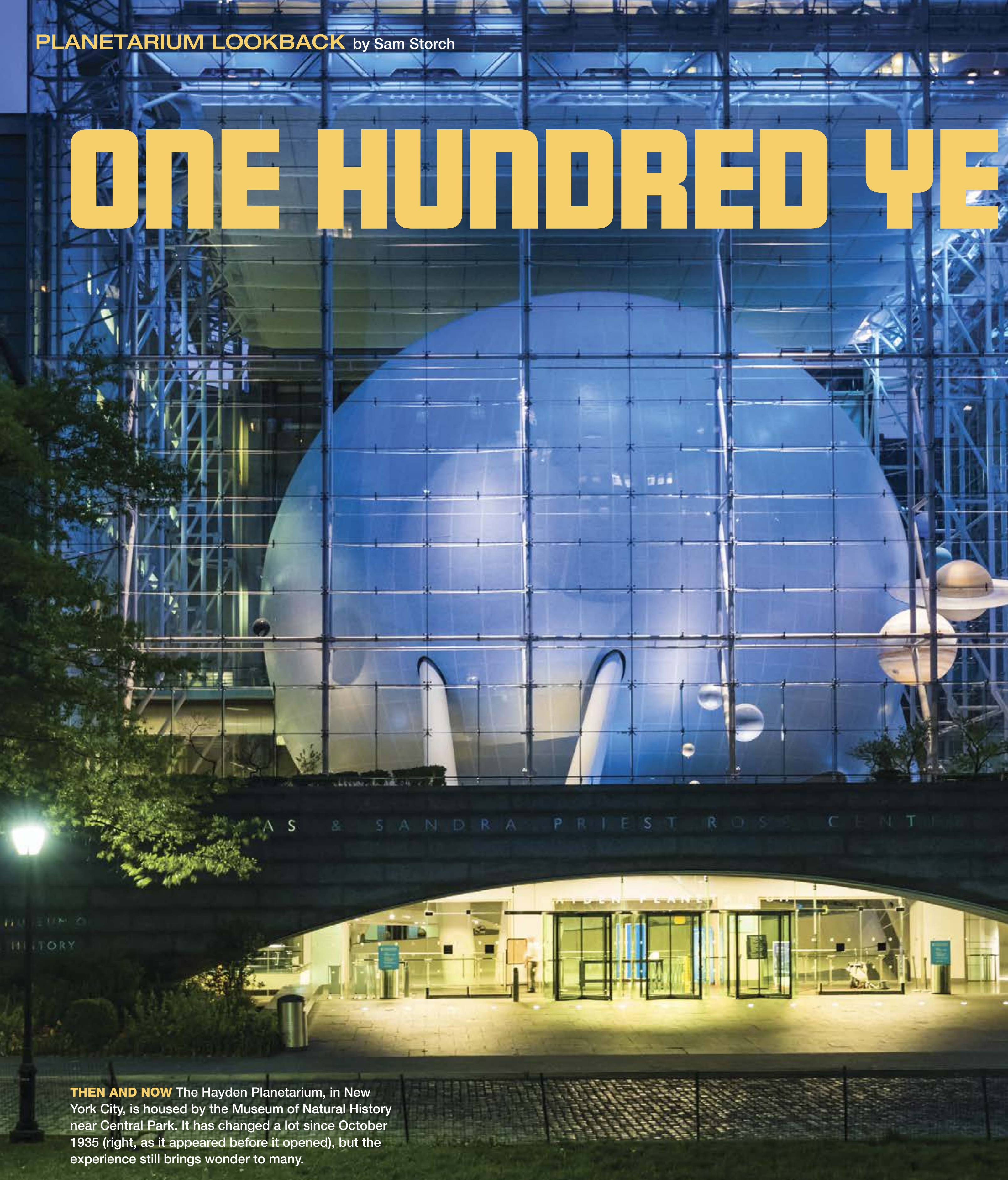
Christiaan Huygens would have loved the idea that his wonderful little book inspired other scientists and astronomy popularizers more than 300 years after his death. And, of course, he would be tremendously excited about all the astronomical achievements and discoveries that we take for granted today, like astronauts on the Moon, rovers on Mars, real images of extrasolar planets, and space telescopes peering into the depths of the universe.

We've come a very long way, studying the cosmos from our diminutive vantage point — our pale blue dot orbiting an inconspicuous star on the outskirts of a middle-of-the-road spiral galaxy. The very last sentence of *Cosmotheoros* reads, "For my part, I shall be very well contented, and shall count I have done a great matter, if I can but come to any knowlege of the nature of things, as they now are, never troubling my head about their beginning, or how they were made, knowing that to be out of the reach of human Knowlege, or even Conjecture."

Like Huygens, we'll have to accept that many of the mysteries of the universe will forever remain beyond our reach.

■ *S&T* Contributing Editor **GOVERT SCHILLING** still cherishes a 50-year-old, 25-guilder Dutch banknote portraying Christiaan Huygens.

ONE HUNDRED YE



THEN AND NOW The Hayden Planetarium, in New York City, is housed by the Museum of Natural History near Central Park. It has changed a lot since October 1935 (right, as it appeared before it opened), but the experience still brings wonder to many.

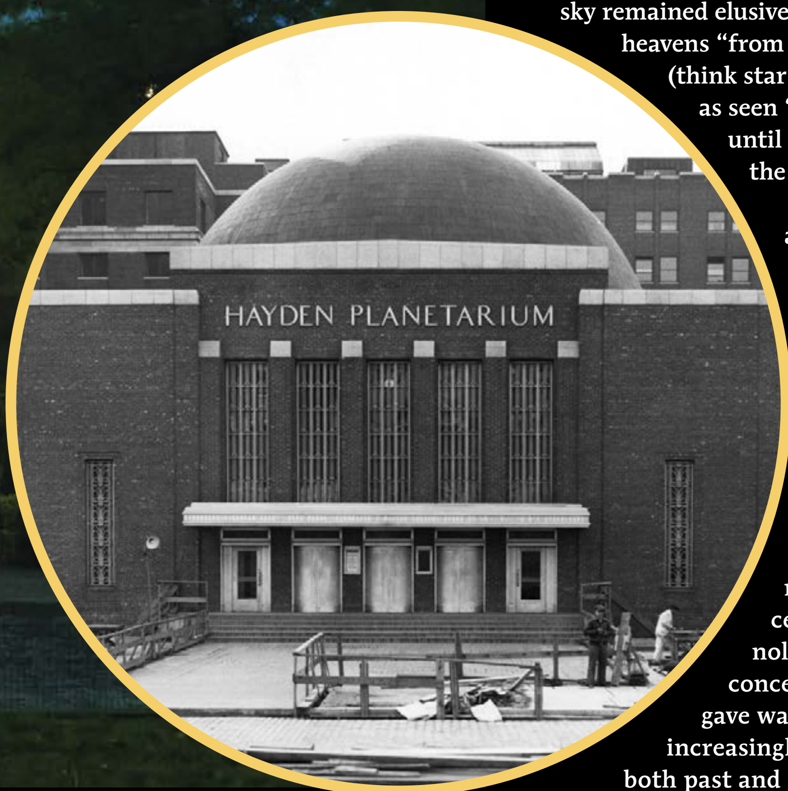
ARS IN THE DARK

As the Hayden Planetarium turns 90 years old this month, we revisit the colorful history of planetariums.

It has been a little more than a century since the public first witnessed nature's sky projected in a planetarium. A dome had been erected on the roof of the Deutsches Museum in downtown Munich, Germany, and within, a Zeiss star projector was working its magic. At last, the Wonder of Jena had faithfully recreated the experience of seeing a starry sky for an audience seated comfortably indoors!

Since then, the gasps of wonder first emitted in that dome have been repeated countless times as planetarium visitors the world over have thrilled to the sight of a star-filled sky — an experience that no other invention of humanity has ever been able to imitate.

Wealthy individuals have long endeavored to bring nature's diversity and beauty within reach of urban populations. This noble objective manifested itself in resources such as aquariums, botanical gardens, and zoos. But the night sky remained elusive. Although methods for viewing the heavens "from the outside" were rather common (think star atlases or orreries), showing the sky as seen "from the inside" would have to wait until October 1923 and the unveiling of the modern planetarium projector.



Today, the starry sky is no longer accessible to many. The planetarium has effectively become a museum where the sky is preserved. Widespread outdoor lighting has erased the stars from view, and for most the night sky would never be a source of wonder but for the planetarium experience.

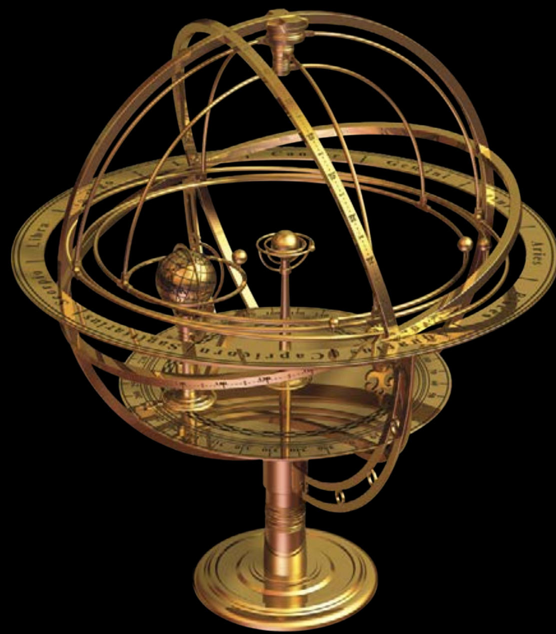
Planetarium Prehistory

Accurately recreating a natural night sky developed over several centuries keeping pace with technological advances. Gradually, purely conceptual models depicting the cosmos gave way to immersive environments, with increasingly reliable accuracy for depicting both past and future celestial events.

THEN: UNDERWOOD ARCHIVES / UIG / SCIENCE PHOTO LIBRARY;
NOW: BRIAN OVERCAST / ALAMY STOCK PHOTO

Maps, Models, and Globes

▲ **EARLY CELESTIAL SPHERE** The Farnese Atlas is the earliest example of a star map that we know of. It shows 42 of Ptolemy's 48 constellations, and in the orientation shown above we see Centaurus with Argo Navis to its left.



▲ **NASCENT PLANETARIUM** Armillary spheres, or mechanical models of the solar system, were the precursors to today's planetariums. The first ones appeared independently in ancient China and ancient Greece.

BIG ENOUGH TO SIT INSIDE This image shows a modern reproduction of the original Gottorp Globe that was sent to Saint Petersburg.

FARNESE ATLAS: CHRONICLE / ALAMY STOCK PHOTO; ARMILLARY SPHERE: KONSTANTIN SHAKLEIN / ALAMY STOCK PHOTO; GOTTORF GLOBE: HENRIK MADSEN / LANDESMUSEEN SCHLOSS GOTTORF

One of the oldest extant representations of the sky that we know of today is the Farnese Atlas, with most estimates dating it to around AD 150 (though there is ongoing debate that might place it earlier in time). It's a sculpted figure depicting Atlas holding a sphere that carries a relief map of the constellations.

The earliest models of the sky and its relation to Earth took the form of armillary spheres, and mechanical devices such as the tellurium and the orrery. Such celestial models were geocentric and were often elaborate constructions ranging in size from tabletop models — such as the simple classroom versions still used today to show the Sun, Earth, and Moon — to larger objects, which at the time included the elaborate machinery of the Rittenhouse Orrery.

The success of the planetarium in accurately reproducing the experience of viewing the sky and its changing appearance based on time and location has mostly relegated armillary spheres and orreries to the role of ornamental decorations in gardens and public places. Nowadays in museums, these devices often occupy the same space as Foucault pendulums and exhibits displaying the fantastical landscapes of other planets.

From 1774 to 1781, the Royal Eisa Eisinga Planetarium in Franeker, the Netherlands, housed an orrery that represented a conceptual middle step between mechanical models to be contemplated from without and those which surrounded the observer. Mechanisms behind walls and ceilings displayed both positional and temporal data in a visual analog to an almanac.

By the early years of the 20th century, two notable mechanical devices provided viewers with an immersive experience under a recreation of a starry sky. In Saint Petersburg, Russia, the Gottorp Globe at the Lomonosov Museum consisted of a globe large enough at 4 meters in diameter for several people to step inside. The inner surface bore a map of the constellations and a number of brighter stars. It was originally designed in the 17th century by German engineers, but shortly thereafter was sent to Russia at the request of Tsar Peter the Great.

In Chicago, the Atwood Sphere (currently housed at the Adler Planetarium) was an even larger construction — several people riding a cart would enter the globe, which then revolved around them. In the earlier days of the Atwood Sphere, candles were used to represent the brighter stars. These were eventually replaced by small lamps that illuminated holes on the globe's surface, simulating a star field that rotated.

Projecting Stars into the Future

By 1920, Walther Bauersfeld, an optical engineer at the Carl Zeiss optics company in Jena, Germany, was working on developing a system that employed a brilliant light source that projected tiny, starlike disks of light onto the interior of a large, hemispherical dome. The entire projection apparatus moved in a manner mimicking Earth's rotation. Smaller auxiliary projectors cast images of the Sun, Moon, and five planets onto the dome, accurately depicting their wanderings among the fixed stars. Yet another elaborate mechanism projected the Moon in its changing phases and positions.

The first unofficial demonstration of the Zeiss Mark I, or the Wonder of Jena as it came to be known, occurred in August 1923, in a temporary 16-meter dome atop the roof of the Zeiss factory. After this, it was installed in a 10-meter dome at the Deutsches Museum where on October 21, 1923, an enthusiastic public was treated to its first official showing.

THE GREATEST PLANETARIUM EFFECT OF ALL TIME

My first visit to a planetarium came when I had reached the age of six, old enough to be admitted to New York's Hayden Planetarium. That was a singular experience for me; the building and exhibits inspired feelings of reverence, awe, and amazed silence. Back then, the lecturer wore a suit and personally conducted us upstairs from the Copernican Room into the planetarium. By the end of that presentation, I'd experienced a totally dark sky for the first time, described patiently by "a voice from heaven" in deep and resonant tones. I approached the console behind which stood the "master of the universe" and swooned at the assortment of controls before him.

That day, my life changed. I never realized that two decades later I would share space in the lecturer's office with some of the giants who presented sky shows. Since those days I've been fortunate to enjoy the friendship of so many professionals who loved bringing their stories to eager audiences. Some of my longest professional and personal friendships came from that "temple to the sky," such as that with Contributing Editor Joe Rao (below, at right, with the author and the Hayden's Zeiss Mark VI).

Standing at the consoles of planetariums both large and small, I realized that no matter the sophistication of the equipment, it would almost always be possible to personalize the sky experience. It was a privilege for me to have the opportunity to do so for children and adults.

My four-plus decades behind consoles spanned what some have called the golden age of planetariums. Modern domed theaters are more technologically capable but often present programming unrelated to the sky. The audiences themselves have far less knowledge of the glorious skies above them, let alone an awareness of the cycles and changes that humans have relied on since the dawn of history. There's much work still waiting to be done in bringing to all people the greatest planetarium effect of all time — the stars.

SAM STORCH

The projector did another back and forth with Jena, where engineers applied finishing touches. After its final relocation at the Deutsches Museum in 1925, planetarium history was forever sealed.

Later projectors could show the sky from any latitude on Earth and demonstrated many additional phenomena — sunrise and sunset colors, the zodiacal light, and depictions of coordinate lines such as the celestial equator, the ecliptic, a precession circle and pole pointers. In addition, models such as the Mark VI were somewhat more stylized and adopted a gentler-on-the-eye appearance, such as abandoning a stark, black finish for a more modern blue tone. In addition, acctractive metal panels hid exposed girder structures from the public's view.

Others Enter the Game

While Zeiss was the first company to bring planetarium projectors to cities around the world, Armand Spitz, often called the "Henry Ford of planetariums," found ways to make smaller and much more affordable models, which could be installed in schools, colleges, and smaller museums. The October 1947 issue of *Sky & Telescope* advertised a Spitz Model A planetarium for $500. Spitz's timing was perfect: Following the Soviet Union's launch of Sputnik in 1957, thousands of schools and colleges installed planetariums as the dawn of the space race transformed science education.

During those years, Japanese manufacturers, such as Minolta and Goto Optical Company got into the game, developing planetariums for both larger and smaller domes. New companies sprang up dedicated to developing projectors with built-in special effects capabilities, preparing customized shows and music, as well as composing complete soundtracks. What with all the equipment out there, still others specialized in the servicing, maintenance, and modification of projectors and theaters.

As projector technology evolved, planetarium programs went beyond simply structured "lectures upon the stars" — a variety of special effects were added to enhance the audience experience. Now rapt visitors could be treated to aurorae, bolides, meteor showers, constellation outlines, lightning bolts, and even slowly moving artificial satellites. Planetarium operators welcomed the advantages that increasingly complex audiovisual control systems offered, for it reduced the daunting complexity of their task.

Eventually, programs using prerecorded soundtracks and narrations replaced live lectures for some shows, and by the 1970s the larger planetariums employed computers to automate many time-critical tasks. As a result, control consoles grew in size as additional panels were added to manage all of the developments in the technologies. Computers allowed for increasinlgy elaborate pre-programmed shows, bringing audiences enhanced planetarium experiences.

The Evolution of the Indoor Universe

Through the decades, the evolution in projection equipment and programming methods ushered in entirely new planetarium designs. For example, the projection of the Sun, Moon, and planets on the dome independently from the star projector itself eliminated many complicated mechanical gear-driven couplings. This in turn led to smaller, modern projectors consisting of a single star ball. Thanks to the increased programming flexibility this setup offers, just about anything can be added to the underlying star field — constellation outlines, simulations of changing weather, or even the sky as seen from other worlds.

The development of high-resolution digital projection technology eventually replaced the traditional "monster in the middle of the room." Early models employed computer screens and fisheye lenses to create digital star fields. These early models generated interesting viewing experiences, but the shows were plagued by dim stars that resembled tiny pixels jumping across the dome. In time, higher refresh rates and brighter sources made those early models obsolete.

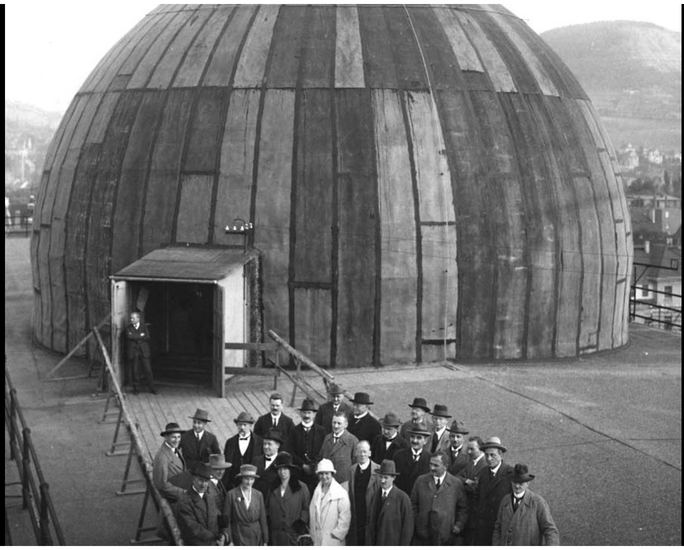
Digital projectors using LCD and laser technologies have

Planetarium Evolution

▶ **BEHOLD THE FIRST MODERN PLANETARIUM** *Left:* Eager visitors congregate for their visit to the first planetarium, which was eventually housed atop the Deutsches Museum in Munich, Germany. Originally produced at the Zeiss factory in Jena, still today it's referred to as the Wonder of Jena.

▶ **FIRST PROJECTOR** *Center:* The Zeiss Mark I was used to project visualizations of the sky onto the dome of the Jena Planetarium. Even as there have been subsequent iterations since then, the principal design remains the same.

▶ **ZEISS MARK IX** *Right:* Featured in many planetariums today, the Zeiss tradition continues strong. The image shows the Mark IX star ball, which is designed for large domes.



ZEISS ARCHIVES

▲ **GROUP EXPERIENCE** The Atwood Sphere allowed for several people to enter a spherical dome in a special cart. The sphere is 17 feet in diameter, and its surface is pierced by 692 holes.

begun to replace the traditional fisheye projectors. By the 1990s, new, smaller planetariums could replace older, worn-out projectors, enabling upgrades to some existing planetariums and for hobbyists to enjoy private planetariums in their homes! As well, some museums now exhibit obsolete projectors as records of both technology and history.

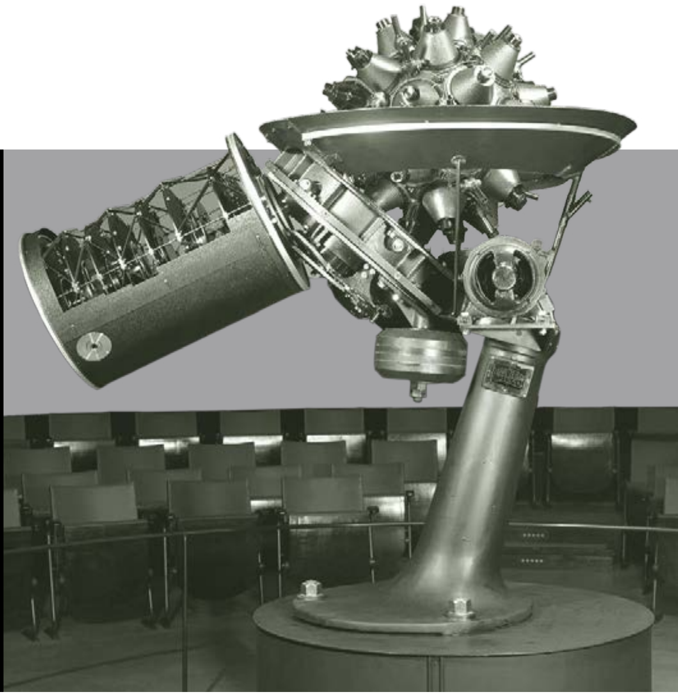
From Planetarium to Digital Theater

For a growing number of facilities, the evolution of technology allowing the projection of anything on the dome has led to a major conceptual transformation from planetarium to "digital theater." The most recent technological development has the entire hemispherical surface of the dome coated in LED display panels, obviating any need for a projector. Audiences still enter a room with a domed ceiling, but now they might be treated to live music accompanying the show, as there is no longer a traditional projector in the way of musicians. Sometimes the show might feature a complete dramatic production with live actors!

Today, some planetariums have dispensed entirely with programs that show the stars. Audiences certainly thrill to full-dome experiences as they fly through canyons, swim among fish, and marvel at celestial sources presented at different wavelengths. They can visit landscapes on other worlds both real and imaginary. Viewers report having "had fun," but the emotional reactions from audiences seeing a glorious, accurate, and unadorned sky are no longer heard. Having had the privilege of presenting live star shows in planetariums both large and small, with primitive equipment or with the very latest technology, I have never tired of the spontaneous delight from audiences both young and old when they see the starry sky gradually emerge from the twilight, patiently and lovingly revealed.

More than 100 years since the Wonder of Jena first impressed audiences, I earnestly hope that planetariums will not evolve into just another entertainment venue and extinguish that visceral emotion. No other device humanity has ever invented is a museum of the heavens, and no other place has given me so many opportunities to reveal the story of how the stars belong to everyone!

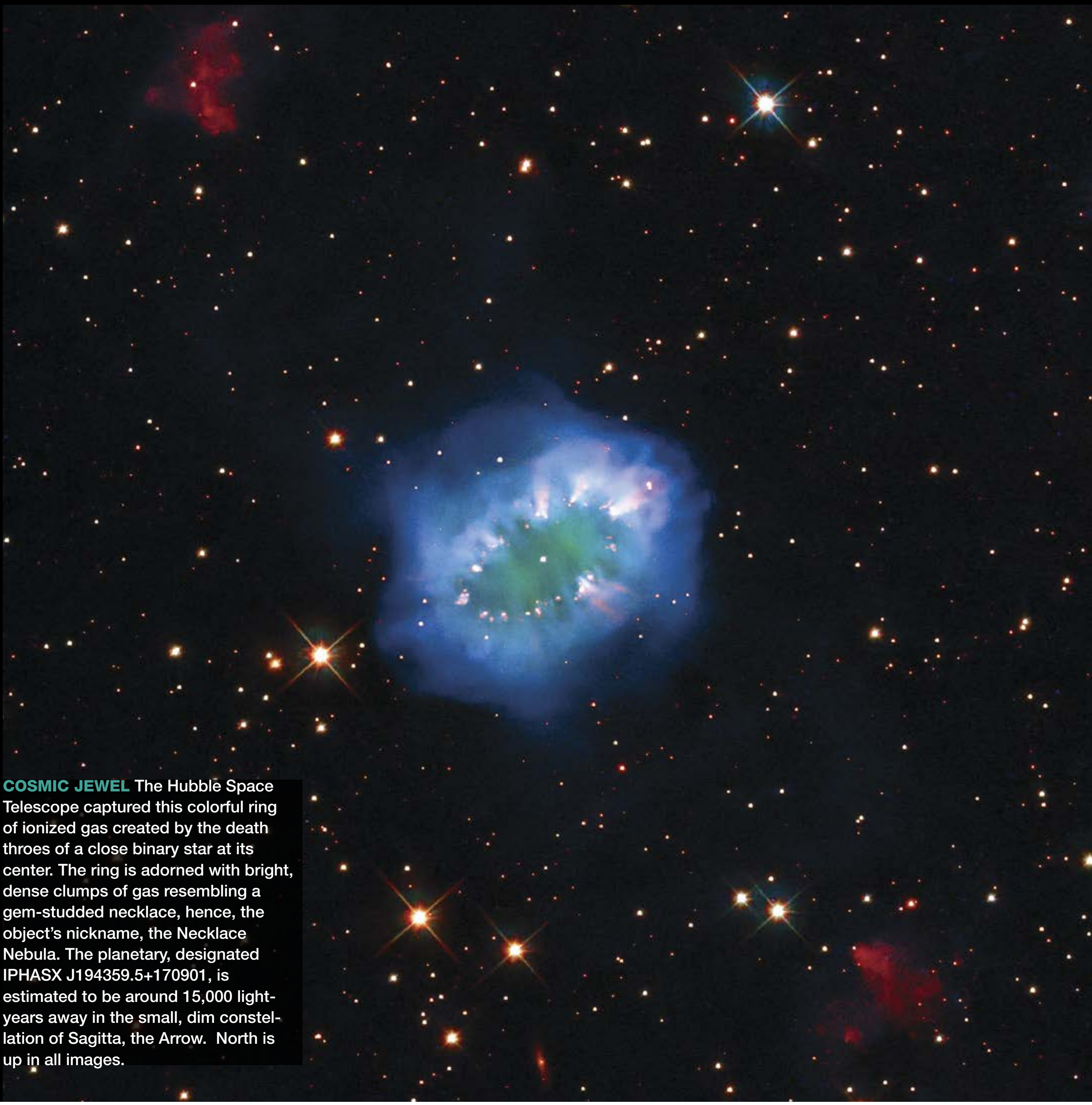
■ **SAM STORCH** put down his pointer in 2010 after more than four decades enjoying working in planetariums large and small. Storch is an elected Fellow of the International Planetarium Society, and received the Distinguished Service Award, the highest award given by the Middle Atlantic Planetarium Society, as well as a Special Service Award from the Northeast Region of the Astronomical League.



ATWOOD SPHERE: COURTESY OF THE ADLER PLANETARIUM; ZEISS MARK 1: ZEISS ARCHIVES; ZEISS MARK IX: ZEISS

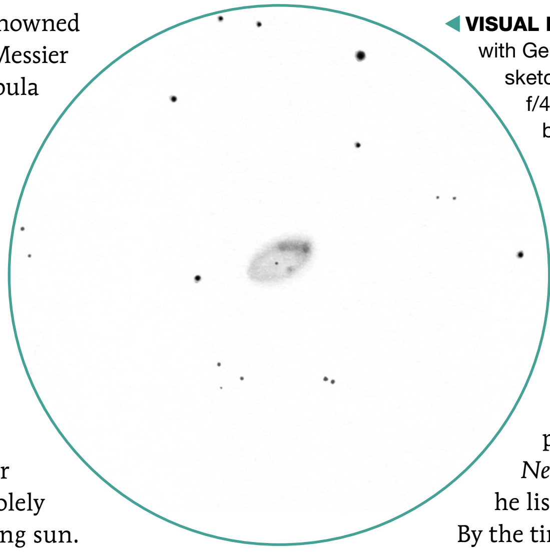
Tracking Down Obscure Planetary Nebulae

Looking for a visual challenge? Try these targets found in recent decades.



COSMIC JEWEL The Hubble Space Telescope captured this colorful ring of ionized gas created by the death throes of a close binary star at its center. The ring is adorned with bright, dense clumps of gas resembling a gem-studded necklace, hence, the object's nickname, the Necklace Nebula. The planetary, designated IPHASX J194359.5+170901, is estimated to be around 15,000 light-years away in the small, dim constellation of Sagitta, the Arrow. North is up in all images.

On the night of July 12, 1764, renowned French comet hunter Charles Messier discovered a 7.4-magnitude nebula in Vulpecula, the Fox, using a telescope with an aperture of 6.4 inches. At 104×, he noted that it “appears in an oval shape; it doesn’t contain any star; its diameter is about 4 minutes of arc.” He listed it as his 27th non-cometary find in his original catalog, which was presented to the French Academy of Sciences in 1771 (see *S&T:* June 2024, p. 76).



◀ **VISUAL IMPRESSION** Compare the Hubble image with German astronomer and artist Uwe Glahn’s sketch of the Necklace Nebula using a 27-inch f/4.2 Newtonian reflector at 977×. The nebula’s bright inner ring, shown in this drawing, spans about 2 light-years across.

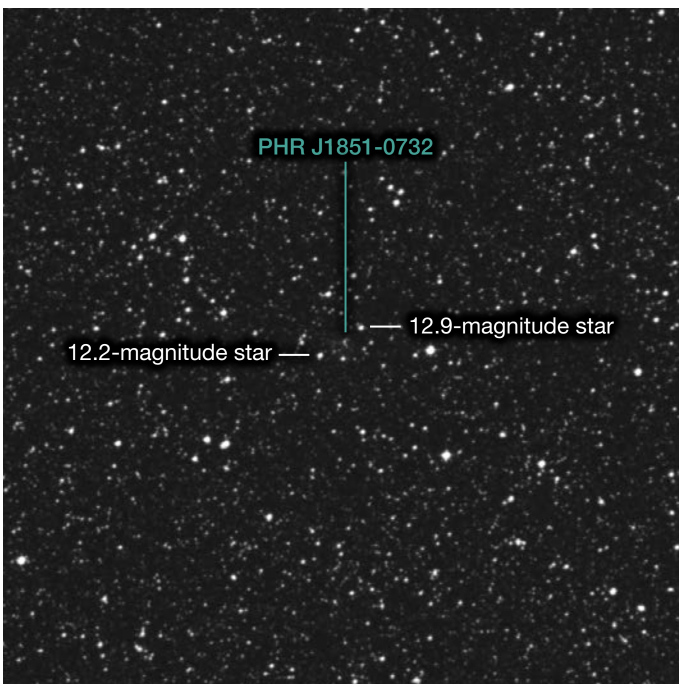
Unbeknownst to Messier, he discovered a kind of object that had never been seen before — a nebula created solely from the expelled outer layers of a dying sun. Intense ultraviolet radiation from the star’s leftover core ionizes the expanding nebula, causing it to glow — or fluoresce — and become visible.

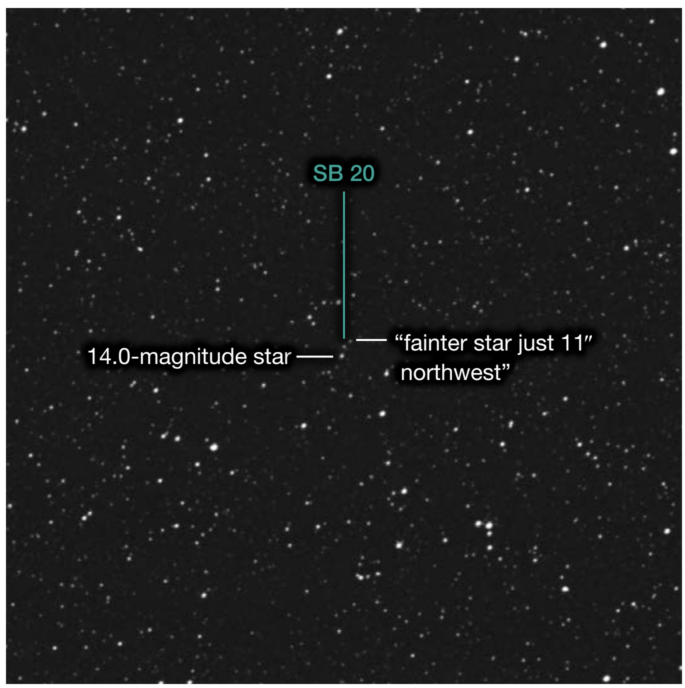
In the eyes of William Herschel and his son, John, however, Messier 27, as the object came to be known, wasn’t a true “planetary nebula” since it didn’t fit the definition of their term at the time. It lacked a round or oval disk with a clearly defined edge and uniform surface brightness. (We now understand that the term is a misnomer since these objects are totally unrelated to planets, but the name stuck.) Indeed, it wasn’t until exactly 100 years after M27’s discovery that British astronomer William Huggins recorded its spectrum and found it exhibited one of the same bright emission lines found in a handful of other known planetary nebulae, including NGC 6543 (the Cat’s Eye Nebula) in Draco, NGC 7009 (the Saturn Nebula) in Aquarius, and M57 (the Ring Nebula) in Lyra.

When John Louis Emil Dreyer published his *New General Catalogue of Nebulae and Clusters of Stars* in 1888, he listed a total of 94 planetary nebulae. By the time the second *Index Catalogue* was published in 1908, the number of such nebulae known in our Milky Way Galaxy had grown to 129. Fast forward to the 1990s and that number had increased tenfold.

Today, the count stands at more than 3,000, thanks to a multitude of spectroscopic and photographic surveys. While most planetaries discovered in the last 40 years are too faint to be seen in amateur telescopes and therefore less familiar to observers, I’ll take you on a tour of 10 nebulae that are sufficiently bright that I’ve seen them all using just my vintage 10-inch Schmidt-Cassegrain telescope.

Many of the planetaries featured in this article don’t have their magnitudes listed in survey catalogs, so the figures given are based on my visual estimates.





▲ **ZOOM IN ON THE PLANETARIES** The planetary nebulae featured in this article are all small and faint, so keep your O III filter handy at the telescope to help boost their visibility. Use the following images from the STScI Digitized Sky Survey to help guide you to the objects’ exact locations (see the text for additional star-hopping instructions). The quotes refer to the author’s descriptions. The fields of view shown are approximately 15′ square.

NECKLACE NEBULA: ESA / HUBBLE & NASA / K. NOLL
FINDER DIAGRAMS THROUGHOUT THE ARTICLE: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY (10)

Hidden in the Scutum Star Cloud

The first target we'll visit happens to be so obscure that you won't find it plotted in either *Uranometria 2000.0* or the *interstellarum Deep Sky Atlas*. Lucky for us, **PHR J1851-0732** is a snap to find in the constellation Scutum, the Shield. The planetary lies 1.3° south of the impressively compact open cluster M11, also known as the Wild Duck Cluster.

Earlier this year, I chased down PHR J1851-0732 for the first time. Using my 10-inch at 135×, I found its location with a detailed star chart in hand but only saw a 12.2-magnitude star with a 12.9-magnitude star 1.1′ northwest. I then threaded on my oxygen III (O III) filter to the eyepiece, and voilà! — with averted vision, a roughly 16th-magnitude, 40″-wide disk suddenly popped into view between the two stars.

So, how did I know about this planetary? Well, for this one and all the rest that we're going to visit, I learned about them from California observer Kent Wallace's 2016 tome *Visual Observations of Planetary Nebulae*. In fact, Wallace believes he made the very first visual sighting of PHR J1851-0732 in 2007 with his 20-inch Dobsonian. Although the object's first spectroscopic observation was made in 2000, its discovery wasn't published in a catalog until 2006.

Archer's Delights

Although they're getting low in the southwestern sky, you can still catch our next two targets in Sagittarius, the Archer. The first object is called **SB 20**. In 1996, Sylvie Beaulieu (Laval University, Québec, Canada) published a list of 28 newly discovered planetary nebulae in her PhD thesis. She and her colleagues found them as part of a survey of the Milky Way's galactic bulge to better study the kinematics of that region. It's not known with certainty, but SB 20 could lie some 9,000 light-years away.

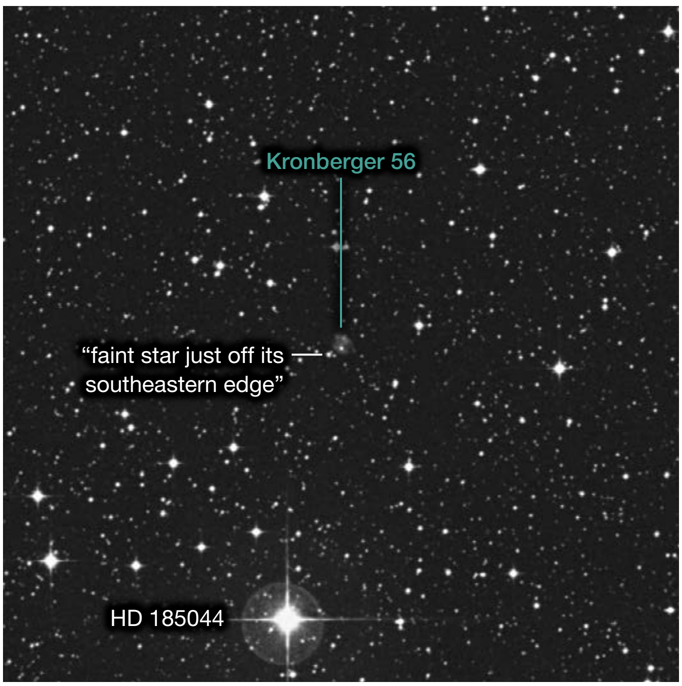
SB 20 is situated 4.3° east-southeast of the coarse, naked-eye open cluster M25. To find it, first center 5.2-magnitude 29 Sagittarii at low power before carefully star-hopping 27′ northward. With my 10-inch at 260× and an image from the Digitized Sky Survey (DSS) in hand, I'm able to find its exact location 12″ north of a 14.0-magnitude field star. There, I see a 15.1-magnitude glint, which is actually the planetary's metal-poor central star. Backing down to 200× and adding an O III filter, the central star now appears almost like its 14.0-magnitude neighbor.

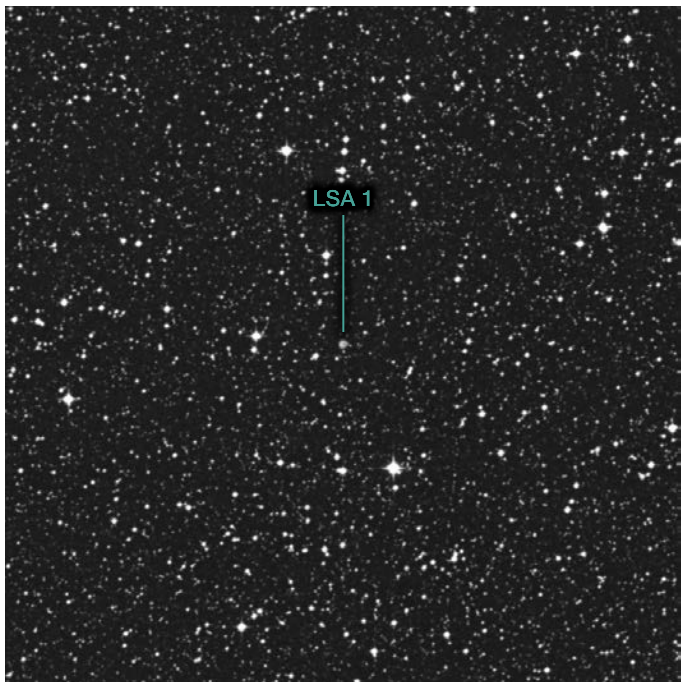
Using my 16-inch Dobsonian at 300×, the central star is easily visible and surrounded by a soft, compact glow. Plus, I can now see a fainter star just 11″ northwest of it. Images reveal that the shell extends out to the star below and above it.

Matthias Kronberger, an Austrian amateur astronomer, discovered our next target while perusing DSS images in 2009. Known as **Kronberger 56** (Kn 56), this planetary nebula holds a special place in my heart since it's the only one I've seen in my 10-inch that was discovered shortly after I fell in love with astronomy in 2008. Kn 56 is located 1.9° northwest of the well-known Local Group galaxy NGC 6822 and 6.2′ north-northwest of the 6.9-magnitude star HD 185044. On nights with great sky transparency, I can see Kn 56 as a small, 14th-magnitude disk in my 10-inch at 94× with the aid of an O III filter. Increasing to 140× and removing the filter, the nebula is still visible, with a faint star just off its southeastern edge. When I use my 16-inch at 300×, the 20″ disk displays an even surface brightness, and I could catch glimpses of a very faint star stuck in the southern edge of the disk.

Flying North

Aquila, the celestial Eagle, is home to many planetary nebulae as its wings spread across a rich part of the Milky Way. In fact,



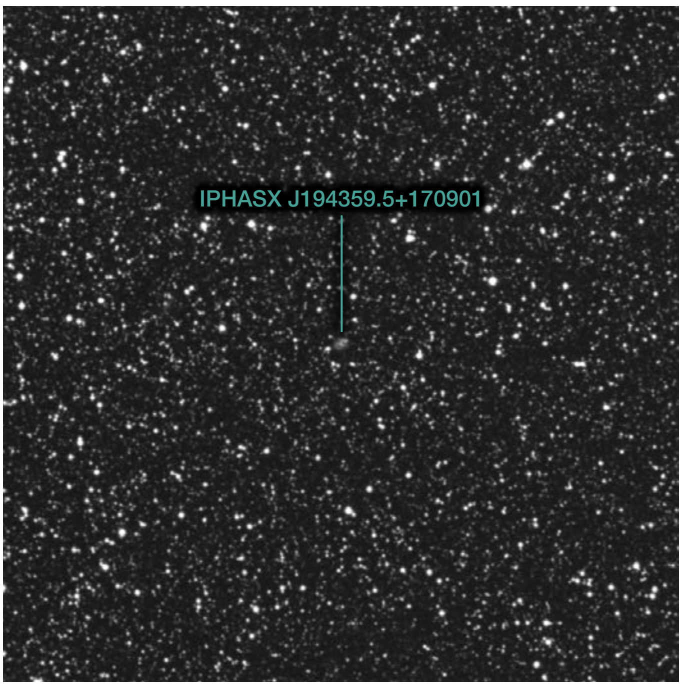


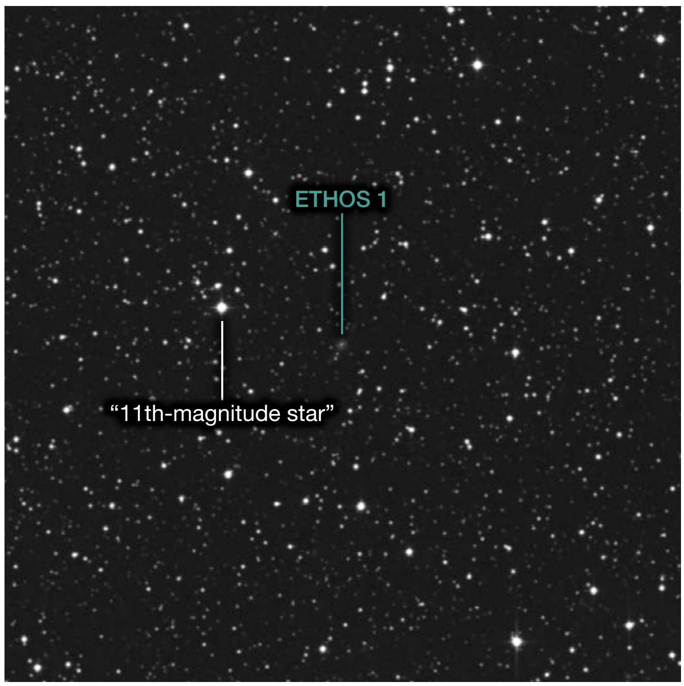
▶ **TUCKED AWAY IN LYRA** While the central star of ETHOS 1 stands out in images, it takes telescopes of 25 to 30 inches of aperture to confidently see it. Texas backyard amateur astrophotographer Gary Imm recorded the 15th-magnitude planetary nebula with an 11-inch Celestron EdgeHD telescope, a ZWO ASI294MM Pro camera, and Astrodon hydrogen-alpha, oxygen III, and RGB filters.

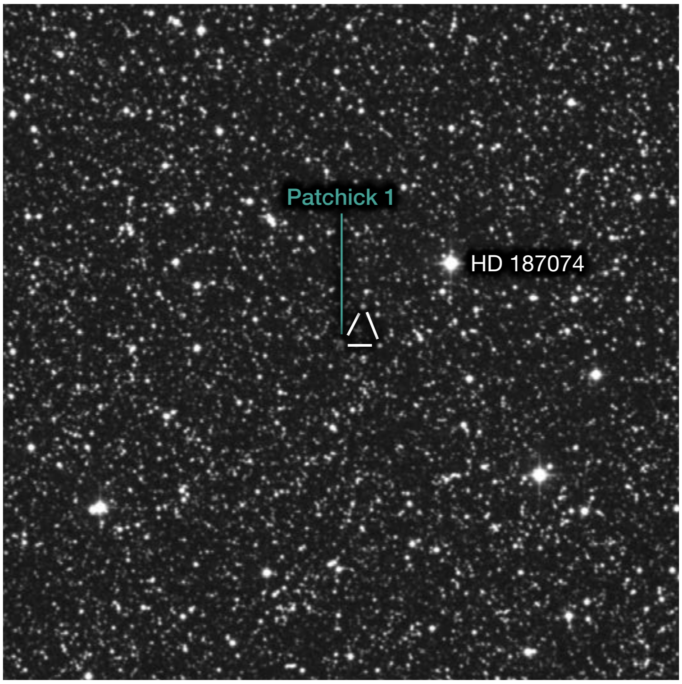
I've observed around two dozen of them, including one that wasn't identified until 1988. It carries the short, nondescript designation **LSA 1**, which stands for Ingemar Lundström, Björn Stenholm, and Agnès Acker. This trio of European astronomers published a paper in *Astronomy & Astrophysics* confirming the object's identity after its spectrum had been first detected on an objective-prism plate in 1973.

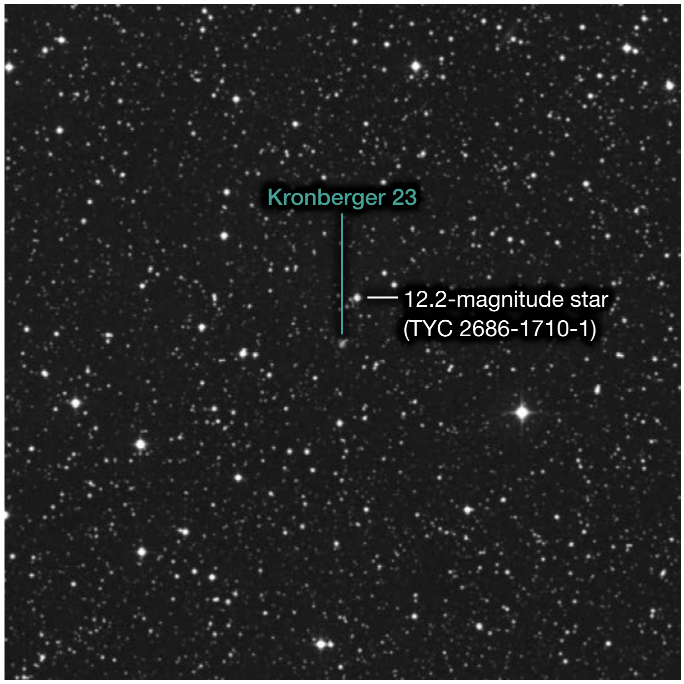
LSA 1 is the only planetary on our tour that you'll find in *Uranometria 2000.0*, specifically the second edition, published in 2001. The planetary resides 2.4° southeast of 3rd-magnitude Lambda (λ) Aquilae and almost 30′ southwest of the 6.6-magnitude star HD 180086. With a lot of effort, I can see it in my 6-inch reflector at 224× as a 15th-magnitude star. With more aperture, LSA 1 shows a noticeable brightening when using an O III filter. Earlier this year, on a morning with great seeing, I was able to view it as a diminutive disk with my 10-inch at 400×.

Staying in the band of the Milky Way and moving north of Aquila, the next constellation you'll meet is Sagitta, the Arrow. It harbors a planetary with the rather convoluted name **IPHASX J194359.5+170901**. Thankfully, the astronomers who discovered the object gave it a catchy nickname: the Necklace Nebula. They came up with this moniker after images taken through a singly ionized nitrogen (N II) filter revealed relatively bright knots in the nebula's ring. The Necklace Nebula was found in images taken in 2005, during a special hydrogen-alpha survey that sought to find highly









reddened (dust-obscured) planetaries. Studies have since shown that we see the ring 31° from face-on and that its central star is a close binary with a carbon-rich secondary.

The Necklace Nebula is located just 0.8° southeast of 4.4-magnitude Beta (β) Sagittae. When I pointed my 10-inch at its exact location for the first time, I couldn't see anything at 94×. It wasn't until I increased the magnification to 200× that I caught glimpses of it. Boosting the magnification to 260×, the object looked like an out-of-focus 15th-magnitude star. However, I found that the nebula responded so incredibly well to my O III filter that I was able to see it even when I backed down to just 94×! When I examined the planetary with my 16-inch at 300×, I couldn't discern any elongation nor knots in its ring. However, German amateur astronomer and artist Uwe Glahn has seen both of these features in his 27-inch Dobsonian.

Ever hear of the Extremely Turquoise Halo Object Survey (ETHOS)? It was designed to detect compact planetary nebulae at high galactic latitudes, and the survey's first confirmed find was published in 2009 as **ETHOS 1**. It lies 11° above the galactic plane in Lyra, but you won't find it on any paper star atlas.

To seek out ETHOS 1, look east of Lyra's famous parallelogram-shaped asterism for the 5th-magnitude variable star Iota (ι) Lyrae. From there, the planetary lies just 1.9° farther east. In my 10-inch at 140× and with an O III filter, it appears as a small, 15th-magnitude nonstellar disk 2.7′ west-southwest of an 11th-magnitude star. Pumping up the magnification to 260× and removing the filter, the planetary isn't terribly difficult to see as a tiny, soft glow if you know exactly where to look!

Images show a spectacular pair of jets emanating in opposite directions from the object's roughly 900-year-old central region. However, the jets not only appear detached from it, but they are thought to be much older. A close binary star with an orbital period of a little more than half a day was discovered at ETHOS 1's center, leaving astronomers with a puzzle as to how the binary created the jets.

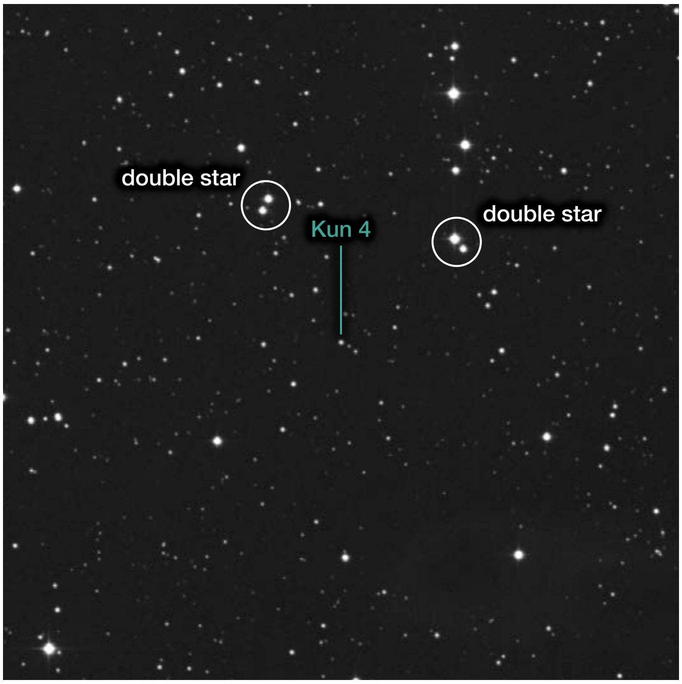
The Celestial Swan

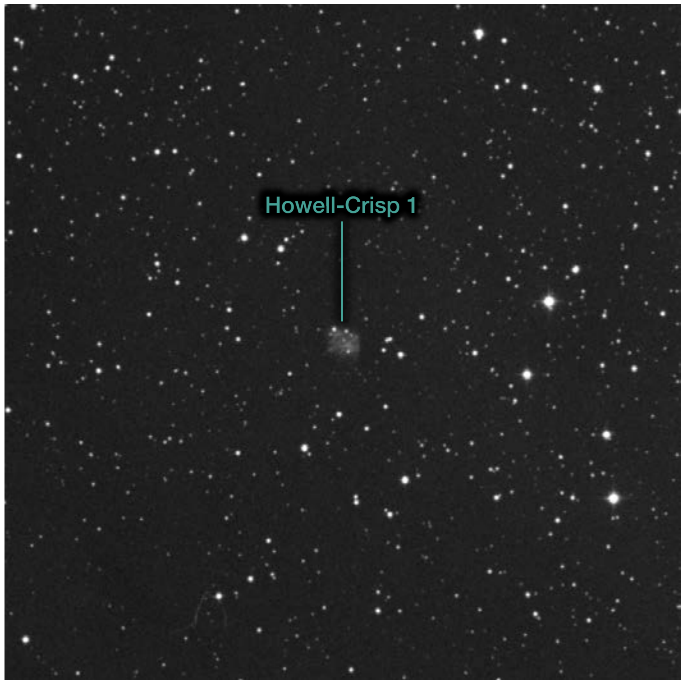
This magazine's Pro-Am Conjunction column featured accomplished California amateur astronomer Dana Patchick in its November 2022 issue (page 57). Since that article appeared, I've used my 10-inch to observe what is likely his brightest planetary nebula discovery to date — **Patchick 1** (Pa 1). He found it in 2003, while scouring digital versions of the Palomar Observatory Sky Survey.

To see Pa 1 for yourself, you'll need to venture into Cygnus and zoom in on the fine double star Albireo, or Beta Cygni. After admiring the double in my 10-inch, I use the scope's 8×50 finder to push about 2° northeast. After both 9 Cygni and Phi (φ) Cygni enter the field, I head 2.6° east of 9 Cygni.

Pa 1 lies in a rich star field, 3′ southeast of the 8.2-magnitude star HD 187074 and forms one of the corners of the equilateral triangle that's about 54″ on a side. With patience and care, I was able to catch the planetary this past spring at 260× as a very small, 16th-magnitude diffuse disk. I didn't need a filter to confirm it because the DSS image that I had with me made the object's identification certain. Amazingly, the seeing that morning happened to be so good that I was

▶ **HIDDEN GEM IN GEMINI** In 2006, using an 80mm f/6 refractor and CCD camera, Michael Howell was able to spot a tiny, previously unnoticed blob in Gemini. It stood out thanks to Richard Crisp, who helped pioneer the use of narrowband filters among amateur astro-imagers. London-based astrophotographer Peter Goodhew captured this view of the pair's planetary nebula discovery, called Howell-Crisp 1, from his remote observatory in southern Spain with his APM-LZOS 152/1200 apochromatic refractor, QSI 6120wsg-8 camera, and Astrodon Hα, O III, and LRGB filters.


double star
Kun 4
double star


Howell-Crisp 1

able to use 400× to see Pa 1 as a soft-edged disk of uniform surface brightness.

Kronberger found our next challenge in 2005, while inspecting survey images. Now known as **Kronberger 23** (Kn 23), it takes determination to find the nebula, which lies 2.5° west-northwest of 52 Cygni and the intricate western section of the Veil Nebula (NGC 6960).

To locate Kn 23, scan 13′ south of 8.5-magnitude HD 334625 to find the 12.2-magnitude star designated TYC 2686-1710-1. From there, Kn 23 is only 1.1′ south-southeast of TYC 2686-1710-1. Without using an O III filter, it's not visible in my 10-inch until I reach 260×, which reveals it as a 16th-magnitude, soft-looking "star." In my 16-inch, Kn 23 was barely visible as a stellar spot at 70× with an O III filter, but not without it.

A Jewel in the Dragon

I'm excited to introduce you to our next target in Draco since, as far as I'm aware, it's the brightest planetary nebula that's been discovered in the last 40 years. Plus, at a declination of +68°, **Kun 4** is circumpolar for many northern observers.

In 1998, Hungarian astronomer Mária Kun published a study on the star-formation activity in the Cepheus Flare, a large molecular cloud that harbors such gems as NGC 7023, the Iris Nebula. Included in the study was a list of candidate pre-main-sequence stars that were discovered in the region with an objective prism. Within the next decade, Kun performed optical spectroscopy and found that the fourth object on her list was actually a planetary nebula!

Kun 4 lies 2° east of 4.5-magnitude Rho (ρ) Draconis. In my 5.1-inch Dobsonian reflector at 59×, Kun 4 is accompanied by two nice pairs of double stars of similar magnitude and identical separation — one 3.5′ north-northeast and the other, 3.5′ northwest. The planetary is visible with averted vision as a "star" of similar brightness to other 14th-magnitude stars in the field. It's when you add an O III filter that Kun 4 reveals its true identify by suddenly appearing brighter. In my 10-inch, however, it remains stellar at all magnifications.

If you find that last one a little too small for your taste, you'll be happy to know that our final target spans about 1′ in size. **Howell-Crisp 1** (HoCr 1), as it is known, resides in western Gemini. Although the constellation doesn't rise until late this year, hang on to this issue and use it as a field guide to track down HoCr 1 as the planetary nebula climbs higher in the eastern sky.

Amateur astrophotographers Michael Howell and Richard Crisp each noticed the object on wide-field images they had taken in early 2006 of the area around Mu (μ) and Eta (η) Geminorum. Later that year, Crisp captured a higher-resolution image of it using an 18-inch Cassegrain. They then reached out to professional astronomers who provided them with an image taken with the 3.5-meter WIYN telescope at Kitt Peak, Arizona, confirming their discovery.

HoCr 1 lies 1.1° north-northeast of Mu and 10.5′ south-southwest of the 7.4-magnitude star HD 44251. In my 10-inch at 117× with an O III filter, it's visible as a small, 14th-magnitude disk. At 260× and without the filter, its disk is very faint and has an irregular surface brightness.

I know many of the planetary nebulae in this tour aren't easy. But if you're like me, you'll get a thrill out of seeing an object that was discovered only in the last few decades. It's akin to seeing a recently discovered comet, except that planetaries stay visible for generations instead of months. And who knows, maybe you'll find the next one!

■ Contributing Editor **SCOTT HARRINGTON** is happy to share planetary nebula sightings with readers who reach out to him at **sn4ark@gmail.com**.

A Tour of Planetary Nebulae

Object	Designation	Constellation	Mag	Size	RA	Dec.
PHR J1851-0732	PNG 026.2-03.4	Scutum	16th	45″ × 35″	18^h 51.5^m	–07° 32′
SB 20	PNG 014.8-08.4	Sagittarius	16th	19″ × 17″	18^h 49.4^m	–19° 52′
Kronberger 56	PNG 025.4-16.4	Sagittarius	14th	40″ × 25″	19^h 37.7^m	–13° 51′
LSA 1	PNG 029.8-07.8	Aquila	15th	14″	19^h 13.9^m	–06° 19′
IPHASX J194359.5+170901	PNG 054.2-03.4	Sagitta	15th	125″ × 25″	19^h 44.0^m	+17° 09′
ETHOS 1	PNG 068.1+11.0	Lyra	15th	19″ × 63″	19^h 16.5^m	+36° 10′
Patchick 1	PNG 065.2+02.2	Cygnus	16th	14″ × 12″	19^h 47.0^m	+29° 30′
Kronberger 23	PNG 072.3-05.3	Cygnus	16th	19″ × 15″	20^h 34.4^m	+31° 19′
Kun 4	PNG 101.9+17.0	Draco	14th	1″	20^h 23.6^m	+68° 07′
Howell-Crisp 1	PNG 188.6+04.4	Gemini	14th	73″ × 59″	06^h 21.7^m	+23° 35′

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 estimates by the author.

SKY AT A GLANCE
October 2025

5 **DUSK:** Face east-southeast to see the waxing gibbous Moon some 2° upper left of Saturn. The view becomes more dramatic as twilight deepens. Turn to page 46 for more on this and other events listed here.

9 **EVENING:** The waning gibbous Moon and the Pleiades rise together above the east-northeastern horizon. Moonlight overwhelms the scene, but binoculars should help tease out the cluster stars.

12 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 9:42 p.m. PDT (see page 50).

14 **MORNING:** Turn to the east to see a pretty, equilateral triangle with 6½°-long sides formed by the last-quarter Moon, Jupiter, and Pollux.

15 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 9:30 p.m. EDT.

16 **MORNING:** The waning crescent Moon leads Regulus above the eastern horizon by roughly 4°.

19 **MORNING:** The soft glow of the zodiacal light should be visible from dark locations at mid-northern latitudes beginning about two hours before sunrise. In the next two weeks, look toward the east for a tall, hazy pyramid of pale light stretching from Cancer through Gemini and into Taurus and beyond.

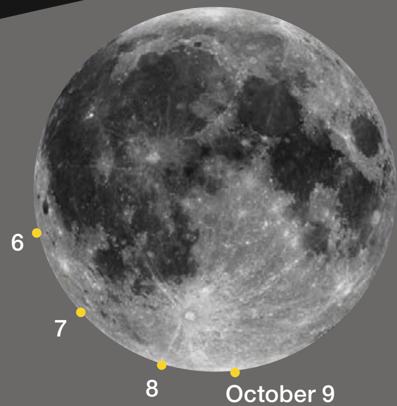
19 **DAWN:** The Moon, two days shy of new, accompanies Venus rising in the east. The thin lunar crescent is a bit less than 4° upper right of the planet.

20–21 **ALL NIGHT:** The Orionid meteor shower is expected to peak. The new Moon augurs favorable viewing conditions. Go to page 49 for more details.

24 **DUSK:** The waxing lunar crescent and Antares adorn the southwestern horizon. The Moon hangs about 1½° below the celestial Scorpion's smoldering heart. Observers in Australia and New Zealand are treated to an occultation event as the Moon eclipses the star.
—**DIANA HANNIKAINEN**

▶ The full Moon rises on September 19, 2013, above the Juan de Fuca Strait between Victoria, British Columbia, and Washington State. GARY SERONIK

OCTOBER 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	31	

FULL MOON
October 7
03:48 UT

LAST QUARTER
October 13
18:13 UT

NEW MOON
October 21
12:25 UT

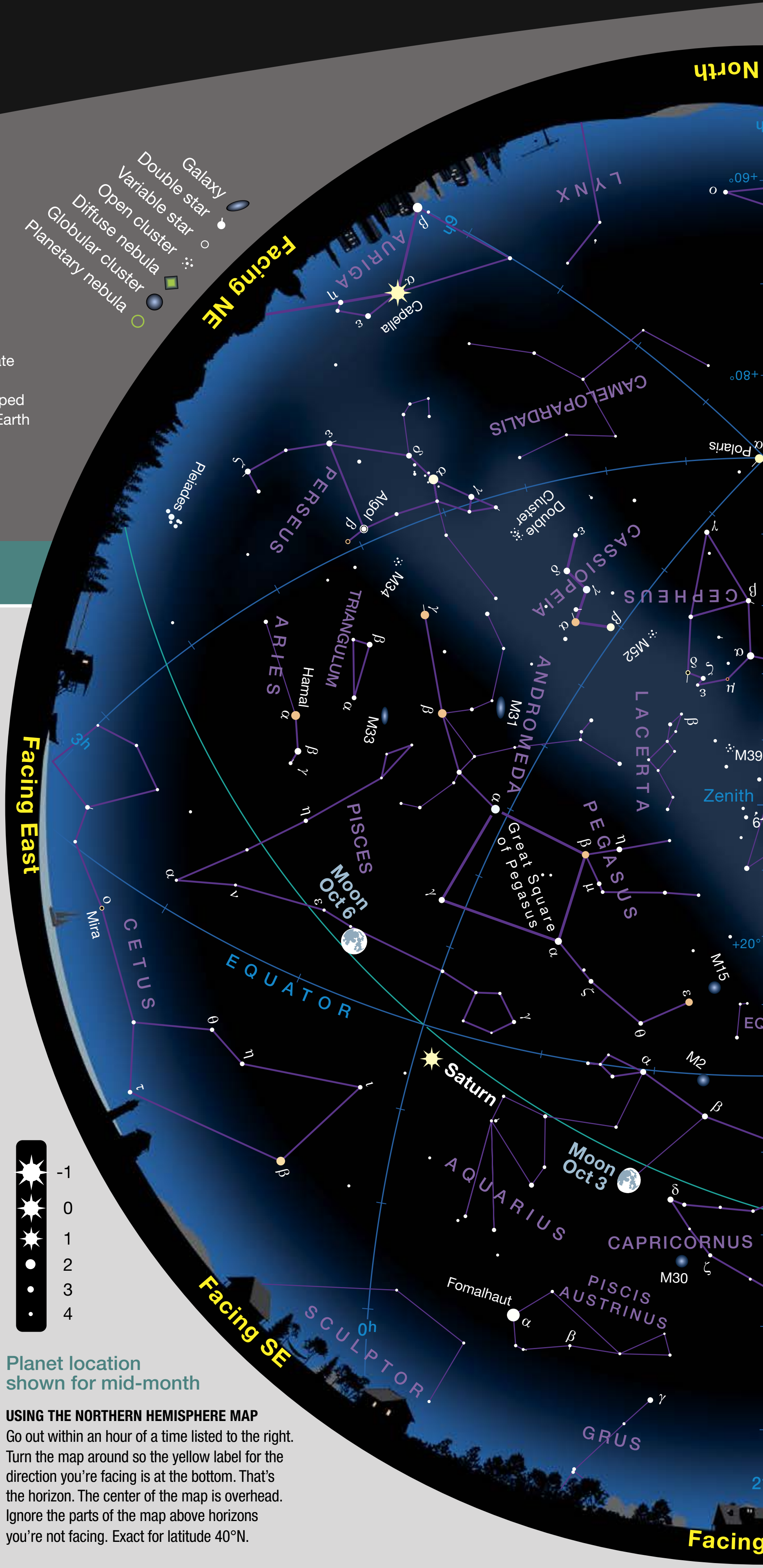
FIRST QUARTER
October 29
16:21 UT

DISTANCES

Perigee	October 8, 13^h UT
359,820 km	Diameter 33′ 13″
Apogee	October 24, 0^h UT
406,444 km	Diameter 29′ 24″

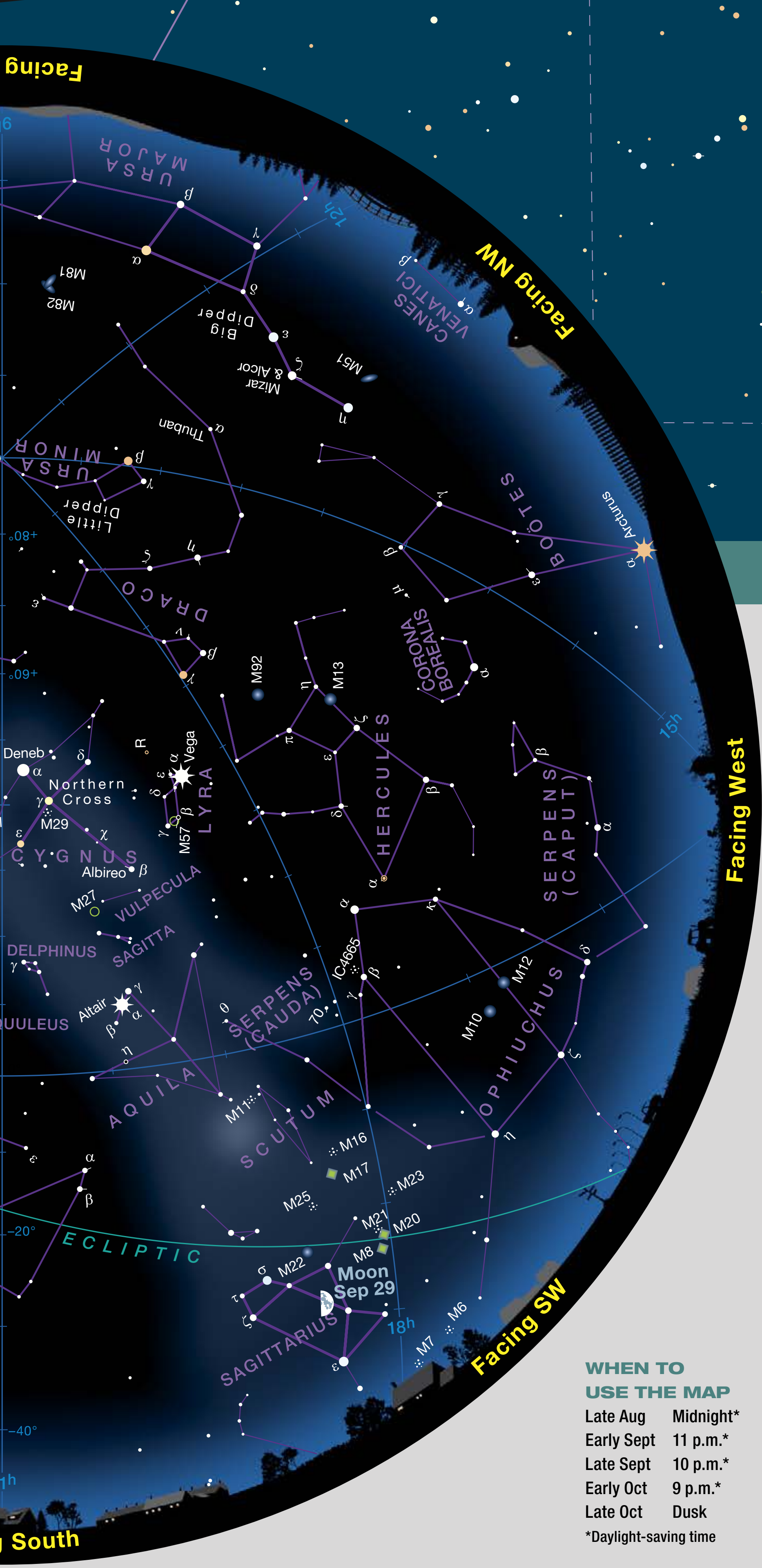
FAVORABLE LIBRATIONS

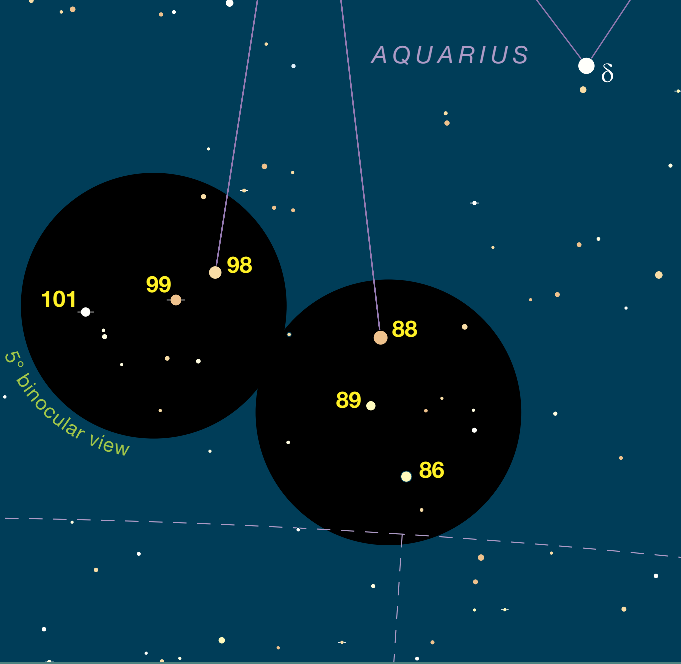
• Rocca Crater	October 6
• Baade Crater	October 7
• Hausen Crater	October 8
• Schomberger Crater	October 9



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

*Daylight-saving time

Binocular Highlight by Mathew Wedel

Asterisms in Aquarius

I don't often cover asterisms in this column. Because they're simply chance groupings of stars, asterisms tell us more about our own capacity for pattern recognition than they do about the nature of the cosmos itself. But stargazing is a human activity, and some asterisms are so instantly recognizable and vivid that they become familiar landmarks as we navigate the night sky.

I recently encountered a distinctive pair of short arcs of stars in southeastern Aquarius, the Water Bearer. Some depictions show these arcs as the bottoms of the streams spilling out of the water jar, and with their near-mirror-image similarity they jumped out at me in my binoculars. Each arc is formed by three sets of 4th- and 5th-magnitude stars. The eastern one is comprised of 98, 99, and 101 Aquarii, while the western set includes 88, 89, and 86 Aquarii. Each arc is a little more than 2½° long, and the two arcs are separated by about 4°.

Interestingly, all six asterism stars are big. The two smallest, 86 and 89 Aquarii, are *G*-type stars broadly comparable to our Sun. However, 101 Aquarii is an *A*-type star, having more than twice the mass and diameter of the Sun. All the rest are *K*-type orange giants, with sizes ranging up to 30 solar diameters. I was raised on the notion that the Sun is a small-to-middling kind of star, but with our improved ability to detect dwarf stars, we now know that it's larger than 95% of the stars in the universe.

It's simply human nature that the brightest lights in the night sky attract our attention — a useful reminder that when we look up, our perception is skewed towards the extraordinary. But that's what makes asterisms fun binocular targets!

■ **MATT WEDEL** is haunted by the thought of all the impossible-to-observe dwarf stars he can't see.

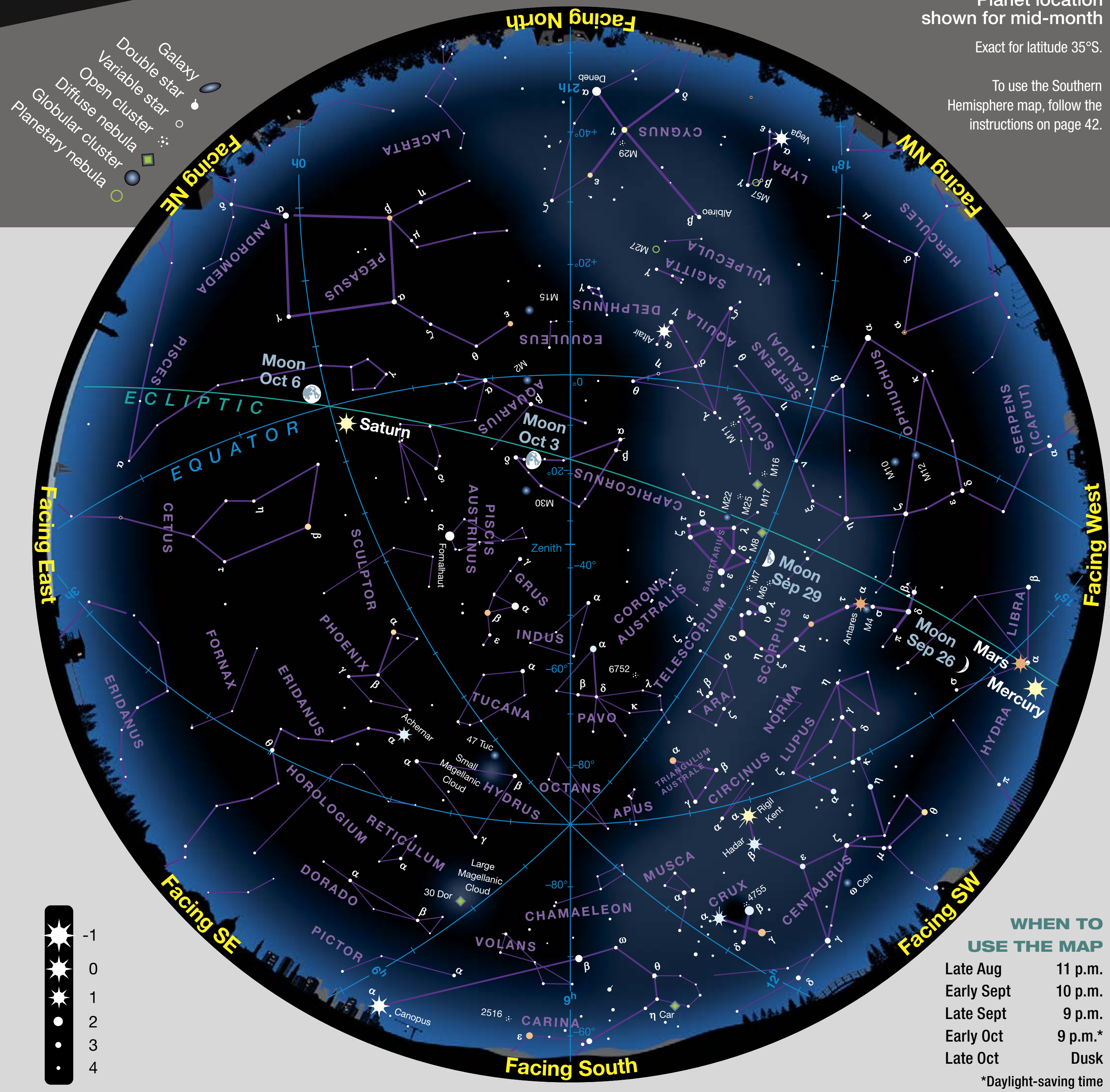
Southern Hemisphere Sky Chart

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 Aug	11 p.m.
Early Sept	10 p.m.
Late Sept	9 p.m.
Early Oct	9 p.m.*
Late Oct	Dusk

*Daylight-saving time

ABOUT HALFWAY BETWEEN the celestial equator and the south celestial pole lies the constellation Grus, the Crane. Its relatively northerly position means at least some of its stars are within reach of everyone in the contiguous U.S. Grus is one of four constellations collectively known as the southern birds, the others being Tucana (the Toucan), Phoenix (the Phoenix), and Pavo (the Peacock).

The constellation's brightest light is Alpha (α) Gruis, a bluish-white, 1.7-magnitude star that's both four times larger and four times more massive than our Sun. The next brightest, Beta (β), is a slightly variable (magnitude 2.0 to 2.3) red giant about 150 times the diameter of the Sun. Bluish-white giant Gamma (γ) shines at magnitude 3.0, while white subgiant Epsilon (ε) is at 3.5. All four are labeled on the chart above. ■

Celestial Reptiles and Amphibians: Creatures of Spirit

You'll need to search high and low for these stellar vertebrates.

▲This illustration from Johannes Hevelius's *Firmamentum Sobiescianum sive Uranographia* star atlas depicts the first time the constellation Lacerta was introduced to the public.

Snake, turtle, frog, crocodile, and salamander. Let's use different cultural interpretations of the night sky to scout out these celestial creatures. All appear on this month's Northern Hemisphere star chart on pages 42–43.

We'll start in the west, where Ophiuchus, the Serpent Bearer, dominates the celestial landscape. In Roman mythology, Ophiuchus is Aesculapius, the god of medicine. We see him in the sky holding Serpens, the Serpent. As told in the 1935 translation of *Poeticon Astronomicon* by Roman mythographer Gaius Julius Hyginus, Aesculapius's association with the serpent originates from a story in which he witnessed a living snake revive a dead snake by placing a special herb on the latter's head. Through this action, Aesculapius discovered the cure for death. After he used the cure, Jupiter smote Aesculapius with a lightning bolt, so he could not raise the dead again. Then, Jupiter gave him a place in the sky as guardian of the snake.

Just east of the Serpent's tail shines 1st-magnitude Altair. Classically, it belongs to Aquila, the Eagle. But Altair and its two attendants can also be imagined as the belly of a celestial Crocodile, with Aquila's southeastern wingtip as the reptile's tail. In a modern interpretation of an African Bantu myth, each time the Sun sets, a giant crocodile on the western edge of the Earth swallows it. Then the crocodile swims below the horizon with the Sun in its belly until it reaches the eastern edge, where it excretes the orb at sunrise. With this in mind, it's not difficult to view Altair as the burning Sun in the crocodile's belly.

Look now toward the *zenith,* the point directly overhead, for Cygnus, the Swan. As depicted in the 2017 edition of Ronald Goodman's book, *Lak̇ot̄a Star Knowledge: Studies In Lak̇ot̄a Stellar Theology,* 1st-magnitude Deneb and the constellation's wings form *Agleṡk̄a,* the Salamander. The amphibian looks toward *Keya,* the Turtle, whose shell is represented by the Great Square of Pegasus. According to native tradition, when a child was born, its umbilical cord was placed in a beaded pouch, either in the shape of a salamander for a boy or a turtle for a girl. Prayers were then addressed to the Salamander and Turtle spirits — which reside in their respective constellations — in order to ask them to bestow their power or essence on the child, such as long life, steadfastness, and fortitude for a girl. As for the boy, just as the salamander can lose its tail, a boy needs to learn how handle loss, be resilient, and adapt.

Leap now to the low southern sky, to 1st-magnitude Fomalhaut in Piscis Austrinus, the Southern Fish, and 2nd-magnitude Diphda — the tail star of Cetus, the Sea Monster — labeled as Beta (β) on the star chart. To early Arab skywatchers, Fomalhaut and Diphda were known as the First and Second Frogs, respectively. Bedouin Arabs often named stars after specific animals, revealing their close connection to nature. Fomalhaut and Diphda likely represented *Hyla felix-arabica*, the Arabian tree frog, and may have symbolized the ability to adapt to a harsh climate. This vibrant green and gold desert amphibian, called a "true gem in the animal kingdom," survived and prospered by adopting an arboreal behavior, which offered it protection and a steady diet of insects.

Lastly, in a dim stretch of the Milky Way between Cygnus and Andromeda, the Chained Maiden, lies inconspicuous Lacerta, the Lizard. Polish astronomer Johannes Hevelius (1611–1687) introduced it in his star catalog. In *Firmamentum Sobiescianum sive Uranographia*, published in 1687, we see the lizard rendered with an alternative title: Stellio. Many modern sources associate the name with *Laudakia stellio* — a species of lizard known as the starred agama, for the black, star-shaped spots on its back. But was that Hevelius's intention?

In a 2022 *Journal of Zoological Sciences* article titled, "The Development and Etymology of Newt," Sanjay Kumar of the Indira Gandhi National Tribal University in Amarkantak, India, writes, "Latin had the name stellio for a type of spotted newt [an amphibian], now used for the species of the genus Stellagama [a lizard]." In the introduction to his catalog, Johannes Hevelius and his wife, Elizabeth, describe Lacerta as "a little animal of many colors, as if adorned with many little stars." It's arguable that Hevelius was giving us a choice when he titled the constellation: Lacerta sive Stellio — Lizard or Newt. You decide.

■ 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.

Eclipsed by the Moon

A trio of lunar occultations highlights October's night sky.

SUNDAY, OCTOBER 5

This evening as twilight fades, cast your gaze toward the east-southeastern horizon to watch the waxing gibbous **Moon** rising along with **Saturn**. This is Luna's closest pairing with a planet all month, though it has several notable stellar encounters too, as you'll read. Saturn shines brightly at magnitude +0.7 a bit more than 2° lower right of the Moon. Full Moon is only 30 hours into the future, so tonight we see the lunar disk 98% illuminated.

The Ringed Planet itself is just two weeks past opposition, which is why it shares the same patch of sky with the *nearly* full Moon — full Moon being the lunar version of "opposition." The two objects will continue to meet on a monthly basis with the Moon's illuminated face transitioning from gibbous, to first quarter, to crescent. When they have their final encounter of the current series next March, it's the new Moon that's near Saturn, though both are too close to the Sun to view.

THURSDAY, OCTOBER 9

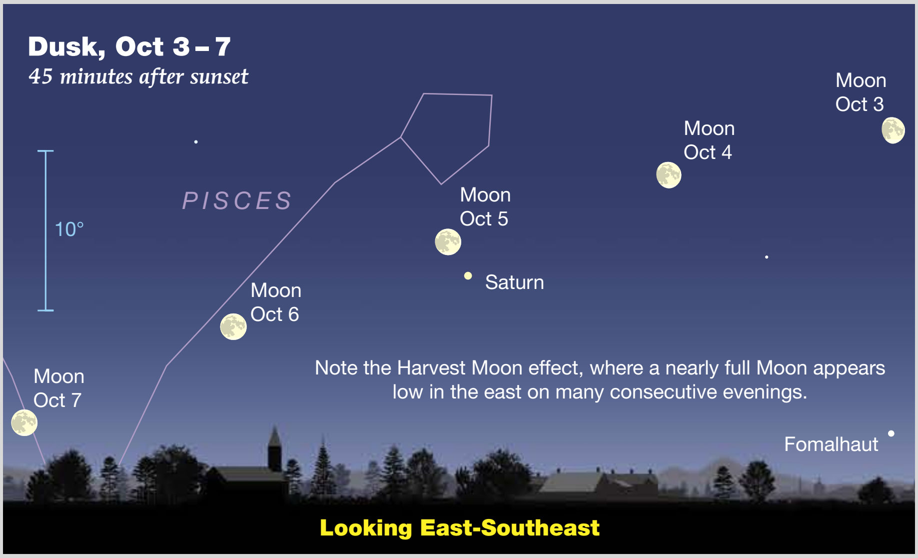
Late this evening the **Moon** approaches the **Pleiades** in Taurus and makes its way through the heart of the cluster, occulting several of its brighter stars in the process. The specific stars involved and the timing depends on where you are — the farther north you're located, the more central the Moon's path across the cluster. (Use an astronomy app or a planetarium program such as *Stellarium* to see which stars the Moon covers from your location.) Unfortunately, the naked-eye view of this event is something less than inspiring. That's because the Moon is an 87%-illuminated waning gibbous and its glare overwhelms most of the cluster stars. Steadily held binoculars offer a vast improvement, and a small telescope is better still.

From start to finish, it takes roughly 2½ hours for the Moon to traverse the Pleaides, during which time several of the cluster's brighter members are eclipsed. Since the dark limb is the trailing edge of the lunar disk tonight, the sudden reappearance of each star seemingly out of nowhere is the most visually interesting aspect of the event. The occultations begin at roughly 11:30 p.m. EDT on the 9th, and wrap up around 2 a.m. EDT on the 10th.

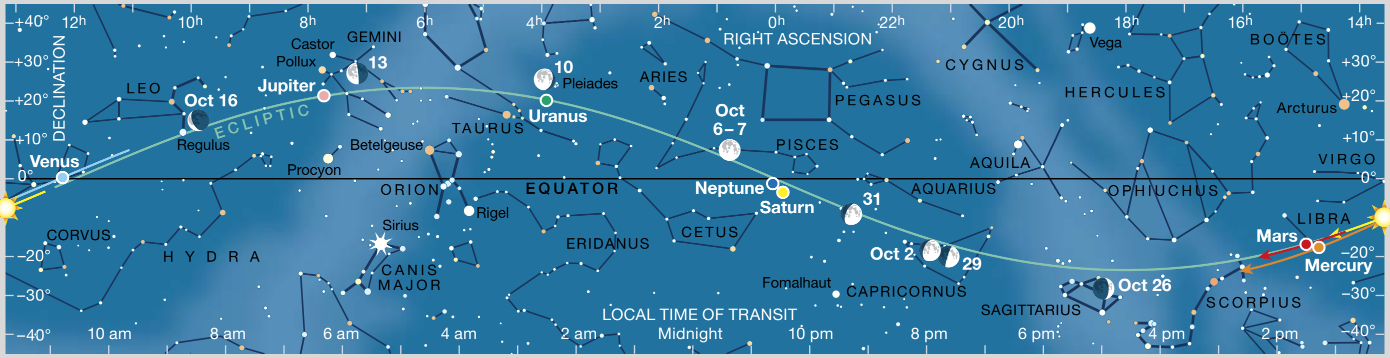
SUNDAY, OCTOBER 19

Pairings of the **Moon** and **Venus** are reliably eye-catching — and those that happen when the gap between them is less than 5° are especially so. This time around, the duo meet in the morning sky with less than 4° separating them. The Moon is a slender, 4%-illuminated crescent sporting a gentle wash of earthshine on its "dark" side. Keep in mind that from the perspective of an observer on the Moon's surface, Earth presents the inverse phase. This means that the lunar sky is adorned with a very bright, 96%-illuminated blue-and-white globe.

As for Venus, it gleams magnificently this morning at magnitude –3.9 — its prominence enhanced by the absence of bright stars in western Virgo, the constellation it presently shares with the Moon. Venus is slowly losing altitude as it lazily drifts toward its January conjunction with the Sun. This morning's is the best of the



▶ 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-October; 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.

remaining Moon-Venus pairings in the planet's current apparition.

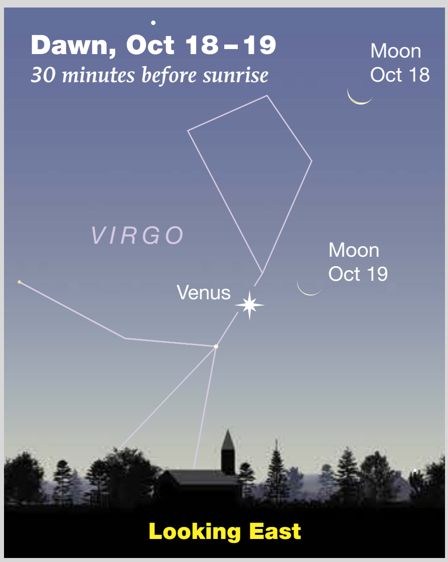
MONDAY, OCTOBER 27

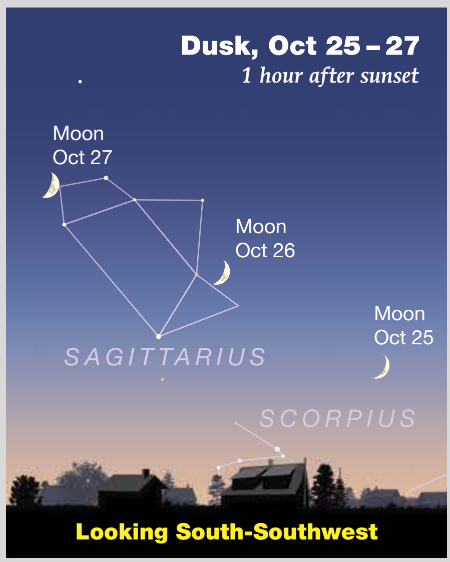
Each month the **Moon** passes near a handful of bright stars and a host of lesser lights too. The most exciting encounters are those in which it eclipses one of these stars. October not only brings us the Pleiades event on the 9th, but two additional occultations involving stars that have around the same magnitude as the brightest Pleiad, Alcyone. The first of these occurs this evening when the Moon covers 3.3-magnitude **Tau (τ) Sagittarii** — the easternmost star in the handle of the Sagittarius Teapot asterism. What makes this occultation more interesting than the one involving the Pleiades is that the Moon is now a waxing crescent, so we see a dark-limb eclipse in which the star suddenly winks out of view. Observers in the eastern U.S. and Canada are in the best position to watch this take place. Once again, use the software or app of your choice to get the specifics for your location.

THURSDAY, OCTOBER 30

Tonight, the **Moon** occults 2.8-magnitude **Delta (δ) Capricorni**. Delta — also known as Deneb Algedi — is the brightest star (by the thinnest of margins) that the Moon covers in October. Once again, we get to enjoy a dark-limb eclipse, this time with a 64%-illuminated waxing gibbous Moon. And like the occultation on the 27th, tonight's favors observers across the eastern half of the U.S. and Canada, as well as much of Mexico and Central America. Those with very good eyesight may be able to enjoy this "now you see it, now you don't" show without optics, but the drama quotient goes up exponentially with binoculars or a telescope. If you want to see the very definition of "instantaneous," you can do no better than to witness the glint of a distant star being extinguished by the advancing dark limb of the Moon. It's an amazing sight each time. Sadly, because stellar occultations happen in instant, you can't share the eyepiece view — everyone needs their own scope or binoculars.

■ Consulting Editor **GARY SERONIK** never passes up the opportunity for some "instant" observing.





Jupiter's Double-Shadow Jamboree

October features numerous opportunities to observe moon-shadow pairs crossing the Jovian disk.

▲ Io and its shadow (left pair) along with Ganymede and its shadow crossed Jupiter simultaneously on March 24, 2016. A double-shadow transit series is currently underway with multiple events taking place from late September through mid-November. In good seeing conditions, a 6-inch telescope clearly shows the shadows of the Galilean moons.

DAMIAN PEACH

Many observers wait until Jupiter is past opposition and conveniently placed in the evening sky before they start viewing the planet regularly. Of course, highly anticipated astronomical events don't care one whit about human biorhythms. Jupiter is still months away from its January 2026 opposition and remains a predawn target blazing away in eastern Gemini. So, if you want to enjoy this month's remarkable series of Jovian double-shadow transits, you'll need to stay up late or set an early alarm. Of the dozen October events, eight are visible from North America and most take place between midnight and dawn.

Watching the stately progress of a Galilean moon's shadow across Jupiter's turbulent cloud tops is often the high point of an evening spent at the telescope. Seeing *two* at the same time is even better. As the table on page 51 shows, single-shadow transits are quite common. Most of these are produced by Io, the innermost of the planet's four large satellites. With an orbital period of just 1.8 days, its shadow crosses Jupiter nearly every other night.

By contrast, shadow transits of Callisto, the outermost Galilean moon, are rare. That's because its distance from the giant planet combined with the slight inclination of its orbit usually causes Callisto's shadow to pass north or south of Jupiter, missing the disk altogether.

Double-shadow transits are infrequent and recur in seasons that last a couple of months. These typically involve Io and Europa, the two innermost Galilean moons. Both orbit close to Jupiter and near its equatorial plane, so their shadows never stray far from the Jovian globe. This is also true for Ganymede, though its shadow appears less often because of its longer orbital period of 7.2 days.

Just like our Moon, the Galilean satellites cast both umbral and penumbral shadows. Io and Europa orbit close enough to Jupiter that each has an umbra that's large compared to its penumbra, which makes their shadows appear dark and distinct. But thanks to

October Double-shadow Transits

Oct.	Shadows	UT Start	UT End
4	**Io and Europa**	**6:49**	**8:17**
6	Io and Ganymede	1:17	1:30
7	Io and Europa	19:46	21:34
11	**Io and Europa**	**8:42**	**10:53**
13	**Io and Ganymede**	**3:11**	**5:29**
14	Io and Europa	21:39	23:53
18	**Io and Europa**	**10:42**	**12:49**
18	**Europa and Callisto**	**13:07**	**13:30**
20	**Io and Ganymede**	**6:24**	**7:18**
21/22	Io and Europa	23:59	1:46
25	**Io and Europa**	**13:18**	**14:42**
29	**Io and Europa**	**2:35**	**3:39**

Bolded events are viewable entirely or in part from the Americas.

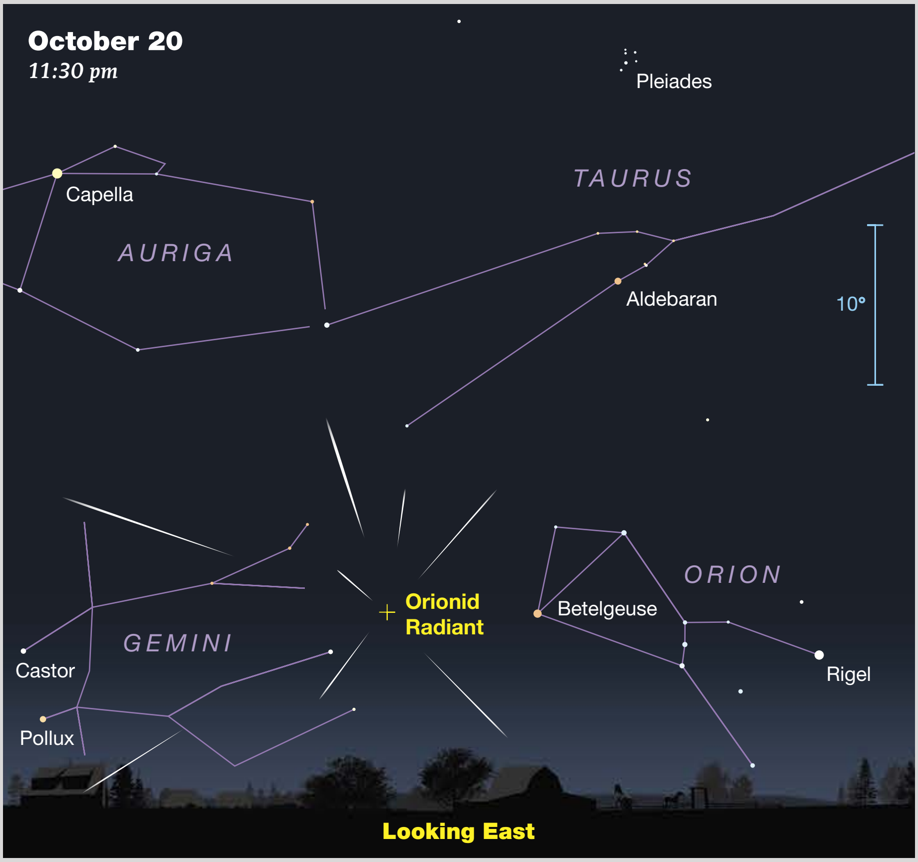
its greater distance from the planet, Callisto's shadow has a relatively larger penumbra, which feathers the shadow's edge and lightens its tone.

The first of the double-shadow events viewable from the Americas begins at 2:49 a.m. EDT on October 4th, when the shadows of both Io and Europa leisurely promenade across Jupiter's South Equatorial Belt. At the same time, the separation between the moons themselves, which lie east of the planet, shrinks. The pair reach the planet's limb at 4:04 a.m., when they appear to merge into a single, elongated oval. Magnifications of 300× or greater may show them as north-south-aligned disks that are just touching. With steady seeing conditions, this sight could rival the double-shadow transit itself. The duo slowly separate as Io passes Europa and they continue their journey across Jupiter's cloudy face.

The show on the 11th is nearly as rewarding. Once again, Io and Europa's shadows track westward across the Jovian disk. This time, the separation between the shadows slowly narrows until they're closer than two dots in a colon when they depart the globe.

A week later, on the 18th, the shadows of Io and Europa begin their journey neck-and-neck, and slowly separate as they make their way westward. Like a handoff in a relay race, 18 minutes after Io's shadow departs Jupiter's disk, Callisto's diffuse shadow enters from the east to join Europa's shadow as it departs on the western limb. Were Io's shadow to linger just a little longer, we would have been treated to a very rare *triple-shadow* transit. The last one took place in 2015, and the next won't occur until 2032.

Because Io, Europa, and Ganymede are in orbital resonance with Jupiter, double-shadow season recurs at 437.64-day (1.2-year) intervals. That means the next set happens from December 2026 through January 2027.



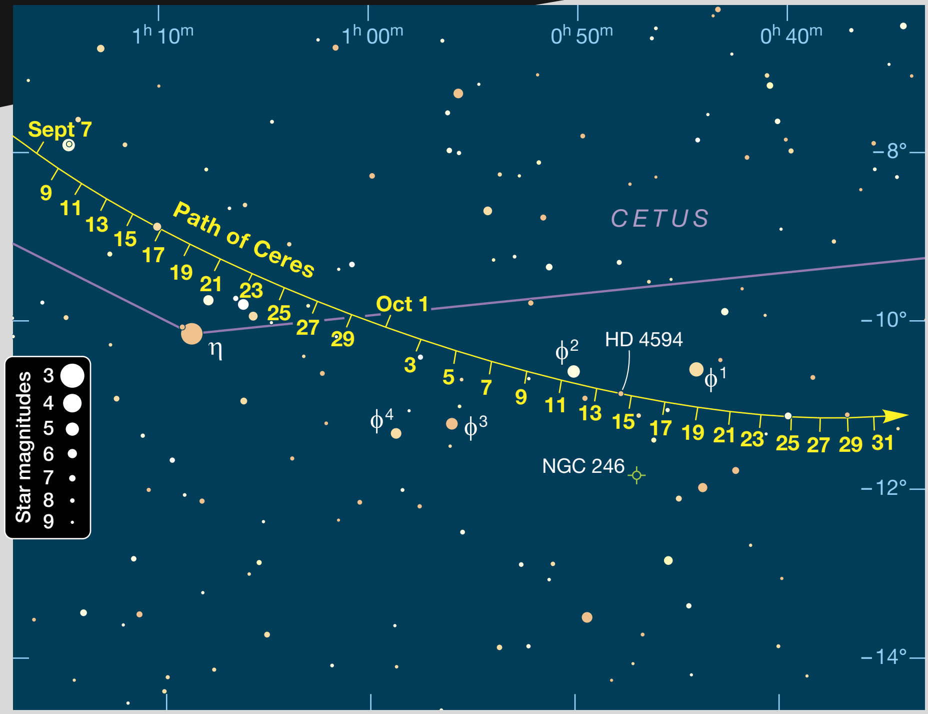
Orionid Perfection

▲ Orionids originate from Halley's Comet and stream from a radiant located in Orion's upraised club. The shower's peak occurs on the night of October 20–21. Orionids can appear in all parts of the sky, but their paths all point back to the radiant.

CIRCUMSTANCES COULDN'T be better for this year's Orionid meteor shower. The peak occurs on the night of October 20–21, when the Moon is absent (new Moon is at 8:25 a.m. EDT on the 21st) and when the worst of the smoke from wildfire season is hopefully behind us. The Orionids usually produce from 10 to 30 speedy meteors per hour when observed from a dark-sky site. Suburban skywatchers can expect to see half as many. No outbursts are predicted this year, but several have occurred in the past. In 2006 and 2007, some observers recorded rates of 60 to 80 meteors per hour.

Orionids appear to fly out from their namesake constellation but actually originate with Halley's Comet. During its periodic visits to the inner solar system, heat from the Sun vaporizes the comet's dust-laden ices, releasing material into space along its orbital path. These grains are composed of silicates, carbon-rich organic compounds, and small amounts of iron- and magnesium-rich metals. Each particle is about as large as a tiny grain of sand.

Earth flies through the comet's debris trail in October, turning the bits of sand into kamikaze-like meteors that strike the atmosphere at more than 66 kilometers per second (148,000 miles per hour). Most Orionids are on the faint side, but their swiftness will make your head turn. As the chart above shows, the meteors stream from a spot located in the Hunter's upraised club. Although the radiant clears the horizon around 11 p.m. local daylight time, wait a few hours until Orion commands the southeastern sky before settling in to enjoy the shower. The best time to watch is from 2 a.m. to 6 a.m.



Ceres at Opposition

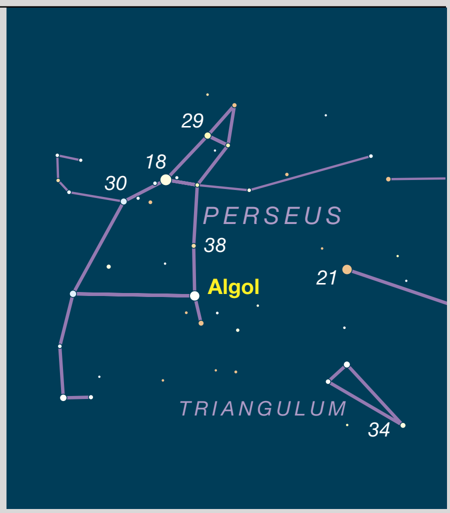
CERES IS SPECIAL. It's the closest dwarf planet and the only one that resides within the main asteroid belt. It shines at magnitude 7.6 when it reaches opposition on October 2nd.

This month Ceres drifts westward across Cetus, the Sea Monster, where it passes south of the 5th-magnitude stars Phi^1 (φ^1) and Phi^2 (φ^2) Ceti. Both aid in finding Ceres. On the night of the 13th, it closes in on the 7.7-magnitude star HD 4594. Ceres glides 2½″ south of the star at around 5:40 a.m. EDT on the morning of the 14th.

Minima of Algol

Sept.	UT	Oct.	UT
3	1:20	1	17:27
5	22:09	4	14:15
8	18:57	7	11:04
11	15:46	10	7:53
14	12:35	13	4:42
17	9:23	16	1:30
20	6:12	18	22:19
23	3:01	21	19:08
25	23:49	24	15:57
28	20:38	27	12:46
		30	9:35

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 reaches the zenith during predawn hours in October. 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

WITH THE CURRENT Jupiter apparition now well underway, the planet rises around midnight local daylight time and transits the meridian at sunrise. On the 15th of the month, Jupiter attains an altitude of 30° at around 2:30 a.m. local daylight time and continues to ascend throughout the night. The planet is a conspicuous sight in eastern Gemini, shining at magnitude –2.2 and presenting a disk 38.6″ across at mid-month.

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.

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.)

September 1: 9:05, 19:00; **2:** 4:56, 14:52; **3:** 0:48, 10:44, 20:39; **4:** 6:35, 16:31; **5:** 2:27, 12:22, 22:18; **6:** 8:14, 18:10; **7:** 4:05, 14:01, 23:57; **8:** 9:53, 19:48; **9:** 5:44, 15:40; **10:** 1:36, 11:31, 21:27; **11:** 7:23, 17:19; **12:** 3:14, 13:10, 23:06; **13:** 9:01, 18:57; **14:** 4:53, 14:49; **15:** 0:44, 10:40, 20:36; **16:** 6:32, 16:27; **17:** 2:23, 12:19, 22:15; **18:** 8:10, 18:06; **19:** 4:02, 13:58, 23:53; **20:** 9:49, 19:45; **21:** 5:40, 15:36; **22:** 1:32, 11:28, 21:23; **23:** 7:19, 17:15; **24:** 3:10, 13:06, 23:02; **25:** 8:58, 18:53; **26:** 4:49, 14:45; **27:** 0:41, 10:36, 20:32; **28:** 6:28, 16:23; **29:** 2:19, 12:15, 22:11; **30:** 8:06, 18:02

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

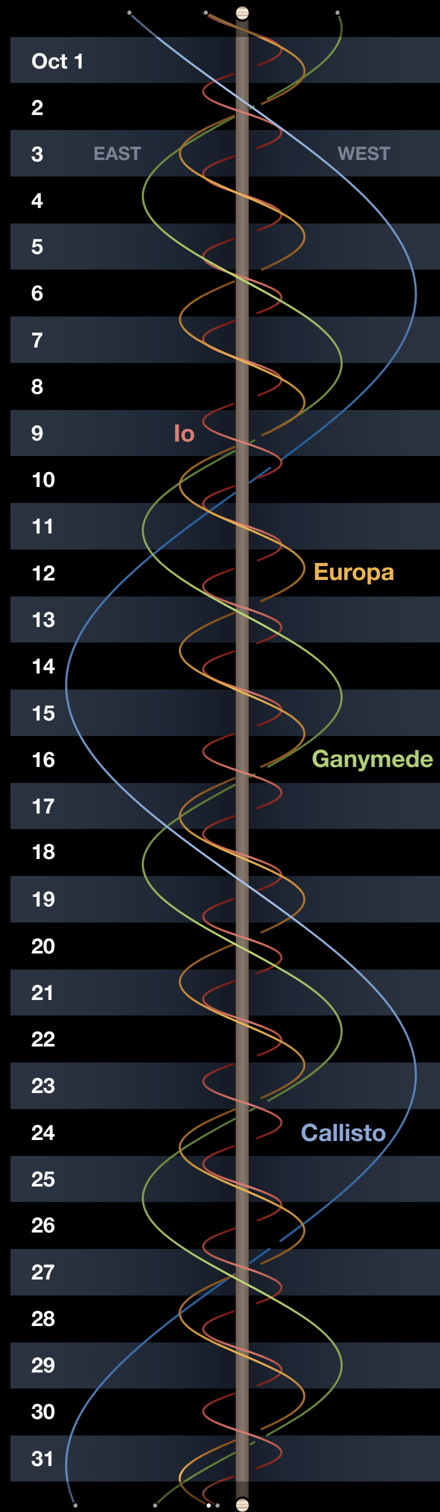
These times assume that the spot will be centered at System II longitude 83° on October 1st. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 83° and 1⅔ minutes later for each degree more than 83°.

Phenomena of Jupiter's Moons, October 2025

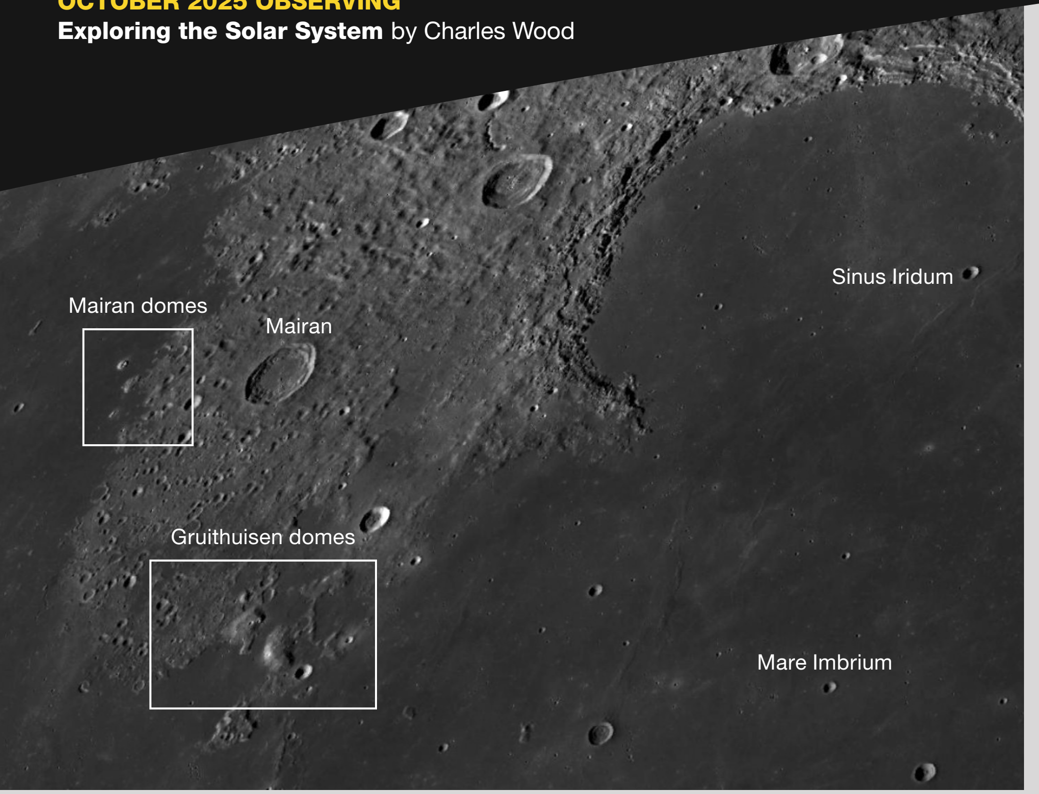
Oct. 1	15:04	I.Ec.D
	18:37	I.Oc.R
	19:08	IV.Sh.I
	22:09	IV.Sh.E
Oct. 2	6:54	IV.Tr.I
	8:15	III.Ec.D
	10:30	IV.Tr.E
	10:54	II.Ec.D
	11:19	III.Ec.R
	12:21	I.Sh.I
	13:22	III.Oc.D
	13:35	I.Tr.I
	14:34	I.Sh.E
	15:50	I.Tr.E
	16:13	II.Oc.R
	16:37	III.Oc.R
Oct. 3	9:32	I.Ec.D
	13:06	I.Oc.R
Oct. 4	5:29	II.Sh.I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



NASA / GSFC / ARIZONA STATE UNIVERSITY (4)

Silicic Lunar Volcanoes

New studies shed light on these enigmatic features.

Our solar system's rocky planets and moons are volcanic worlds, partially covered with molten mantle rocks that erupted onto their surfaces. Seventy percent of Earth's crust is ocean floors composed of iron- and magnesium-rich volcanic rocks called *basalts*, which also occur widely in continental terrains. Similarly, the Moon has vast deposits of basaltic maria rocks, and evidence suggests that the smooth, broad plains on Mars and Venus are basaltic.

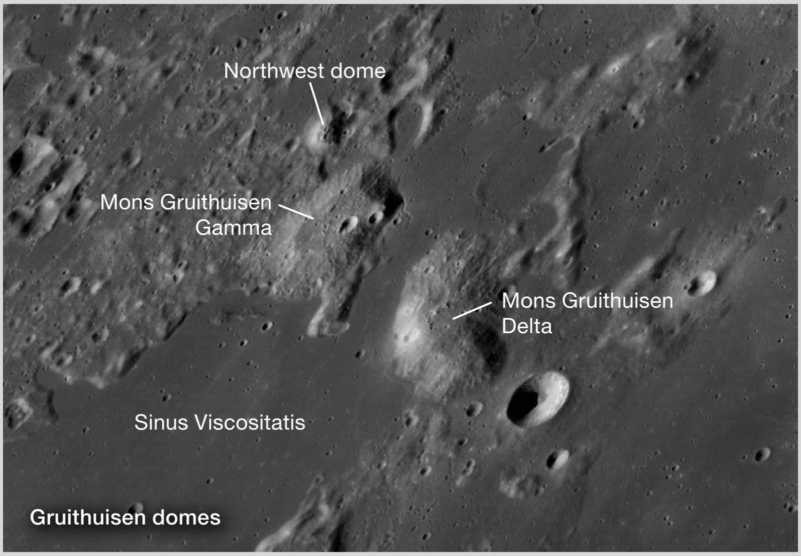
The second most common igneous rocks on Earth are silica-rich ones called *granites* when solidified in the crust; rocks of similar composition erupted as lava flows, ash, and glass deposits are called *rhyolites*. Basalts and other dark-hued, dense, magnesium- and iron-rich rocks are classified as *mafic*. Granites, rhyolites, and similar lighter-colored, less-dense rocks are referred to as *silicic*, since they contain much more silica minerals than basalts.

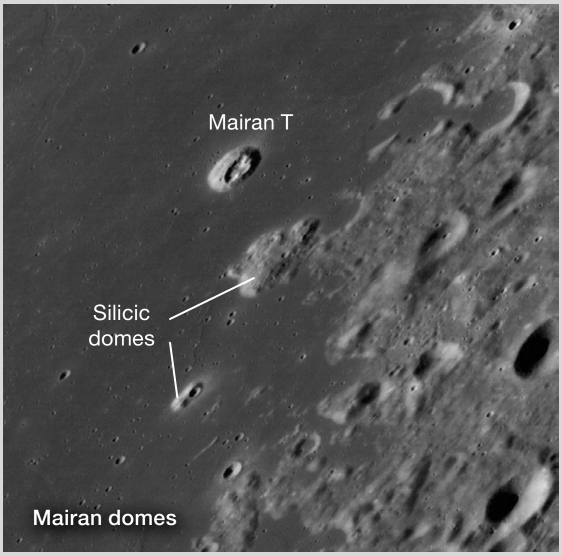
Unlike basalts, granite and rhyolite materials are much less common on the Moon, with only small fragments found in the lunar samples returned by Apollo astronauts. However, the Gruithuisen domes, located southwest of Sinus Iridum along the Imbrium Basin rim, have long been considered to be made of silicic rocks. In 2016, M. A. Ivanov, J. W. Head, and A. Bystrov published the most comprehensive survey of the Gruithuisen domes in *Icarus*. According to the researchers, two of the domes — **Mons Gruithuisen Gamma** and **Mons Gruithuisen Delta** — look nothing like the much more common mare domes, such as the Hortensius domes between the craters Copernicus and Kepler. The latter are a few hundred meters tall with very gentle slopes of only a few degrees and are composed of dark-hued mare basalts. In contrast, Gamma and Delta are 1.8 and 1.2 kilometers (1.1 and 0.75 miles) high, respectively, have flank slopes up to 23°, and are brighter than the surrounding mare. They're morphologically similar to silicic domes on Earth, which commonly have rhyolitic compositions. Spectroscopic analyses of the Gruithuisen domes are consistent with the features being constructed of rhyolite lavas and ash deposits.

Finding the Gruithuisen domes through the telescope is relatively easy since they appear as two bright, shadow-casting mounds just on the mare-ejecta boundary southwest of Sinus Iridum. Discerning details is more challenging since Gamma is only about 20 km in diameter and Delta is elongated with a major axis of 30 km. The tops of both domes are relatively flat rather than rounded, though Gamma's steeper slope is quite apparent. NASA's Lunar Reconnaissance Orbiter Camera (LROC) images reveal that the domes' surfaces are rough, with evidence of massive lava flows on the south of Gamma and to the southeast and north of Delta. Multispectral data and LROC images have led researchers to the discovery of a third, smaller silicic dome northwest of Gamma.

A 68-km-wide bay of lava extends from Oceanus Procellarum to the Gruithuisen domes. In 2022, the International Astronomical Union officially named this feature *Sinus Viscositatis* (Bay of Stickiness), since silicic lavas, such as those that formed the Gruithuisen domes, are very viscous and flow sluggishly. Crater counts published by Ivanov, Head, and Bystrov indicate that Gamma and Delta formed about 3.8 billion years ago, with the nearby lavas erupting between 3.7 and 2.6 billion years ago. Since the Imbrium Basin and the Sinus Iridum crater were both formed about 3.9 billion years ago, this means that the silicic lavas came right after the basin formation and just before the inundation of the mare lavas. Thus, two distinctly different magmas formed and erupted in the same area at about the same time.

Another smaller silicic complex of extrusive volcanics is found just 250 km northwest of the Gruithuisen domes and west of the 40-km-wide crater Mairan in northern Oceanus Procel-





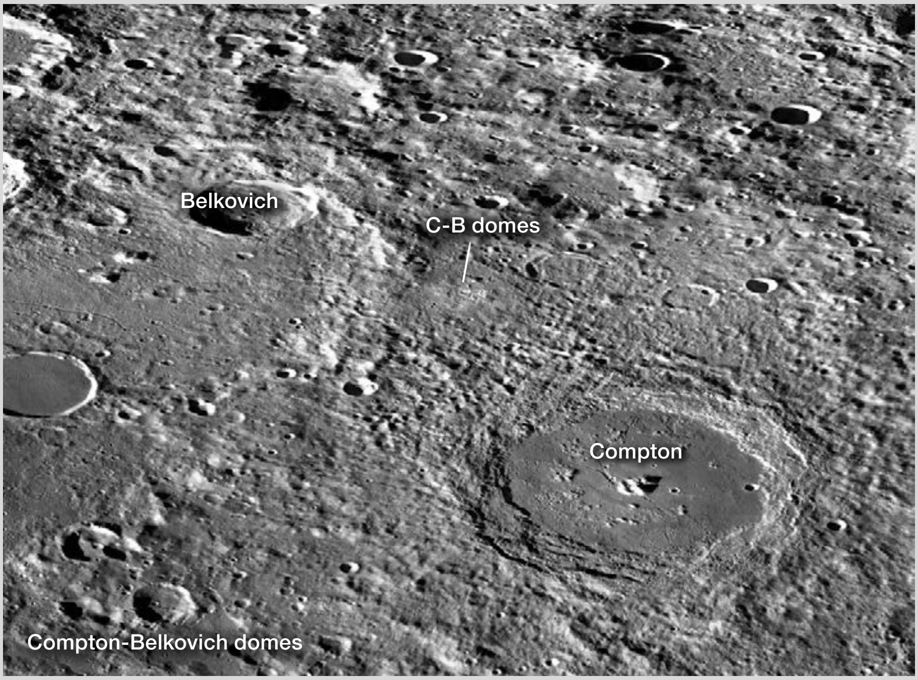
larum. Its most striking feature is the 7-km-wide, 770-meter-high (2,500-feet-high) steep-sided cone of the **Mairan T** summit crater. The Mairan T mountain is bright and spectrally silicic. Two other smaller silicic domes lie southeast of T.

In 2011, researchers recognized another area of silicic volcanism just over the Moon's northeastern limb, beyond **Mare Humboldtianum** and its basin. A strong thorium anomaly between the craters **Compton** and **Belkovich** drew attention to the area, which is notably brighter than its surroundings, contains small domes, and a raised area 25 by 35 km across. Spectral data indicate rocks of silicic composition. This Compton–Belkovich (C–B) feature occurs in the rugged far-side highlands, making landforms there neither as conspicuous nor as well defined as the Gruithuisen and Mairan domes that rise above the surrounding dark mare lavas. The morphology of C–B is quite different from the previously described silicic domes. Domes at C–B are just a few kilometers across, short and clustered together, looking like small hills rather than individual volcanoes. Additionally, C–B has an elliptical raised boundary, or rim, with a depressed center. It appears to be a single, large silicic volcanic structure rather than individual domes.

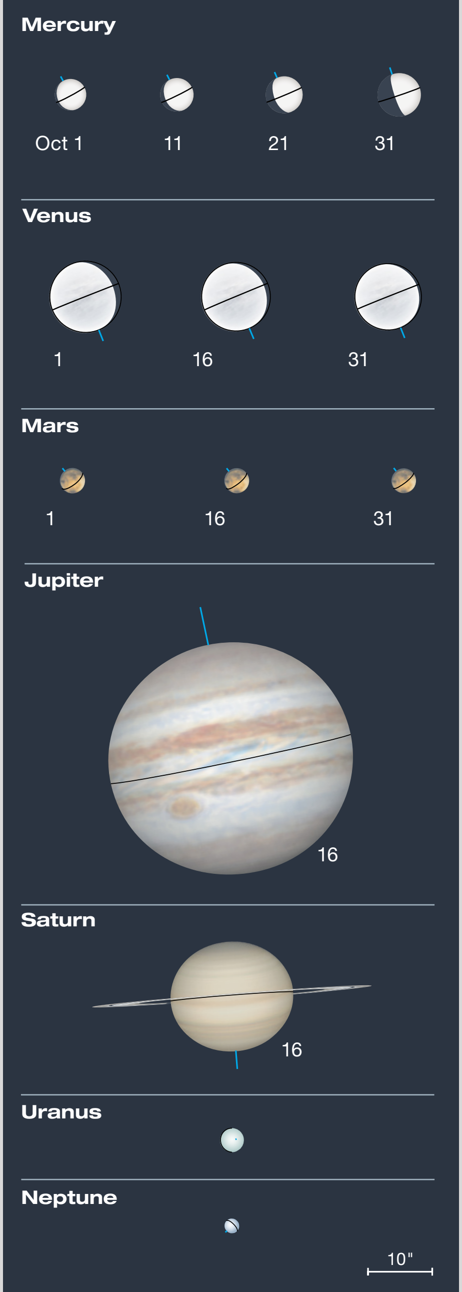
One common characteristic is that both C–B and Gruithuisen are situated in regions with high thorium anomalies that provides thermal energy. C–B's anomaly is the strongest on the Moon, corresponding to the highest lunar heat flow. Scientists interpret this heat as being generated by a buried, 50-km-wide granite mass called a *batholith*. A recent study presents compelling evidence that Wolf crater in Mare Nubium is a silicic volcanic caldera, also associated with a thorium anomaly.

Overall, the origin of lunar silicic volcanism has been quite uncertain because on Earth such silicic materials are commonly formed in water-rich, plate tectonic environments where basaltic magma interacts with silica-rich, granitic crustal rocks. The Moon lacks plate tectonics and, until recently, any significant granitic terrains were unknown. Now, with two — at C–B and Wolf crater — a new understanding may soon unfold. Blue Ghost, a NASA-funded spacecraft, is scheduled to land on Gruithuisen Gamma in 2028 and could provide new evidence about these enigmatic silicic lavas.

■ Contributing Editor **CHUCK WOOD** is coauthor of the newly published *Extreme Illumination Atlas of the Moon* available at **amazon.com**.



PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** out of view all month • **Venus** visible at dawn all month • **Mars** lost in the Sun's glare all month • **Jupiter** rises around midnight and visible to dawn • **Saturn** visible at dusk and transits before midnight.



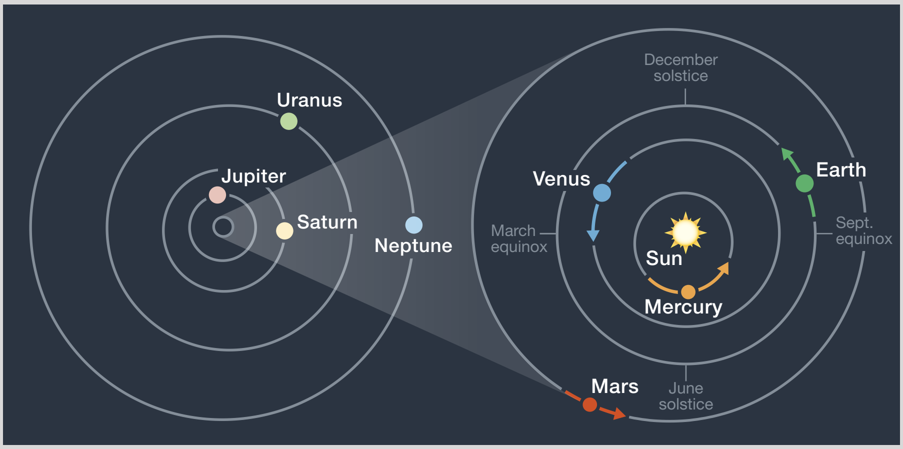
October Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$12^h\ 28.4^m$	–3° 04′	—	–26.8	31′ 57″	—	1.001
	31	$14^h\ 20.5^m$	–14° 00′	—	–26.8	32′ 13″	—	0.993
Mercury	1	$13^h\ 16.8^m$	–8° 14′	13° Ev	–0.5	4.9″	93%	1.368
	11	$14^h\ 13.0^m$	–14° 44′	18° Ev	–0.2	5.2″	87%	1.290
	21	$15^h\ 06.6^m$	–19° 54′	22° Ev	–0.2	5.8″	77%	1.166
	31	$15^h\ 53.5^m$	–23° 13′	24° Ev	–0.2	6.8″	61%	0.995
Venus	1	$11^h\ 02.0^m$	+7° 35′	24° Mo	–3.9	11.1″	91%	1.506
	11	$11^h\ 47.9^m$	+2° 55′	22° Mo	–3.9	10.8″	93%	1.546
	21	$12^h\ 33.6^m$	–1° 57′	19° Mo	–3.9	10.5″	95%	1.582
	31	$13^h\ 19.7^m$	–6° 48′	17° Mo	–3.9	10.3″	96%	1.614
Mars	1	$14^h\ 12.7^m$	–13° 26′	28° Ev	+1.6	4.0″	98%	2.356
	16	$14^h\ 53.2^m$	–16° 48′	23° Ev	+1.5	3.9″	98%	2.387
	31	$15^h\ 36.0^m$	–19° 43′	19° Ev	+1.5	3.9″	99%	2.408
Jupiter	1	$7^h\ 35.5^m$	+21° 39′	76° Mo	–2.1	36.9″	99%	5.335
	31	$7^h\ 46.0^m$	+21° 17′	103° Mo	–2.3	40.4″	99%	4.877
Saturn	1	$23^h\ 54.4^m$	–3° 20′	169° Ev	+0.7	19.4″	100%	8.561
	31	$23^h\ 47.3^m$	–4° 04′	138° Ev	+0.9	18.9″	100%	8.777
Uranus	16	$3^h\ 53.4^m$	+20° 02′	142° Mo	+5.6	3.8″	100%	18.708
Neptune	16	$0^h\ 01.4^m$	–1° 21′	157° Ev	+7.8	2.4″	100%	28.965

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

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



▲ **FIRE IN THE SKY** Although green is the dominant color of most auroral displays, shades of yellow, orange, purple, and even red can appear. The colors depend on the specific particles in Earth's atmosphere being excited to luminescence and their altitude — red being predominantly produced by high-altitude oxygen. Although many of these hues are visible to the unaided eye during very bright events, all colors are rendered much more vividly in photographs.

ALL IMAGES COURTESY OF THE AUTHOR

Easy Aurora Photography

Capturing the ethereal shimmering lights has never been easier.

If I were to draw up a list of the top five most thrilling sky sights, I'd include a total solar eclipse, a bright new comet, a total lunar eclipse, a meteor storm, and a fantastic auroral display. And of these I'd say the aurora is the easiest to photograph. Although there's no such thing as "no-brainer" astrophotography, capturing the northern lights (or southern lights) can be done with relatively basic gear and some simple techniques.

Now is the Time

As most readers know, auroral activity rises and falls with the solar cycle (*S&T:* Oct. 2023, p. 74), and the peak of the current cycle has just happened. Maybe. This is one of those things that's only possible to pinpoint after the fact. Regardless, the Sun is very active, so current conditions are about as ideal as they get. What's less well known is that there's also a seasonal component to auroral activity. For reasons that aren't completely understood, aurorae tend to like the equinoxes. That's why, statistically, the best months for keeping an eye out for the spectacle are April and October.

Although high-latitude regions get to see the aurora most often, during very powerful episodes even locations near the tropics can see them. Indeed, no matter where you live in the contiguous U.S., chances are you've witnessed several impressive displays over the past couple of years.

Aurorae can burst forth with little or no warning and can also be surprisingly short-lived. That's why Tip #1 is: *Always be prepared*. I say this through bitter personal experience — more than once I've missed the best part of a northern-lights show stuck indoors scrambling to get my equipment together. Don't let that happen to you!

Getting Smart

Being ready is one thing, having the right gear is another. This leads me to Tip #2: *The camera you actually have always takes better photos than the one you* wish *you had*. So, if all you have is a smartphone, there's no reason you can't try your hand at aurora photography. The cameras in these do-all devices have improved by leaps and bounds over the years and are now capable of

◀ **SMART SHOW** This backyard aurora photo was captured with a six-year-old Samsung Galaxy S10 smartphone. Despite the device's relative age, it did a fine job of recording the curtains of light that lit the skies over southern British Columbia last October. Newer phones can do even better.

credible night-sky images. However, their primary photographic mission remains daylight snapshots of the Three F's: friends, family, and food. Unlocking your phone's astronomical potential usually means getting under the hood to investigate menu options that are often tucked away.

There are so many different smartphone models and operating systems that giving specific instructions for each one is beyond the scope of this article. However, if you can find a Night, Manual, or Pro mode, you're looking in the right place. I have a Samsung Galaxy, which has a Night mode, but I find that the Pro setting usually produces better results because it allows me to choose a wider range of parameters, most important of which is the exposure time. That said, it's usually a matter of trying things out to see what works best.

The other setting to pay attention to is the zoom level. Most smartphones have decent, wide-angle lenses — and that's what you want for shooting aurora. Select the lowest zoom setting available to encompass the greatest amount of sky and create the most dramatic and captivating shots.

Like any kind of night-sky photography, exposure times for aurorae can run pretty long. That's why it's helpful to have a couple of accessories at hand. These include a tripod, a smartphone tripod adapter, and a Bluetooth wireless shutter release. I've seen all three sold together as a set for just $20! Sure, the tripod isn't great, but it doesn't have to be — your phone doesn't weigh very much. If you already have a tripod, you can just get the bracket and the remote and be on your way.

Returning to Tip #1, part of being prepared is to go out on the next clear night and take some constellation shots so that you become familiar with your smartphone's camera settings and how to use it in the dark. Trust me on this — you'll be glad you did. You don't want to be figuring this stuff out when an aurora kicks off and you're desperate to get a photo to post on social media!

A Shot in the Dark

Modern smartphones can produce remarkable images, but for truly impressive aurora shots, it's still better to use a "real" camera, be that a DSLR or any of the many mirrorless cameras now available. Just about any model you're likely to encounter these days has outstanding low-light performance and offers a range of lens options to help you bring home the bacon, photographically speaking. With the camera's capabilities essentially a given, the quality of your photos mostly depends on the settings you use and the lens you choose.

It goes without saying that you need a tripod. Any reasonably sturdy one fitted with a good ball head will work. A remote shutter release (or intervalometer) is also a big help. But probably the most important gear-related piece of the imaging puzzle is a good, wide-angle lens. Since the most impressive auroral displays can fill the entire sky, there's no such thing as one that's *too* wide — even a fisheye lens has its place. A suitable lens is such a crucial piece of gear that I bought one specifically for aurora photography — a used Sigma 10–20mm f/4 zoom to pair with my rather ancient Nikon D5100 DSLR camera and its

◀ **SMARTPHONE SETUP** First-rate aurora photos can be made with basic gear, be it a smartphone (*left*) or conventional camera. Both methods require a tripod, but the smartphone option also needs the inexpensive adapter bracket shown here. Fortunately, typical devices are lightweight, which means that just about any tripod will be sturdy enough to allow the long exposure times required for pleasing aurora portraits.

▲ **AURORAE ON TOUR** To catch a truly amazing display of northern lights, it helps to hit the road. Few locations combine the ethereal spectacle with dramatic scenery as nicely as Iceland. In this photo, taken last October, a shimmering aurora hovers over the *Sky & Telescope* group's tour bus.

crop-format sensor. But even with my lens's sky-spanning 99°-wide field of view, there are times when I wished I could go even wider.

As with most astrophotography, you'll be operating in Manual mode and shooting RAW files for the greatest post-processing flexibility. I generally set the white balance to Daylight to get the most natural colors. The rest of the settings depend on how bright the aurora is. You effectively have three variables to work with: lens aperture, exposure time, and ISO setting. For a night's shooting, my preference is to select a lens aperture and exposure time and then leave them alone. I keep up with the display's ever-changing brightness by tweaking the ISO.

As a starting point, I set the lens to the widest aperture that yields acceptable star images — "acceptable" being purely a matter of taste. As it happens, that's f/4 with the lens I use. Next, I dial in 10 seconds for my exposure time. I find some of the fine details in a fast-moving aurora begin to smear together with longer exposures. That leaves me with just ISO to consider. Since most modern cameras have excellent, low-noise performance even at high ISOs, this strategy works well.

I usually select ISO 1600 then monitor the camera's histogram display to ensure the main hump of the curve is nicely separated from the graph's left edge, but not so much that highlights are overexposed (clipped). If the aurora is bright enough for that to happen, I'll throttle down the ISO to 800 or less. If the images are coming out dim, I'll bump the ISO up as high as 3200. Outside of that range, I'll shorten or lengthen my exposure time as required.

My initial settings may prove different than what works for you. If you have a better camera and faster lens, you can start with even shorter exposures and/or lower ISO settings. Experimentation is the key — but always with an eye on the histogram to judge the results. That leads to Tip #3: *Trust the histogram, not your eyes*. Evaluating your shots by looking at the camera screen in the dark practically guarantees underexposure. And there are few things more disappointing than reviewing your shots the next morning only to discover then that all your photos are badly underexposed. I've seen this mistake on every aurora tour I've ever been on.

Composition Matters

What separates a good aurora image from a truly *great* one? In a word, composition. Yes, the aurora is the star of the show, but you can make your photos so much more inspiring by simply paying attention to what else is in the frame. If possible, try to include a compelling foreground — even if that amounts to nothing more than the silhouette of a distant hill or a copse of trees. Shots that lack a horizon leave the viewer feeling slightly disoriented and without a sense of scale and location. It's easy to achieve this when you're someplace as exotic as Iceland, but even if you're shooting from a suburban backyard, you still can try to make the best of what's around you.

A second strategy to add a bit of interest to your aurora photos is to include a recognizable constellation or asterism. The Big Dipper is an obvious choice for Northern Hemisphere shooters, but the bright stars of Taurus and Orion can also lend an extra dimension to otherwise routine aurora shots.

Knowing what to include is only half the battle — you also need to keep an eye out for things that don't belong in the frame. Your neighbor's porch light, an overlit building, or an awkwardly intrusive tree branch are all elements that detract and distract. Sometimes, in the heat of the moment, it's easy to overlook flaws that become blindingly obvious the next morning. As landscape photographers often suggest, be sure to do a "perimeter search."

Finally, here's Tip #4: *Don't end up watching the entire night's action on your camera's viewscreen*. Take the time to look up and soak in the spectacle with your eyes alone. Taking pictures is a way of preserving a moment — but you don't want camera settings, lenses, and histograms to be all you remember. You want to relive the feeling of standing under a shifting curtain of luminosity pierced by the light of distant stars. That's where the real memories live.

■ Consulting Editor **GARY SERONIK** leads *Sky & Telescope*'s annual Iceland Aurora Adventure tour.

Exploring Barnard's E

Do a deep dive into a dark nebula monogram.

▲ **PLATE 41** E. E. Barnard took this photo with the Bruce Photographic Telescope in 1905. Two dark nebulae, B142 and B143, form the E. The star at lower left is 3rd-magnitude Gamma (γ) Aquilae. This view is about twice as wide as most binoculars produce but conveys what can be seen on a transparent night. A section of the Great Rift runs along the right side of the photo. North is up.

We're on the cusp between summer and autumn, and Earth is rotating the Milky Way past the meridian as the sky darkens. On clear nights far from city lights, the hazy band of our home galaxy is the most prominent feature above us. It's split by a ragged dark lane stretching from Cygnus to Sagittarius — the Great Rift. It's also punctuated along its length by a variety of smaller dark features that help give the Milky Way its distinctive texture.

These dark nebulae are essentially unilluminated clouds of interstellar gas and dust. They're common in most spiral galaxies and look particularly dramatic when a galaxy is viewed edge-on. From our position within the Milky Way, we get an insider's perspective when looking at these opaque objects, which are especially pleasant to view on moonless summer and early autumn nights.

Dark nebulae are seen in silhouette as they block the light from stars or bright nebulae lying behind them. Besides the huge dark lanes and patches visible to the unaided eye, our galaxy holds myriad smaller dark nebulae, such as the curvy outline of the Lagoon Nebula (M8) and the three dark lanes of the Trifid Nebula (M20), both in Sagittarius. There are other examples, including many that can be quite difficult to detect, such as the Horsehead Nebula (B33) in Orion and the even more challenging Cone Nebula in Monoceros.

However, one of the most accessible dark nebulae, both in distinctiveness and size, is the delight of **B142** and **B143** that together form **Barnard's E** in northwestern Aquila.

A Brief History of Dark Nebulae

The American astronomer Edward Emerson Barnard's monumental work, *A Photographic Atlas of Selected Regions of the Milky Way*, was published posthumously in 1927. Nearly 100 years later, his still-spectacular photographs highlight 369 small dark nebulae (see *S&T:* Aug. 2023, p. 28).

In the late 18th century, astronomers debated whether these opaque areas were starless holes in the Milky Way or unilluminated matter blocking starlight. William Herschel was a central figure in this debate, and though he thought the features were starless holes, there was no way to settle the issue through visual observations alone.

At first, Barnard agreed with Herschel, but that was before he embarked on his first photographic survey at Lick Observatory in 1889 using an existing 6-inch portrait camera. For his second survey he used a purpose-built 10-inch instrument — the Bruce Astrograph. Named after Catherine Wolfe Bruce, who financed the telescope, it came into service in 1904. After closely studying his Milky Way photos, Barnard was convinced that at least some of these dark areas were nebulae blocking starlight. He left a little wiggle room for starless voids, though. In a 1919 article he wrote:

> *It would be unwise to assume that all the dark places shown on photographs of the sky are due to intervening opaque masses between us and the stars. In a considerable number of cases no other explanation seems possible, but some of them are doubtless only vacancies.*
>
> *I do not think it necessary to urge the fact that there are obscuring masses of matter in space. This has been quite definitely proved in my former papers on the subject.*

At the time, astronomers were gradually accepting the nature of these objects and initially referred to them as *absorption nebulae*, likening them to terrestrial clouds blocking the Sun. However, it wasn't until 1930 that Swiss-American astronomer Robert Trumpler demonstrated that dark nebulae were indeed absorbing background starlight.

It was during his second photographic survey, in August 1905, that Barnard imaged a patch of nebulosity in Aquila with the Bruce astrograph. He listed the dark nebulae as entries 142 and 143 in his catalog. As is true for all 369 objects included, his descriptive notes are brief:

> B142*: Large; irregular; about 40′ E and W; BD +10 4016 in E part [note that here "E part" means "eastern part"]*

> B143*: Rather narrow, angular marking; the outline of a square 30′ in diameter, with the W side missing.*

At somehwere between 750 and 2,000 light-years away, the nebulae are pretty close as deep-sky objects go. (The lack of stars in front of the nebulae as shown in my sketch on page 60 attest to this.) The total mass of B143, the visually densest part of the complex, is between 0.5 and 1.0 solar masses, depending on the method used to estimate it. B142 probably has less mass given its visual and photographic appearance.

Observing the E

Together, the two dark nebulae look very much like the capital letter E, and 10×42 binoculars show them wonderfully well, along with several other dark nebulae in the neighborhood. Binoculars also let you see the E in its correct orientation. But let's examine its upside-down telescopic appearance first. To find it, scan roughly 1.5° due west of 2.7-magnitude Gamma (γ) Aquilae, or Tarazed.

My history of observing Barnard's E was pretty slim until I experienced a view of it under a spectacularly dark and transparent sky in September 2022. I'd joined my good friends Chuck and Judy Dethloff, cofounders of the Oregon Star Party, at Logan Valley in eastern Oregon, one of the finest dark-sky sites in the Pacific Northwest.

On our second night of observing I was treated to an exceptional view of Barnard's E through my 30-inch f/2.7 Dobsonian. Because its focal length is only 81 inches, it produces a 1.15°-wide field of view at 82× with a 25-mm Explore Scientific 100° apparent field and a Baader MPCC coma corrector. Even though the combination results in an exit pupil of 9 mm, the view was excellent. The E is commonly listed to be about ½° long north to south, but to me it looked closer to about ¾° and was nicely framed in the 25-mm eyepiece.

My observing notes from that September night read:

> *On a whim, I pointed the scope at Barnard's E — and wow, what a view! The three horizontal parts of the E are the most distinctive, with the connecting vertical parts less so. The edges of the more sharply delineated parts of the dark nebula are softly and faintly illuminated, giving them a 3D appearance — just marvelous! (Nearby B334, B336, and B337 look pretty awesome too!) 82× and 113×, 21.61 SQM [Sky Quality Meter].*

The vertical connection between the top and center horizontal members of B143 was distinct, making it look like a squared-off letter C. There's no vertical dark connection to B142, although my brain certainly tried to see one. Conversely, several stars help make up for this lack of darkness, and two in particular — 8.1-magnitude HD 185898 and 8.7-magnitude HD 185782 — are lined up just right to help complete the E.

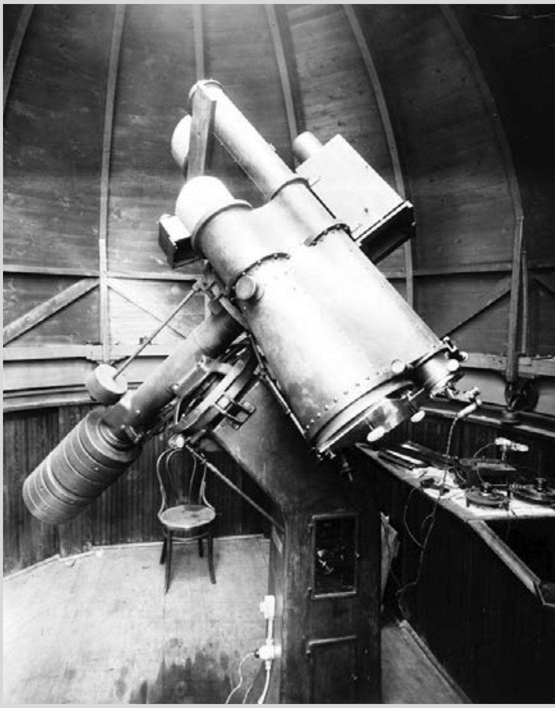
Fast forward to April 2025. I was able to revisit Barnard's E under an exceptionally dark sky at Chickahominy Reservoir in southeastern Oregon, which delightfully expanded on my earlier observations. This time I had my 10×42 binoculars, 80-mm finderscope, 8-inch f/3.3 Dobsonian, as well as my 30-inch. While observing the E, I kept wondering which view Barnard would have liked best — they were all quite remarkable. My most enjoyable views were from opposite ends of the aperture range. In my 10×42 binoculars:

> *Arguably this is the most enjoyable view! The super-wide 6.5-degree-wide field of view is gorgeous, and shows just how big the E is — much larger than I expected. The Milky Way through here is beautiful and is variegated with lots of diffuse dark nebulae. 21.96 SQM.*

Perhaps the most pleasing aspects of the binocular view was not only seeing the E in its proper orientation, but also in its wider Milky Way context. No joke — binoculars might be the only optics you need to appreciate this object.

However, the view in my 30-inch wasn't too shabby, either:

> *. . . the edges of the entire E look less dark than the center areas — almost giving them a slightly luminous look! The darkest part is the end of the "bottom" arm (B142) — its end is rather definite. No sign of the dark convolutions in B143 though. 82×, 21.92 SQM.*



▶ **SPECIAL INSTRUMENTS** The Bruce Photographic Telescope that Barnard used for his second survey of the Milky Way comprises the 10-inch camera, a 6.25-inch photographic telescope, a 3.5-inch refractor guide scope, with a lantern lens (the box on top).

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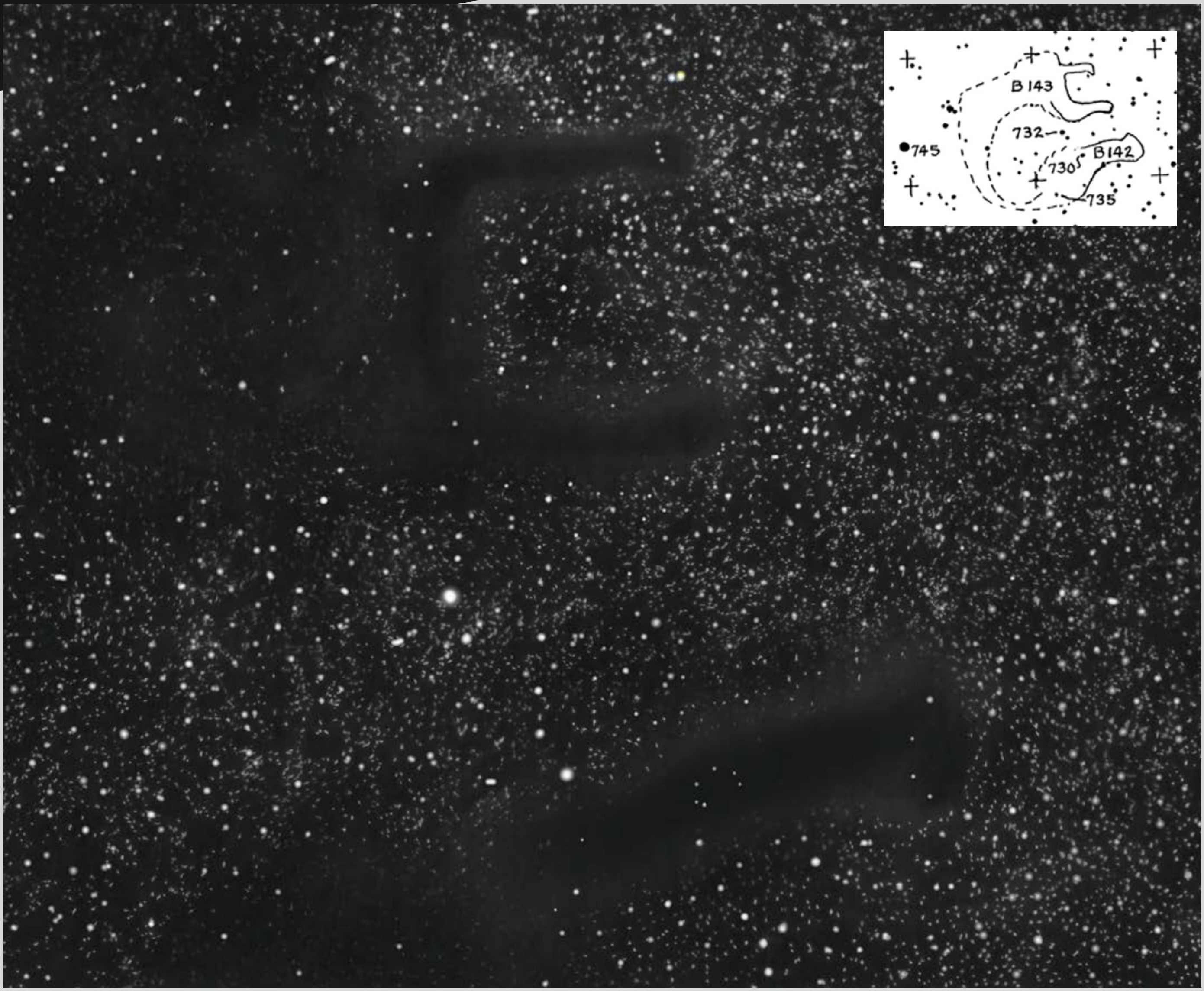

▲ **EXCEPTIONAL VIEW OF THE E** My sketch gives an idea of the view I enjoyed of B143 (top) and B142 (bottom) through my 30-inch Dobsonian at 140×. The contrast and sharpness were exceptional. Note how B143 is less distinctly defined on its eastern (left) side and how the Milky Way stars shine undiminished between B143 and B142. The inset shows a crop of a hand-drawn chart depicting how Barnard saw B143 arcing eastward and south to connect with B142. The cross-marks are 1° of declination, and the star HD 185898 is identified as 732 and HD 185782 is labeled as 730.

SKETCH: HOWARD BANICH; ZOOM: BARNARD, EDWARD EMERSON / *A PHOTOGRAPHIC ATLAS OF SELECTED REGIONS OF THE MILKY WAY* / EDWIN B. FROST AND MARY R. CALVERT / CARNEGIE INSTITUTION OF WASHINGTON, 1927

> *I then tried 140×, and wow, the effect of the light edges and darker centers was really pronounced! Also, the contrast and sharpness of the 17-mm Nikon eyepiece was superb on the E, and edges out the 10×42 binos for the most enjoyable view. 21.92 SQM.*

This observation was not only memorably beautiful but added an unmistakable sense of depth and cloud-like reality to the E. Because I saw this in April, it was an early morning object fairly low in the southeastern sky instead of its mid-summer evening location when it's near the meridian. That aside, I'll never forget the remarkable clarity of the eyepiece view, and how dark the sky background looked at low power. Too bad inky-black and crystal-clear skies don't happen together more often. And since the nebula's visibility depends on its contrast with the background stars, nebula filters aren't helpful.

Of course, the object's E shape is just a chance juxtaposition of unilluminated interstellar gas and dust, and looks like it does only from our perspective. The letter E in various alphabets has been developing for only around 2,700 years, while the material that B142 and B143 are made of has existed for billions of years in one form or another. The age of its current shape is unknown but is certainly *far* older than our alphabet.

So, our pareidolic perceptions count for little in this reality, but that doesn't take away from our enjoyment of the E's cosmic and accidental alphabetic shape.

■ Contributing Editor **HOWARD BANICH** appreciates the fact that B412 and B143 mimic Barnard's initials and that his E is appropriately silhouetted against the Milky Way.

▶ VERSATILE SMARTSCOPE

Spectrum Optics releases the first model in its new line of smart telescopes. The MirroSky SPi53 ($799.99) is a modular "intelligent astrosystem" that can be used for both imaging and visual use. The system is built around a 53-mm ED refractor, a Go To alt-azimuth mount, and a CMOS camera with a Sony IMX662, 2.1-mp color detector. Together, the system aligns, identifies, and centers targets by plate-solving images with its onboard computer, then transmits exposures to your Apple or Android mobile device running the *MirroSky* app via a Wi-Fi connection. The 53-mm ED refractor connects to the mount with a Vixen-style dovetail rail and saddle and can be used as a finderscope on larger instruments. The camera resides in a small removable housing that fits in the refractor's 1¼-inch helical focuser and connects to the mount via a USB-C cable. The camera can be swapped out with standard 1¼-inch-format eyepieces and star diagonals. The SPi53 is powered by an internal, rechargeable battery. The system comes with a small tabletop tripod and a pair of USB-C cables.

Spectrum Optical Instruments
20914 Bake Pkwy., Suite 108, Lake Forest, CA 92630; spectrumoi.com

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▶ SEEING MONITOR

Santa Barbara Scientific partners with QHYCCD to bring you the SM-4 and SM-4 EX seeing monitors ($1,849 and $2,449, respectively). These devices are built around a QHY5III462M CMOS camera and 30-mm objective lens that continually image stars near the celestial pole to provide accurate, real-time updates on atmospheric steadiness. Both units are housed in a weather-resistant aluminum case with an optical-quality window to protect it from the elements. They connect to standard tripods or ball heads via a ¼-20 threaded port. The SM-4 EX includes a USB-3 extender, an ethernet transmitter, and a receiver that allows use of the seeing monitor positioned several hundred feet away from the control computer. Both seeing monitors are controlled with the *Seeing Monitor* software for Windows operating systems.

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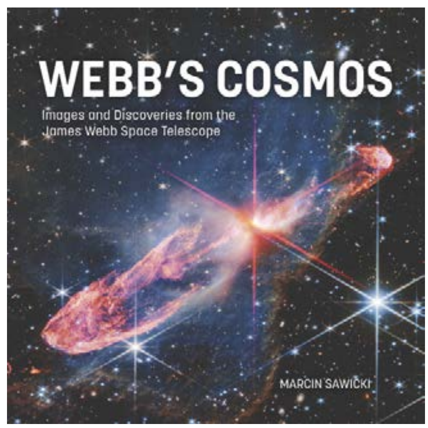
▶ JAMES WEBB BOOK



Astronomer Marcin Sawicki announces his new book *Webb's Cosmos: Images and Discoveries from the James Webb Space Telescope* ($49.95). The book showcases some 200 color photographs produced by the telescope in the nearly four years in operation. It begins with a chapter discussing the origin and development of its design, followed by sections organized by subject matter, including stars and gas clouds, galaxies, and the planets in our solar system and beyond. Many of the images compare the observatory's infrared images with visible-light versions recorded by the Hubble Space Telescope and other major NASA missions. *Webb's Cosmos* is richly illustrated with additional graphics explaining concepts like the expansion of space and why infrared light is so important to understanding the universe around us. Hardcover, 25-by-25 centimeters (10-by-10 inches), 304 pages, ISBN 978-0-228105-73-2.

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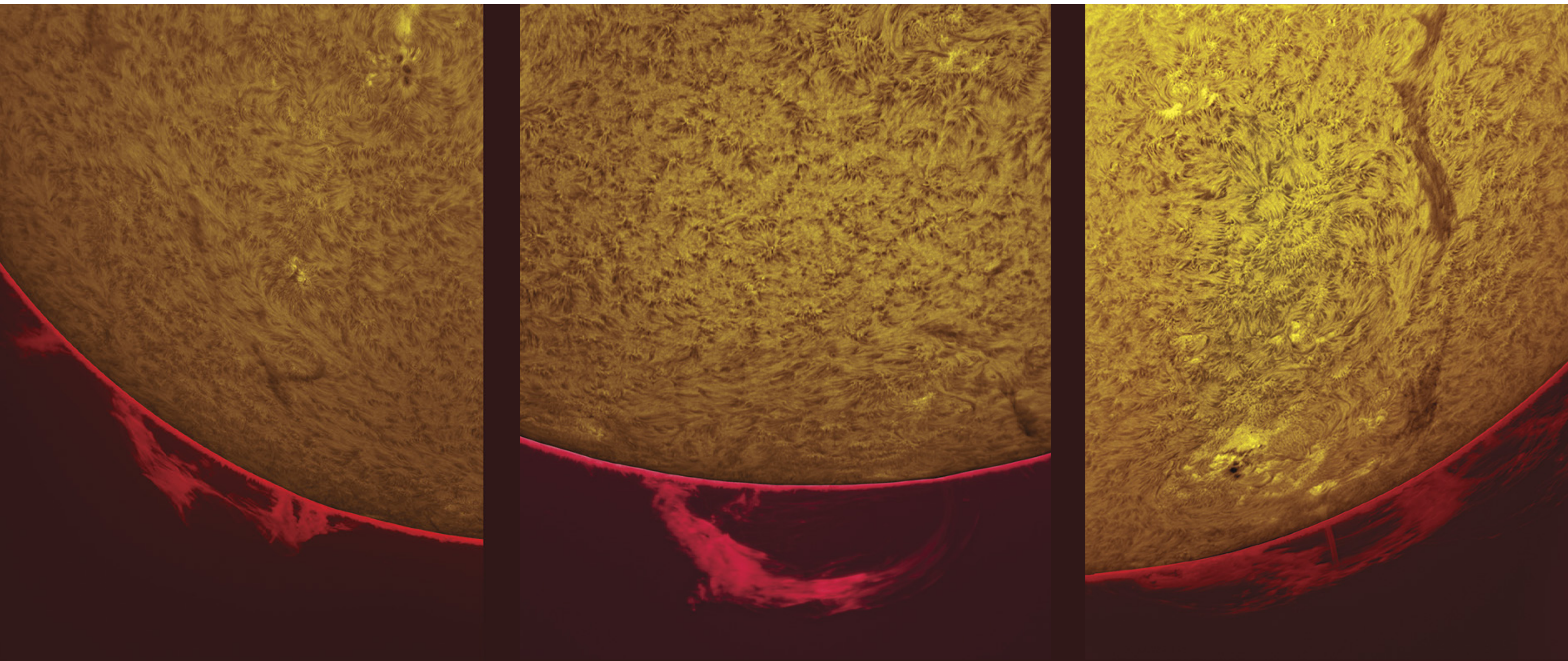
New Product Showcase is a reader service featuring innovative equipment and software of interest to amateur astronomers. The descriptions are based largely on information supplied by the manufacturers or distributors. Sky & Telescope *assumes no responsibility for the accuracy of vendors' statements.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



Imaging Solar Prominences

Here's how to capture these flowing streams of glowing plasma.

We're well into solar maximum, and so it's a great time to explore our active Sun and all its marvelous details. The Sun's visible disk, called the photosphere, is often peppered with sunspots, while the layer above it, the chromosphere, is even busier with snaking filaments and towering, shimmering prominences ringing the solar limb. Capturing dramatic images of these dynamic displays is easier than ever. There are several ways to do it, but here's the method I use.

Narrowband Displays

Prominences are clouds of plasma that are held aloft tens of thousands of kilometers above the chromosphere by powerful magnetic fields bursting through the solar surface. When seen along the Sun's limb (edge) against a dark background sky, they present a wide range of structural forms, from hovering, detached clouds to massive arches and loops.

There are two main types of prominences. *Quiescent prominences* are statically held in place by weak but stable magnetic fields and can last for days or weeks or even months at a time. They resemble tall spikes, trees, shrubs, or mounds on massive scales many times larger than Earth. As the Sun rotates, these features appear as dark silhouettes, called filaments, against the brighter solar disk.

While a prominence is suspended above the limb, several things can happen. Most often, it sinks back into the photosphere and vanish. Sometimes the magnetic fields supporting the plasma collapse, causing the prominence to jettison into space over the course of a few hours. Known as an *ascending* or *eruptive prominence*, witnessing such an event is a solar observer's dream.

▲ **LIMB DANCE** Massive solar prominences are seen suspended above the solar limb on several days in 2024.

Solar flares occurring along the limb can also create many interesting effects. Flares, which are intense bursts of light and radiation, are usually seen on the Sun's disk near sunspots and active regions that become much brighter than the rest of the chromosphere for a short time. But occasionally, they occur while an active region is rotating onto or off the solar disk. When this happens, they briefly display sprays or jet-like bursts of plasma accompanied by very dramatic arching prominences. But the most photogenic period occurs as the flare starts settling — for a few hours afterward the flares can display gorgeous loops. These beautiful hoop-like prominences can circulate plasma in Slinky-shaped coils and drizzle plasma down to the surface in what is called *coronal rain*.

◀ **IMAGING ARSENAL** The author with one of his imaging platforms, which includes (among other scopes) a Lunt Solar Systems LS100THa dedicated hydrogen-alpha solar telescope.

There are two primary regions of the spectrum where prominences are visible. First and best is in the light of hydrogen alpha (Hα) at 656.3 nanometers. At this wavelength, prominences on the limb appear bright with excellent contrast and details. The atmospheric seeing at the red end of the spectrum also is far better than at shorter wavelengths, yielding sharper images overall.

The second region is the near-ultraviolet calcium-K (CaK) and calcium-H (CaH) wavelengths at around 393.4 nm and 396.9 nm, respectively. While they're not easy to see visually, being so deep into the violet end of the spectrum, the broader spectral response of a camera sensor shows them well.

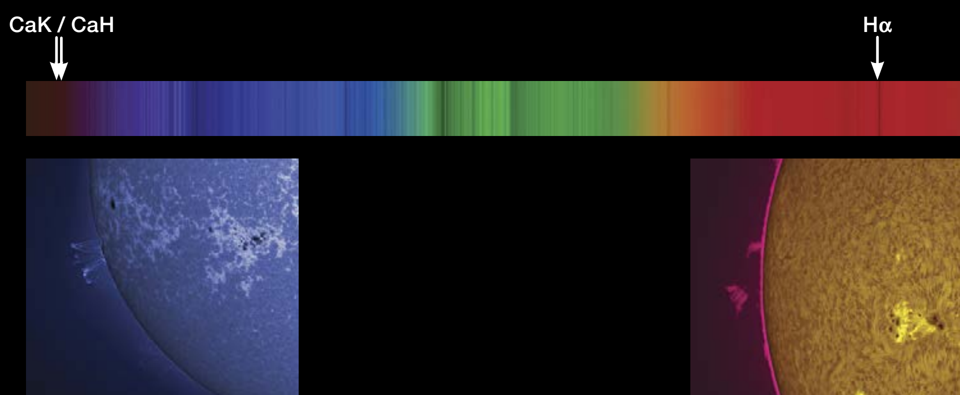
Prominences appear much fainter and more diffuse in the light of calcium partly due to the specific parts of the chromosphere that we're seeing. CaK and CaH show details on the solar disk that are lower and cooler in the chromosphere than Hα.

Tools for the Task

The most common and safest way to see prominences (aside from during a total solar eclipse) is with a refracting telescope fitted with a CaK or *solar* Hα filter (the latter shouldn't be confused with filters meant for deep-sky imaging, which are unsafe for solar work). Several companies produce these specialized, narrowband solar filters and even complete, dedicated solar telescopes with filters permanently installed. The bandwidth of the filters required to reveal prominences doesn't need to be as narrow as required for full-disk imaging. A 1-nm passband will show prominences clearly, though the solar disk will be very bright and distracting. Better still is the current crop of 0.7-nm filters which yield good contrast for both the disk and prominences. Narrower filters or stacking two filters together should be avoided because the view would be dimmer and require longer exposures. In addition, rapid motions of the plasma within a prominence will move their structures out of band due to the Doppler effect, causing them to fade out.

The ideal solar telescope is an achromat that permits you to capture the entire solar disk on your detector. Most 60-to-90-mm refractors with focal ratios between f/6 and f/8 will do the job when paired with common sensor formats. In addition, you can zoom in with a Barlow lens or other telecentric image amplifiers such as the Tele Vue Powermates. This range of magnification on the sensor will show fine details down to the limits of normal, average daytime seeing conditions.

As for your detector, practically any camera can record prominences through a CaK or Hα solar filter, although a monochrome camera is preferred as you're targeting a single wavelength of light. The choice of sensor size and its photosites (pixels) depends on several factors, including your telescope's focal length and whether you want to image the entire solar disk or concentrate on smaller, select regions. Smaller pixels effectively increase your magnification and



TARGETED WAVELENGTHS The chromosphere, where prominences are seen, is visible in three narrow regions of the spectrum. They are strongest at the red end of the spectrum at 656.3 nanometers (hydrogen alpha) and fainter in the violet regions of 393.4 and 396.9 nm, the calcium-K and calcium-H bands, respectively.

reduce the need for the more powerful Barlows or Powermates.

Cooling the camera isn't essential since the exposures are short, though it's recommended to keep the sensor temperature stable so you can apply calibration frames properly.

Also, be aware that some solar and planetary cameras on the market are limited to 8 bits analog-to-digital resolution. This yields only 256 shades of grey and is barely sufficient to yield good contrast. A better choice is a 12-bit or 16-bit camera which provides 65,535 shades. I find the difference in image quality between an 8-bit and 12-bit camera to be staggering.

While you can record solar features with a deep-sky camera, you'll obtain the best results using newer, dedicated high-speed planetary video cameras with a fast, USB 3.0 output. These cameras generate dozens of frames per second, which improves your chances of capturing some frames during moments of steady seeing.

Capture Technique

Once you've assembled your gear, here's how to get the most out of it under the Sun. The best time for solar photography is during the early- to mid-morning hours, before the Sun heats up your surroundings and spoils the seeing.

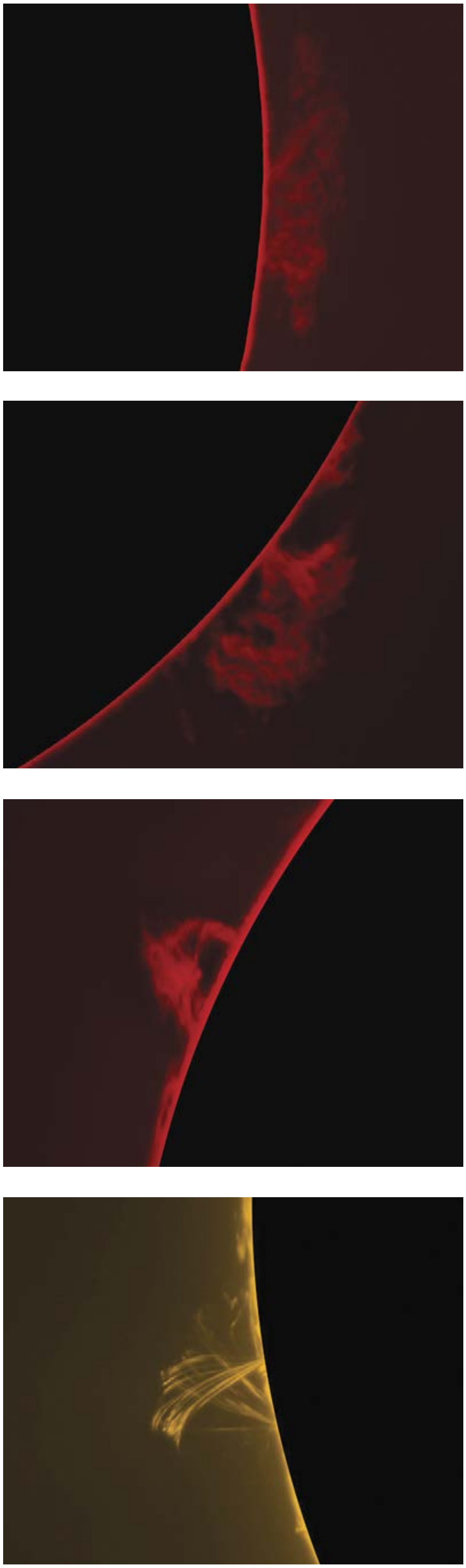
Unlike deep-sky astrophotography where the final masterpiece is produced in the digital darkroom, solar imaging doesn't require a lot of post-processing besides stacking and sharpening. As such, your choice for imaging software and the settings you choose are far more critical. You can't simply go back and reshoot a gorgeous prominence the next day if your image doesn't come out as expected.

While the manufacturer's control program that comes with most cameras is usually sufficient to capture some images, dedicated software specifically designed for the job offers far more options. I'm partial to the freeware *FireCapture* (**www.firecapture.de**), which offers many settings for planetary, lunar, and solar imaging. Another good option is *SharpCap* (**sharpcap.co.uk**), which is also free. Both output images or videos in a variety of formats that are compatible with most post-processing software.

The three most critical settings you need to be familiar with are *exposure*, *gain*, and *gamma*. While the first two are commonly used for lunar and planetary imaging, you may need to activate the gamma slider in the settings menu manually if it's not already present.

So, what is gamma and how do we use it for solar imaging? Gamma is a tonal range setting that establishes the midtone contrast. Mathematically, gamma ranges from 0 to 2, and sometimes higher, with 1 being the normal midtone contrast setting. Values less than 1 yield a strong midtone contrast boost, while more than 1 does the opposite. When imaging prominences, your target is set against a nearly black background with the prominence ranging in brightness from brilliant white at the base to extremely dim and tenuous at its top. To record the entire range without overexposing the base of the prominence or any bright spicules (short, needlelike prominences), I like to increase the gamma to more than 1, with around 1.5 as a good starting point. How gamma is measured varies depending on the camera control program. *Firecapture* offers a range of 0 to 100, with 50 being the midrange gamma equivalent of 1. For prominences, I prefer settings between 75 and 100.

Getting the initial exposure and contrast as best as possible while recording your video at the telescope is crucial to pulling out the fine details later in processing. With the



▶ **PROMINENCE MORPHOLOGIES** Prominences can appear in a variety of shapes, sizes, and forms. The most common are seen at right and often resemble hedges, trees, arches, and loops.

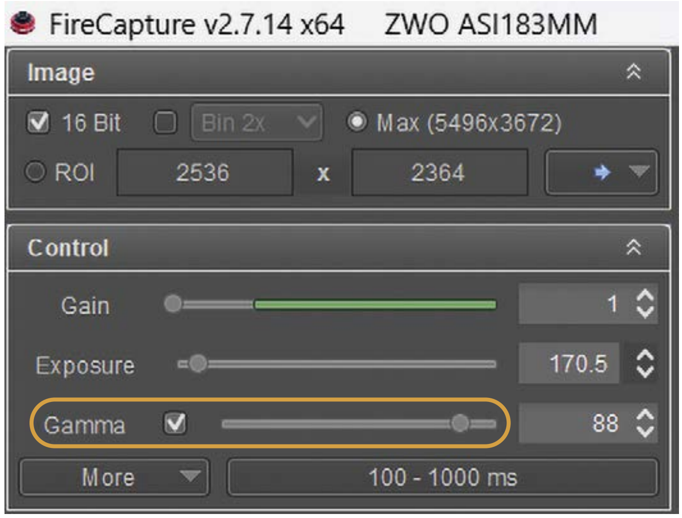
gamma set initially to around 1.5, adjust the exposure such that the solar disk is completely saturated (appears white) while ensuring spicules along the limb aren't also saturated. As the sky background will vary considerably due to atmospheric scattering and water vapor, the goal here is to set this to appear gray rather than black.

I keep the gain set to the lowest value so that noise levels in the resulting videos are negligible. It's more important to set gain to a minimum than to get the shortest possible exposure times.

How many subframes you take on each video clip depends on your camera noise levels, the seeing conditions, and the length of each video. Prominences move noticeably in only a few minutes (sometimes less), setting a limit on the length of your recording. For example, if your camera records 10 frames per second, you're limited to maybe 180 frames to avoid motion blurring at high magnifications. With fast-moving prominences, you're limited even further to about 30 seconds or less. Full-disk recordings can be several minutes long as movements in prominences aren't as apparent at this lower image scale.

After recording your videos, be sure to spend a few minutes capturing some calibration frames. Taking flats and darks are a critical step to producing your best solar images. Flat-field frames not only clean up dust spots, but they also correct vignetting, which causes the corners of your field to appear darker than the center.

To record my flat-field frames, I stretch a white plastic grocery bag over my telescope aperture and shoot about 100 frames with the exposure time adjusted to place the histogram's peak in the middle range in *FireCapture*. Flat-fields for high-magnification images are a bit trickier. I aim the scope near the center of the solar disk where there are no sunspots or filaments and defocus the telescope to make the disk uniform in brightness. Then, with the same gain and gamma



▲ **CONTRAST BOOST** Adjust the ***Gamma*** slider in your control software (the example shows *FireCapture*) in order to set the midtone contrast before recording your videos.

settings used for the prominences, I adjust the exposure until the histogram peaks at the midpoint.

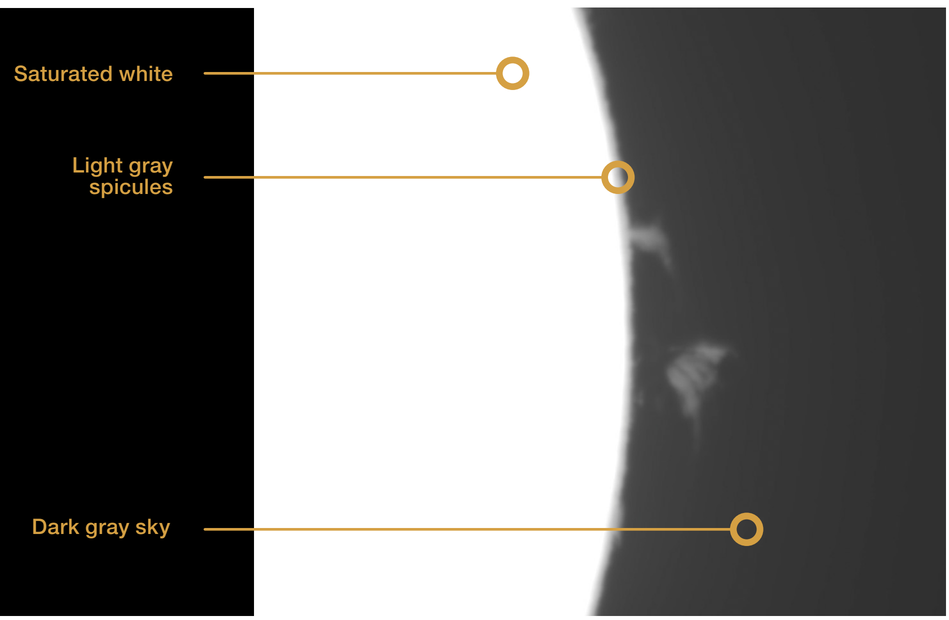
Dark frames are optional, but consider that every bit of noise removed from your image set will increase the quality of your final results. (Darks are recorded with the same exposure time and settings, but with the lens cap on.)

Data Reduction

Solar imagers today have several choices of software that can automatically align and stack solar images and videos. One of the best that consistently produces the sharpest results, in my opinion, is the freeware *Autostakkert!4*, by Emil Kraaikamp (**autostakkert.com**).

To use the program, I start by creating my dark and flat-field calibration frames. First, I'll select ***Surface*** in the Image

EYEBALLING EXPOSURE You can't use the histogram to determine the best exposure for prominences because the solar disk needs to be overexposed in order to achieve the best signal in the prominences. Increase your exposure until the solar disk is saturated but the spicules (short, spiky prominences) are bright but gray. The background sky should also be dark but not black, so that the faintest plasma is revealed in the recording.



Stabilization section. Then I click ***1) Open*** and navigate to my video files and select my dark exposure video. Now, I select ***Create Master Frame (uses master dark if loaded)*** from the Image Calibration pulldown menu. A new window opens where I'll save the resulting stack. I choose an appropriate filename like MasterDark.tif and in a few moments, the video is stacked into my first master dark. I repeat the process for each dark and flat-field video.

With the calibration images ready, I'll open my first prominence video and load the master calibration files by selecting ***Load Master Dark*** and then ***Load Master Flat*** from the Image Calibration option in the pulldown menu.

Next, I select an image stabilization anchor by holding down the Ctrl button and clicking on a distinct feature within a prominence, then press ***2) Analyse***. In a minute or two the stabilization process is finished. At this point I need to manually select the registration boxes for the image. I first select an alignment box size of, say, 32 from the options along the left side of the preview window. Now I'll click on spicules on the solar limb and a few on the prominence (or prominences, if there are several).

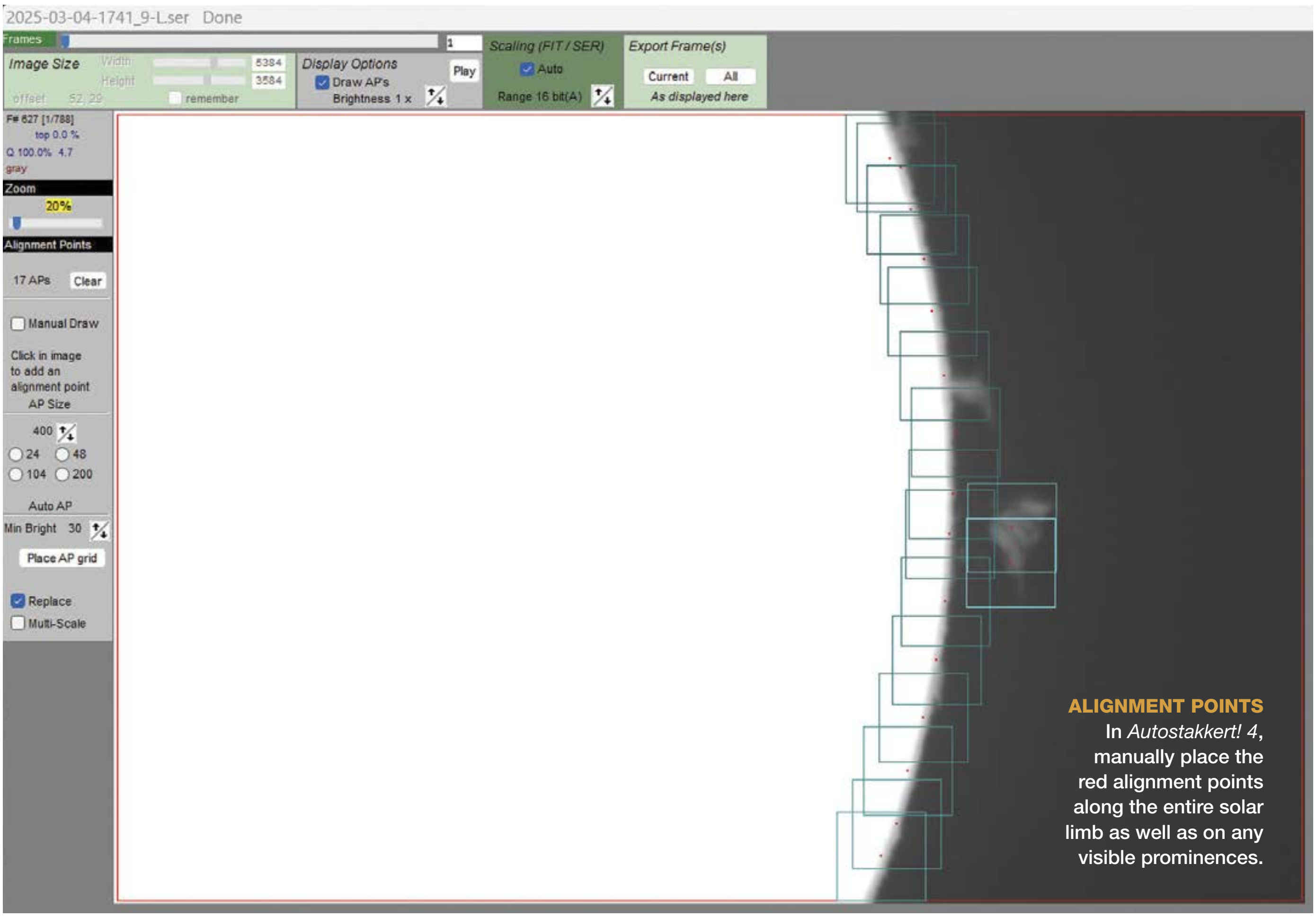
When I feel I've chosen enough alignment points, in the Stack Options column I first choose an output format (I prefer FITS, though the software also can export 16-bit TIFF and PNG files). For the final setting before stacking, I enter either the exact number or percentage of frames to stack in the right column of the control window. I typically select percentage and stack both 10% and 20% and click ***3) Stack***. After it's finished, I repeat the routine for each video, making sure to select different dark frames to match the exposure being stacked.

Additional Processing

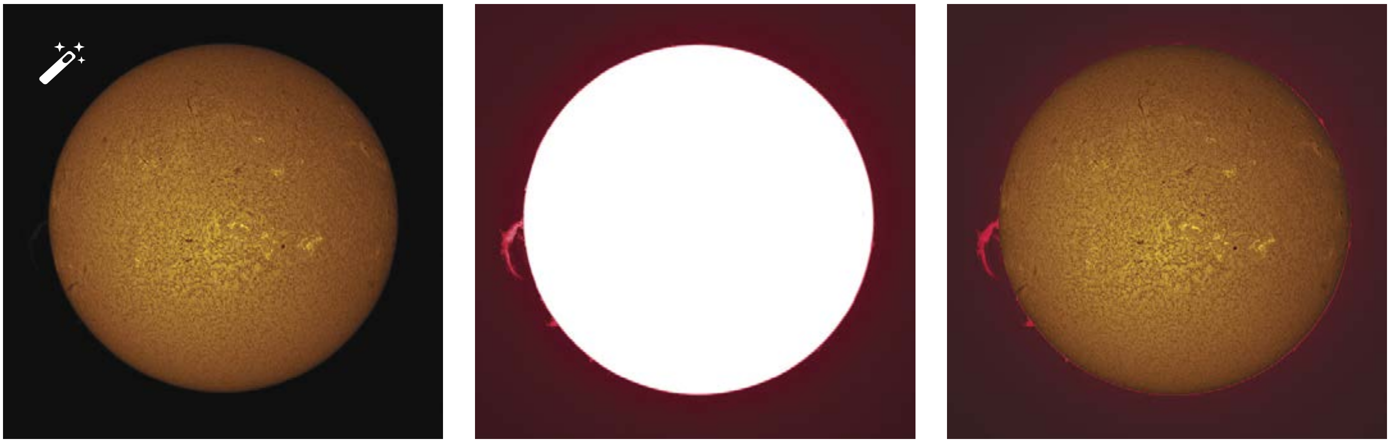
After stacking each video set, the images are ready for sharpening and other cosmetic work. I often use both *PixInsight* and *Adobe Photoshop* (*S&T:* July 2024, page 60). I typically sharpen with *PixInsight's* wavelets tool since daytime seeing at my observatory in northern Arizona is typically very poor, but your conditions may be better.

The rest of the cosmetic work is performed in *Photoshop*. I start by darkening the background sky by choosing ***Image > Adjustments > Levels*** from the pulldown menu. In the Levels palette, I move the left slider toward the right until it's near the start of the histogram signal.

Next, I'll deal with the overexposed solar disk. There are two ways to address the disk — either filling it with black to resemble a total solar eclipse, or a properly exposed chromosphere image recorded before or after the prominence video.



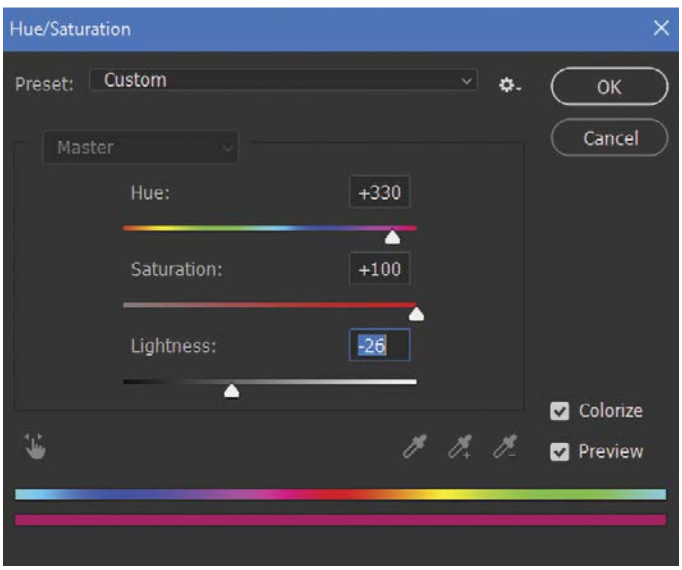
ALIGNMENT POINTS In *Autostakkert! 4*, manually place the red alignment points along the entire solar limb as well as on any visible prominences.



▲ **COMPOSITING COMPLETION** Combining a properly exposed disk image (left) with a prominence shot (middle) is fairly easy in *Adobe Photoshop.* Use the ***Magic Wand*** tool to select the background of the disk image, then invert the selection and copy it to the clipboard as explained below. Now click on the prominence image and paste the selection in. You'll need to use the ***Move*** tool to nudge the layer into position (right).

It's fairly straightforward to select the overexposed area in *Photoshop* using the ***Magic Wand*** tool with its Tolerance set at 40. Just click on the disk area to select it. Switch to the ***Paint Bucket*** tool and make sure the ***Color Picker*** at the bottom of the Tools palette is set to black on top, then click on the selected area. Voilà! The disk turns black.

If I've shot a properly exposed disk image to create a composite view, I'll start by cutting out the disk and copying it to the clipboard. I'll first use the ***Magic Wand*** tool to select the sky around the disk. I'll adjust the tool's Tolerance setting and click the background until the selection tightly fits around the limb and then invert the selection with ***Select* > *Inverse*** from the pulldown menu. Next, I apply around 100 pixels of smoothing (***Select* > *Modify* > *Smooth***). I then contract the selection 2 or 3 pixels to avoid a dark rim along the Sun's edge and copy the selection with ***Edit* > *Copy***. Now I'll open the prominence image and paste the selection using ***Edit* > *Paste***. Then, using the ***Move*** tool I drag the disk layer over the white area of the prominence shot until it's centered. If some of the disk's bright rim is still visible, I can slightly stretch the pasted image by selecting ***Edit* > *Transform* > *Scale***, then I grab the corner of the layer and drag it out slightly until the saturated disk image is covered.



▲ **COLORIZATION** Adding hue to the result, if desired, is easy in *Adobe Photoshop* using the ***Hue/Saturation*** tool.

With color and sharpness addressed, I usually colorize the image with some hue shade for aesthetic effect. In *Photoshop,* I use ***Hue/Saturation*** found in the pulldown menu at ***Image* > *Adjustments* > *Hue/Saturation*** and select the Colorize checkbox at the bottom. I then adjust the ***Hue*** slider to the desired color and set the ***Saturation*** slider to between 80% and 100%, and adjust the ***Lightness*** slider such that the dark sky outside the Sun is the proper shade.

The color you choose to make your picture is up to you, though I prefer mine to approximate the true color of the wavelength targeted. Prominences seen during a total solar eclipse are always an intense pink color, the natural deep-red color of hydrogen alpha (roughly a Hue value of 330). Other colors that are popular with solar imagers are red (360), amber (35), and blue-violet (242) for CaK images.

Don't Forget the Sunscreen

Prominences are an extremely rewarding target because they never appear the same day to day, and can even radically change or dramatically blast into space within minutes. Even better is they can appear at any time during the solar cycle — not just at solar maximum. With some care and a bit of planning and patience, you can capture some of the most dramatic and powerful events in the entire solar system right from your backyard.

■ The International Astronomical Union has designated asteroid 70850 Schur in recognition of **CHRIS SCHUR**'s and his wife, Dawn's, outstanding work in the fields of astro-imaging and paleontology. Visit their website at **schursastrophotography.com**.

Starpoint Australis Portable Observatories

These observing tents offer a sturdy shelter for traveling imagers and observers.

The Octans and the Phoenix portable observatories shown ready for a night of imaging and observing. Both models are spacious enough to house a full-fledged mobile observatory.

Phoenix Observatory

Base price: $374;
$549 with wind shield;
$699 with ground mat and wind shield

Octans Observatory

Base price: $549;
$749 with optional wind shield;
$879 with ground mat and wind shield

starpointaustralis.com.au

What We Like

Tough and durable

Clever wind blocking

Screw-in tent stakes

What We Don't Like

Tent poles slightly too long

**Prices subject to change*

OVER THE YEARS I've tried a few observing tents but have yet to find one to my liking. My favorite event is the Winter Star Party in the Florida Keys, an excellent location with very dark skies to the south, but one that can often be quite breezy. For astro-camping trips like this, I'd even considered making a PVC-based "box" with tied down tarps to block the wind. But after an unusually windy week in 2024, I began to search for a better solution.

A couple of months later at the Northeast Astronomy Forum (NEAF), I encountered Starpoint Australis, a new manufacturer offering a pair of portable observatories designed with rough weather in mind. Their tent's thick material and wind-shield design looked to be the answer to my problems. So, after speaking with the owner, Brendan

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▼▶ Assembling of each observatory is similar to most camping tents. Begin by staking down the ground pads (1). Secure the tent to each peg using the S-hook carabiners (2), then insert the four structure poles (3). Next, insert the ends of each post into the eight aluminum posts at the base of the tent (4). Insert the long pole into the top sleeve, then connect the wind shield and its structural pole (5).

Mitchell, he sent me both of their tents to try out for this review.

Bundled For Travel

The Starpoint Australis Octans and Phoenix portable observatories are identical in every respect except for size. The Octans is largest with a diameter of 3.8 meters (12 feet) at its base and a weight of 24.4 kilograms (53.8 pounds). The smaller Phoenix model is 2.8 meters across and weighs in at 18 kg. They are both fairly heavy, something to remember when traveling with one. Both wall heights are similar with the Phoenix being only 100 millimeters (4 inches) shorter than the 1.6-meter height of the Octans. The wind shield on the Octans extends its height to 2.5 meters, while the shield raises the Phoenix's height to 2.1 meters.

Each observatory tent is made with thick, waterproof, 420D polyester with a PU coating. The outside is reflective silver designed to minimize daytime heating, while the interior is flat black to prevent light from being scattered. The overall design will be familiar to anyone who has assembled a modern camping tent. Aluminum tent poles extend and are threaded through sleeves in the tent to support the structure. Although the tents have a thick floor, there's also an optional ground mat for added protection on rough terrain.

Two doors on opposite sides each have a pair of zippered layers — one solid for nighttime use, and a screened flap to allow airflow during the day while keeping curious critters outside. Both can be rolled open and tied neatly at the bottom. A cover is included that's made of the same material as the tent that's tied down over the top to protect against precipitation. An additional set of poles are installed that raise its center to allow rain to drain off preventing pooling (an important feature that shouldn't be neglected, as I soon discovered).

▲ *Left:* The tent pegs screw into the ground and offer a more solid anchor than typical tent stakes. A custom bit is included to attach to a hand drill making the task quick and easy. *Right:* Aluminum S-hook carabiner clips fasten the tent base to the tent peg. Also seen is the aluminum peg that secures the structural poles.

The standout feature of both models, in my opinion, are the optional wind shields. You can raise the shield up completely around the circumference of the tent or just one section to block the wind (or light) coming from that direction. This is exactly what I needed for my annual and sometimes breezy Winter Star Party trip, and useful at my dark-sky site in South Florida as well.

Another excellent feature is something I've been missing all my life — tent pegs (stakes) that screw into the ground rather than needing to be pounded in. Starpoint Australis even includes a custom bit for a cordless drill so you can quickly screw the stakes in and out of the ground. Not only is this a huge timesaver, but the threaded pegs provide far better anchoring than standard tent stakes.

Field Assembly

Although I'm quite familiar with assembling camping tents, the lack of included instructions made setup for these observatories bewildering. Fortunately, there is a YouTube video that walks you through the whole process at **https://is.gd/obsassembly.** I confess that my first time assembling the Octans had me checking my notes a few

▼ The Phoenix model has plenty of room for movement around an equatorially mounted and short telescope.

4

5

times, but the learning curve isn't steep. Once you've done it a couple of times, it's easy to repeat the process. It only takes about 30 minutes or so to set up either tent.

The typical setup goes like this: First lay down the ground mat and secure it with the stakes. Next, lay out the tent and secure the base to the ground mat's rings using the aluminum S-hook carabiners. If you don't have the ground mat, you'd connect the S-hooks directly to the tent stakes.

So far, this is pretty standard tent assembly, but I needed to watch the video to figure out how the tent poles are installed. There's a set of sleeves along the sides of the tent, but initially I thought the poles should pass through the extra set of sleeves along the top aperture. However, these are for the very long pole (9-meters for the Octans) that makes a complete circle at the top of the tent. Keeping the top opening taut and rigid isn't a feature found in typical camping tents, nor any observing tents I'd encountered previously. Wind loves flaccid pieces of fabric to grab hold of, and this design aims to prevent that.

The final piece to install is the optional wind shield — something I regard as an essential purchase. The shield is a continuous loop of fabric with a thick and remarkably strong strip of Velcro connecting the shield to the top of the tent wall. The top of the wind

▲ The accessory covers did a good job of keeping rain out of the tents. The orange posts (*left*) support the rain fly and install in pockets along the interior of the base of each tent. These are required to ensure a taut cover to prevent pooling.

shield accepts another lengthy tent pole exactly like the top aperture ring. To install the two poles, I assembled them outside the structure then brought one partially into the tent while curving it along the interior, where I started feeding it through the aperture sleeves. This was a bit tricky. After completing the aperture ring, I repeated the procedure for the pole that installs within the top of the wind shield. Next, four sets of telescoping poles connect to the wind-shield. These are used to raise the entire shield or just a section of it.

A cover is also provided to protect your gear from rain and prevent heating up the interior during the day. However, this can't be used with the wind shield extended, so you need to be sure your telescope is oriented such that it doesn't protrude above the top edge of the tent.

The cover attaches to the tent body with four very thick Velcro anchor points, and a set of rope lines tie down its corners. It's supported by four orange poles that keep it elevated for good drainage and to provide more clearance over your scope. Because the tent is nice and rigid, the cover can be pulled over quite taut. This prevents wind from catching loose fabric and rain from being blown in.

In the Field

Both the Octans and Phoenix portable observatories performed as advertised and met my expectations. The tent material and poles stood up well to my

▼▶ Four telescoping poles (*left*) raise all (*middle*) or part (*right*) of the wind shield as needed.

abuse, and the interior didn't become an oven in the blasting Sun in Florida. Although the interiors weren't cool during a hot sunny day, the tent trapped considerably less heat than any I've used in the intense Florida Sun.

The smaller Phoenix model is quite roomy with about 6 square meters of interior space. It's plenty of room for a midsized mount and telescope such as an 8-inch f/4 astrograph. I had a Software Bisque Paramount MYT with my Astro-Physics 92-mm Stowaway comfortably operating within, along with piles of my gear stored inside and a chair. At night, I could sit inside the Phoenix with my scope, lean back, and stargaze. The wall material is quite opaque and allowed me to use my laptop to preview my images without worrying about the light disturbing my neighbors.

The Octans, on the other hand, is simply a palace. It's a meter wider and provides 11.3 square meters of ground space — nearly twice as much as the Phoenix. At the Winter Star Party, I had a Software Bisque Paramount MYT with a Celestron C14, a 6-foot table, a chair, piles of Pelican cases, and a small air mattress and sleeping bag inside the tent and didn't feel cramped at all! This is truly a portable observatory, well matched for rugged environments and temperamental weather. It can house some serious gear while serving double duty as a shelter.

I had one particularly breezy night this year while I was imaging Mars. I used the tent both with and without the wind shield extended. I could easily see in the live camera display how the bouncing ball of Mars slowed down and stabilized once the wind shield was up. Success!

Rain can be a formidable challenge, and Florida will never disappoint when it comes to heavy downpours. For my first experience putting the cover on before rain, I decided the scopes in the center under the cover would provide a natural slope, and the rain would drain off easily. This turned out to be a mistake — the rain pooled deeply on one side of the cover where it could have poured inside. I was able to rearrange the tie downs and get good drainage over the edge of the tent, then all was well. Subsequently, I made it a habit to use the provided center structure poles, and it was never an issue again. The only water inside either tent, even after some torrential rain, was from condensation. Again, Florida.

▲ The aluminum structural poles can break if they're bent too far as seen at left. Fortunately, the broken end could be trimmed and still put to use (*right*).

The aluminum poles that came with the tents had some issues. The poles that hold up the cover were too long by a whole section length. I had to fold over one section to shorten them, or else the cover was pushed too high to protect the whole opening. The tent structure poles also appeared to be little too long, but not by as much. They made for a very tight fit, and I over-stressed one of the poles during assembly, shattering it. Unlike when fiberglass poles break, it wasn't completely destroyed. I was able to cut away the broken end, which made the pole just a few inches shorter and easier to use. I told Starpoint Australis about both of these issues and was told that the tent poles in the first production run did come out longer than specified and that future kits would have poles the correct length.

Observatories to Go

Whether you are looking for a sturdy observing tent, or a larger, portable observatory outpost, both the Phoenix and Octans are good solutions. Each is heavy-duty and durable and proved capable of standing up to the Florida Sun and weather well. Both models should keep your equipment dry and safe during star parties and allow you to observe all night long no matter what the wind does.

■ Contributing Editor **RICHARD S. WRIGHT, JR.** serves as vendor coordinator for the Winter Star Party.

▲ The Octans model is especially roomy. While using it at the 2025 Winter Star Party, it provided plenty of space for a Paramount MYT mount, a 14-inch Celestron EdgeHD telescope, a sleeping bag, a table, and a chair.

 by Camille M. Carlisle

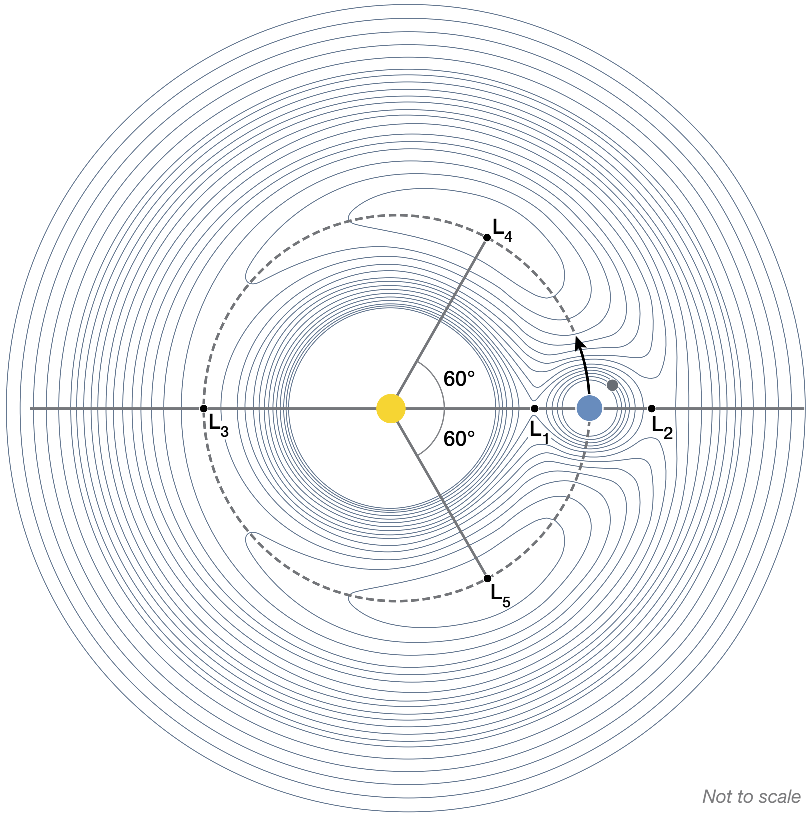
What are Lagrangian points?

IMAGINE SETTING two bowling balls on a waterbed. Each makes a divot in the mattress. You also place a marble on the bed, near the bowling balls.

Then you roll the bowling balls around each other on the bed. As the balls move, the mattress's contours change. The marble will have a hard time staying put — it'll likely be flung away or crash into one of the balls.

Something similar happens in the solar system. When two massive bodies in space — such as Earth and the Sun — orbit each other, they create an ever-changing gravitational landscape. (That's the waterbed.) Each of the two bodies warps space around itself. As the two bodies move, the gravitational effects they exert on their surroundings combine in different ways.

There are, however, five safe zones on the space mattress. Here, a third, much smaller body (say, an asteroid or a spacecraft) can travel with the two larger bodies, maintaining a constant distance from them both. These are the Lagrangian points. For the technically minded among you: At these points, the gravitational pull exerted by the two large bodies equals the centripetal force needed for the third, smaller body to keep its place in the orbital dance.



▲ **LAGRANGIAN POINTS** Five gravitational equilibrium points exist in the Sun-Earth system, where a much smaller body can orbit the Sun while maintaining a fixed location with respect to both our star (yellow dot) and Earth (blue dot). Closer contour lines correspond to stronger forces.

BEATRIZ INGLESSIS & LEAH TISCIONE / *S&T*; CONTOURS: NASA / WMAP SCIENCE TEAM

Parking Spots

Let's call the three bodies m_1, m_2, and m_3, in descending order of mass.

The first three Lagrangian points lie along a line that passes through m_1 and m_2. L_1 lies between m_1 and m_2 (order: m_1-m_3-m_2), and L_2 lies on m_2's other side (m_1-m_2-m_3). L_3 lies approximately on m_2's orbit but 180° away, on the other side of m_1 (m_3-m_1-m_2).

In the Sun-Earth system, we use L_1 and L_2 as spacecraft parking spots. L_1, which lies between the Sun and Earth, is a great location for Sun-studying craft, since they have an uninterrupted view of our star. A telescope at L_2, conversely, can keep its back to the Sun, Earth, and the Moon and stare into deep space. The James Webb Space Telescope is at L_2. We don't use L_3.

These three points are only safe for so long. They are saddle-shaped ridges bordering the mattress divots, oriented with the stirrups along the line connecting m_1 and m_2. If little m_3 comes too close to a stirrup side, it'll slide off and out of the safe zone.

Both L_1 and L_2 are only stable for 23 days or so. To stay put, spacecraft adjust course and attitude regularly.

L_3 is stable a bit longer, about 150 years. Perpetually hidden from Earth's view behind the Sun, L_3 would be a bad place to park a spacecraft that needed to communicate with Earth. But as astrophysicist Neil Cornish wrote in 1998, the 150-year time scale makes L_3 "a good place to park your invasion force while final preparations are made."

Stable Orbits

Unlike the first three Lagrangian points, L_4 and L_5 each lie at the vertex of an equilateral triangle, with m_1 and m_2 at the other two vertices. L_4 leads m_2 in its orbit about m_1; L_5 trails it.

L_4 and L_5 are stable, so long as the ratio between m_1 and m_2's masses is greater than 24.96. (Yes, that's very specific — blame Joseph-Louis Lagrange, the Italian-French mathematician who discovered these two points' existence in 1772.) The ratio holds true for the Sun-Earth system and several other pairings in the solar system.

L_4 and L_5 are shaped like hilltops, not saddles. When an object — such as a speck of dust or an asteroid — rolls down the hill, it picks up speed. The same force that spins up hurricanes on Earth then swings the object into a stable orbit around the hill. But other factors can boot little m_3 out over time.

Asteroids collected in a planet's L_4 and L_5 points are called Trojans. We've found Trojans shadowing several of the planets. Jupiter takes the prize, with more than 15,000 so far. We've found two for Earth, both at L_4. ■

A Trunkful of Tools

Who I am, what I did in the desert, and where we're going.

▲ Vera, the 16-inch hexapod Dobsonian, is ready for clear skies at the Texas Star Party. The 3D-printed bits of this scope are available under "Maff" at **printables.com**.

STARGAZING WITH A telescope you've made yourself is a sublime feeling. It's sweet enough to tolerate some jank or field repair and muttered profanity not included in store-bought instruments. The tradeoffs vary: Better portability, lower cost, and sharper views can all be had — though maybe not in tandem. And the best experience on a DIY project is first light, the first time you focus the finished scope on a field of stars. That's when all the notebook scribbles and splinter-riddled hands are vindicated.

I should introduce myself. By day I'm a physics teacher in Texas, where a few hundred know me as Mr. Kissner.

I cut my teeth in amateur telescope making building things in the digital era: My first "power tool" (besides a drill) was a 3D printer. Readers may recognize me from the Hadley Telescope (*S&T:* Jan. 2023, p. 70), a framework for 3D-printing simple, attractive reflectors. I dreamed (and CADed) it up instead of studying for qualifying exams after seeing one too many Christmas trees with terrible Bird-Jones reflectors underneath. Today, a few thousand Hadleys now see starlight worldwide. And from here on, I'll be the voice behind the workbench — at least until I'm an old-timer myself, clinging to my 3D printers as rookies churn out scopes from their newfangled replicators.

When Jerry Oltion adapted Telescope Workshop into Astronomer's Workbench, the scope broadened to include all the things we build for our hobby. Small, useful gadgets really have their place: Telrad heaters, stargazing chairs, and gyroscopic cup holders are indispensable. That focus won't change, and neither will Gary Seronik's legacy of covering amazing ATM projects.

Since I don't have an inbox full of submissions yet, I'll share one of my own projects.

I like to name my more impactful scopes after astronomers. "Vera" (Rubin) began when I, then a swamped graduate student, bought a 16-inch mirror in an online auction on eBay. With bated breath and some clenching, I did what one should do in these situations: watch and wait until the very last few seconds before bidding. Yet all the sweat and stress were wasted — no one else made a bid. Thirty pounds of glass was mine, for just $100 and a road trip.

▲ The secondary mirror assembly is held in position with steel wires connected to ukulele tuning pegs.

Goals are the foundation of a good project. My last ATM telescope — a deeply experimental 12-inch Dob — was riddled with problems, including a tedious field assembly, a focuser afraid of heavy loads, and a woefully imprecise truss. I had my eyes on the 2023 Texas Star Party (TSP) and my Dob traveled poorly. So, my goal crystallized: Build the 16-inch, without the problems of the 12-inch, by the first week of May.

The star party began the day I finished grad school, which would have been perfect timing, if only Vera were finished. Trusses lay unattached, fan holes

ALL PHOTOS COURTESY OF THE AUTHOR

undrilled, and my wire secondary spider was still a spool along with some ukulele tuning pegs. Still, I threw the half-finished scope and a pile of tools in my trunk and drove all the way across Texas.

To call this a gamble is an understatement. My design had gobs of experimental features I'd only seen online. I 3D-printed the fiddly bits, including the truss clamps, secondary hub and focuser interface. Was this allowed? The six-truss is a type of hexapod, where optical alignment is achieved by twisting its trusses in pairs; the secondary mirror "floats" in a web of wires. No collimation knobs whatsoever.

I camped next to fellow ATM Chris Hildreth, whose work I hope you'll see in this column in the near future. The first two nights were rainy, but this was as much a letdown as it was a silver lining: no lost stargazing due to the state of my scope! So, Chris and I worked feverishly under a canopy, protecting us from both the Sun and storm alike. We kept busy soldering, drilling, and stringing. Making a spider based on the *tensegrity* (tensional integrity) structural principle is an exercise in acupuncture. I ran thin, steel wire through a hub out to eight ukulele tuning pegs. My fingers spent the next several days perforated, a fact I was reminded of with each focuser turn.

On the third evening, clouds gave way to that special post-deluge clarity. We had everything mounted with

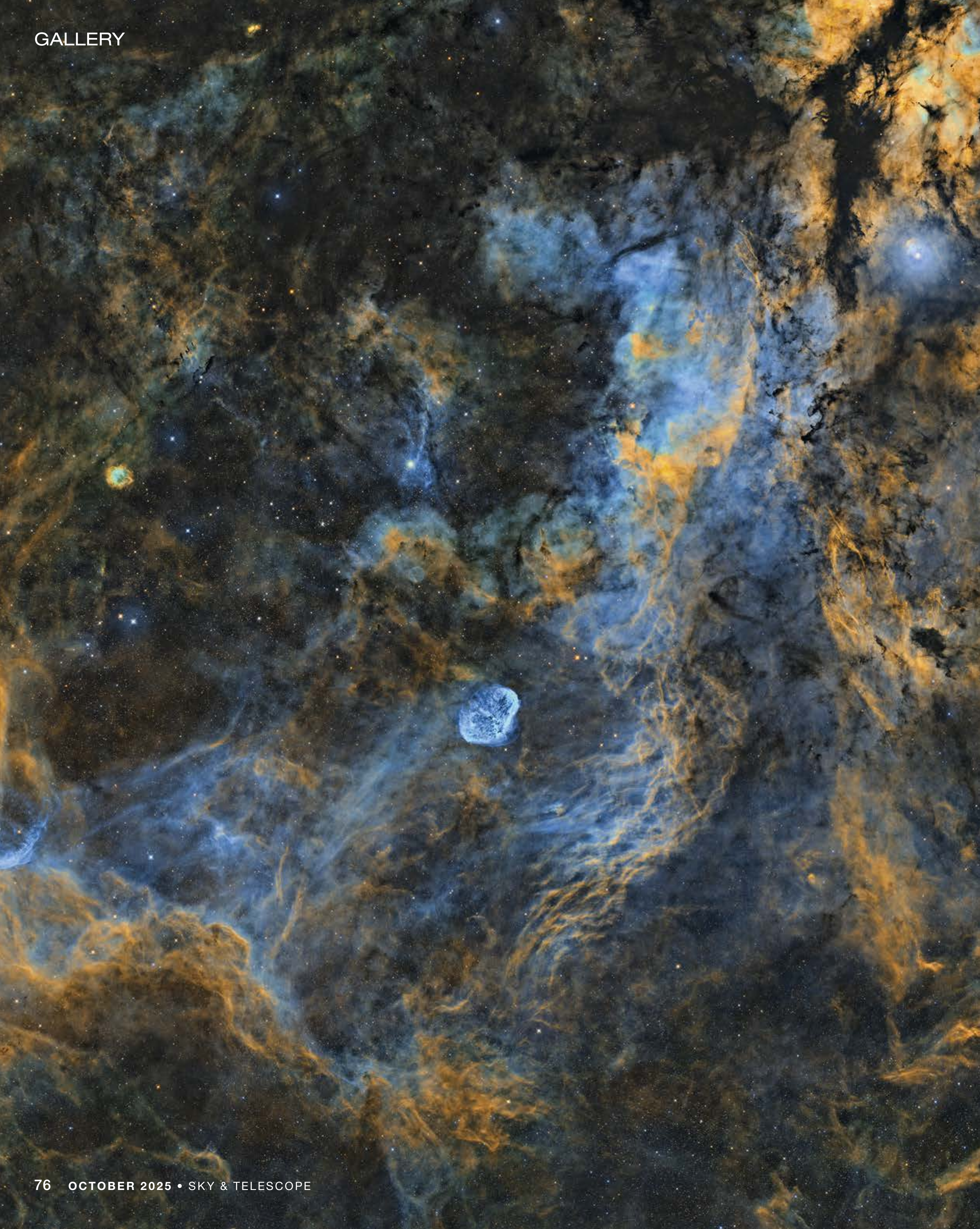
▲ The author's workbench at home where the magic happens.

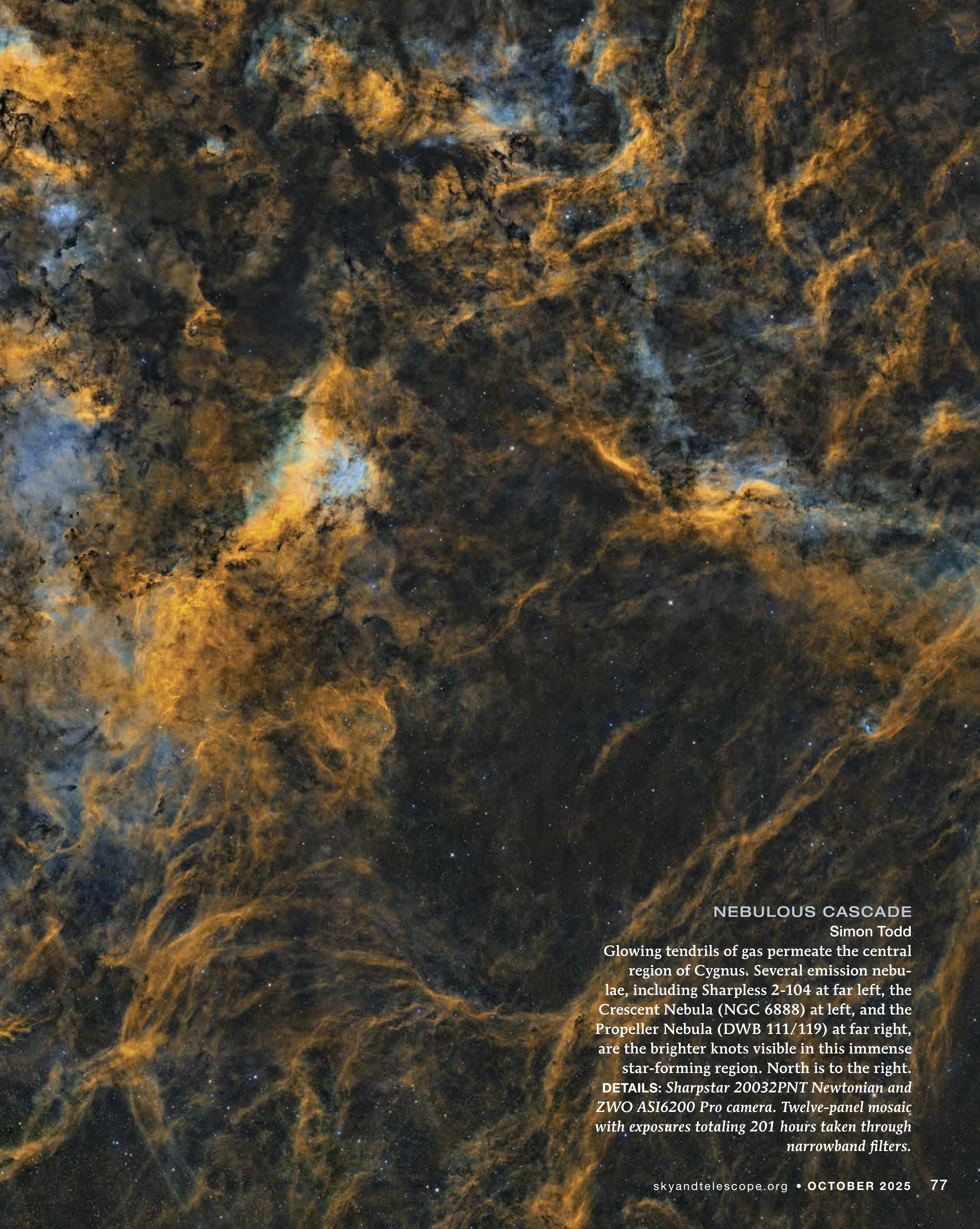
minutes to spare as Arcturus dimly came into view. Vera's adjustable truss came out a few inches too long and the twisting of poles that followed took years off my wrists' life. But slowly, the defocused donut became a beautiful, sharp star. I was struck by the intense color that aperture brings, and the clean star shape a wire spider presents. Whatever feeling a successful project brings, this had to be a superlative version of it (owed largely to Chris's help).

Jerry leaves big shoes to fill, and I'm honored to continue his column. I won't mess with his formula much. But as an avid 3D-printer, you'll see more printable projects to kick your astronomy up a notch, from lens caps to entire optical tube assemblies. And as I blunder my way through astrophotography, I'll also expand the column in that direction — watch for a guided star tracker you can build in less than a week! We might lose some screws along the way, but Astronomer's Workbench is still about homemade telescopes and other DIY doodads to streamline stargazing.

■ Contributing Editor **JONATHAN KISSNER** is excited to pick up the ATM torch. Enthused tinkerers can send him their project ideas at **workbench.kissner@gmail.com**.

▲ *Left:* A 3D-printed tuner-twisting bit helped tremendously while stringing the tensegrity secondary mirror assembly. *Middle:* While finishing the trusses, onlookers winced as I let the sky clean my mirror. *Right:* At least I could still see through the rear-view mirror.



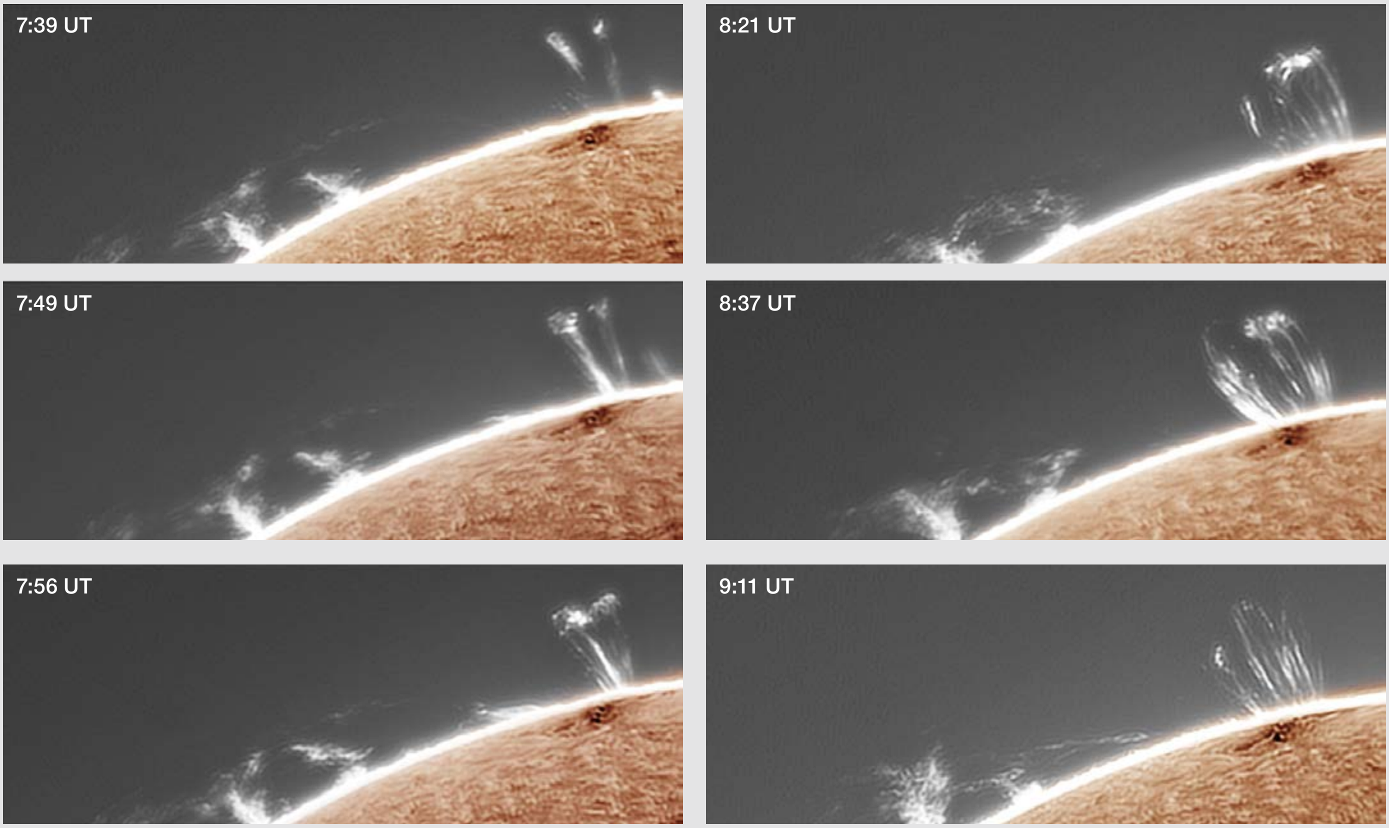


NEBULOUS CASCADE

Simon Todd

Glowing tendrils of gas permeate the central region of Cygnus. Several emission nebulae, including Sharpless 2-104 at far left, the Crescent Nebula (NGC 6888) at left, and the Propeller Nebula (DWB 111/119) at far right, are the brighter knots visible in this immense star-forming region. North is to the right.

DETAILS: *Sharpstar 20032PNT Newtonian and ZWO ASI6200 Pro camera. Twelve-panel mosaic with exposures totaling 201 hours taken through narrowband filters.*



△ CORONAL RAIN

Tom Nolasco

Several intricate prominences sprung up from the Sun's northeastern limb on June 3rd. Over a period of 1½ hours, cooling plasma in the corona condensed and fell back down into the chromosphere like rain.

DETAILS: *Lunt 60-mm solar telescope and ZWO ASI 174MM camera. Each image is a stack of 2,000 video frames.*

▽ MENIR DA MEADA AND THE MILKY WAY

Sérgio Conceição

The Milky Way from Perseus to Scorpius neatly framed Menir da Meada standing stone in Castelo de Vide, Portugal, on August 6, 2023. A meteorite is cutting through Lacerta at left as the Andromeda Galaxy is rising between the trees below.

DETAILS: *Canon EOS R6 camera and 15-mm lens. Total exposure: 2 minutes at f/2.8, ISO 640.*

SELENE AND THE PLEIADES

Patricio Calderari

The Moon appears yellowish as it passed through the Pleiades (M45) in the dawn hours of June 23rd. Alcyone and its companions (center) are the bright members of the cluster visible just above the lunar limb lit by earthshine while several fainter members of the iconic cluster are about to be eclipsed by the sunlit crescent. **DETAILS:** *Nikon D850 camera and 500-mm lens. Total exposure: 30 seconds at f/6.3, ISO 640.*

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FOCAL POINT by John Sebas

Holy Cow

Hey diddle diddle, the cat and the fiddle, the cow really does jump over (on, and partially around) the Moon.

I AM A BUSY family doctor, aged 71, based in St. Cloud, Minnesota, where I've practiced medicine for the past 30 years. As a primarily naked-eye observer, I've participated in a number of local star parties, where I've always had a lot of fun. I especially enjoy it when kids and their parents see the rings of Saturn for the first time. But, the Moon wasn't really my friend, it would often bleach out the sky on observing night.

At one point, I was being called in to the hospital at night on a more frequent basis, and I started paying attention to the Moon. I noticed that Earth's rotation would carry it westward by approximately 30° every two hours, which was the average time I would spend in the hospital, delivering a baby or admitting a patient. I also started enjoying views of the Moon during my frequent long bike rides in the evening.

As I began to study the Moon more with the naked eye, I focused on patterns, lunar *pareidolia*, that is, seeing meaningful shapes in random patterns — the Man in the Moon being a famous example. But I could not see the Man or the Rabbit or any of the most popular shapes without invoking much imagination. However, one memorable night, the more I looked, the more it became clear to me that what I *could* easily see was a cow on the Moon! It was made up of multiple marias between 12 o'clock and 3 o'clock on the disk of the full Moon. And Mare Crisium served as a halo over the cow's head. Holy Cow!

> Then I laughed. Could this be the whimsical "cow jumping over the Moon?"

▲The cow on the Moon jumps clockwise throughout the night.

Then I laughed. Could this be the whimsical "cow jumping over the Moon?" Whoa! Surely others must have seen this. Sometime, somewhere. So, I started investigating.

Alas, even after asking my astronomy friends, purchasing multiple books on the Moon, searching the internet, and so on, the best I could come up with were several prints where an artist had depicted a cow on the Moon. But the astronomy literature yielded nothing.

Next, I looked up the origin of the beloved English nursery rhyme, *Hey Diddle Diddle*. From what I can tell, even the author's name is unknown. For all I know, Mother Goose herself wrote it.

An epiphany came when one of the students at our office, after hearing my cow banter, pointed out that when she drove in to work early one morning, she saw the lunar cow standing on its nose in the far west at sunrise! That meant it had rolled about 90° degrees clockwise from sunset to sunrise, the end of the Moon's nighttime journey. Could this be "the cow jumping over the Moon"?

I had to ask myself, why the clockwise roll? I experimented with an Earth globe, placing my iPhone at various latitudes and taking pictures of objects, such as a vase on a table. I'd then turn the globe 180° counterclockwise and take another photo, to compare the view from "moonrise" to "moonset."

Eureka! Here in Minnesota at latitude 45° north, the Moon jumps — or rolls — by about 90° clockwise. At the equator, that roll would be around 180° clockwise. And at the North Pole, no movement at all! The roll appears to be a function not only of the counterclockwise rotation of the Earth, but also the specific latitude of the observer. Contributing Editor Bob King reminded me that the Moon's north pole is always in the direction of Earth's North Pole. And, voilà — just remember where you're standing on Earth.

Gather round a couple of kids and their friends, and head outdoors one moonlit night (try for the eight-day-old waxing gibbous). When you recite the ditty, intone the third line as, "The cow jumped over the mooooooooooon."

■ **JOHN SEBAS** has been looking skyward ever since he was 12 years old when he witnessed a fireball in Stratford, Connecticut, on April 25, 1966.

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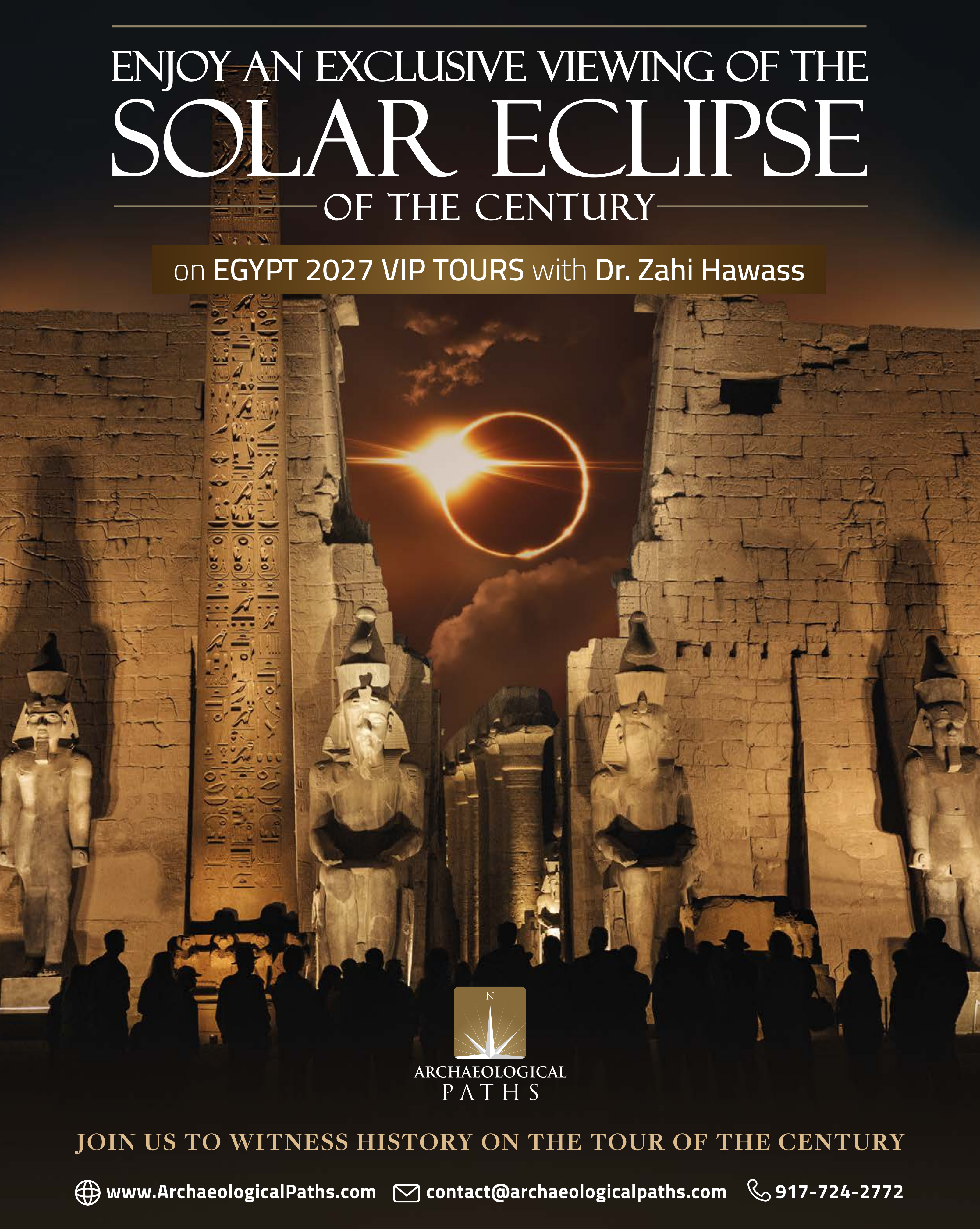
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