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Cicero's Science Fiction

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OCTOBER 2026

Reflection Nebulae for October Nights

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ON THE COVER



A trio of blue reflection nebulae in Cygnus

PAOLO MORONI

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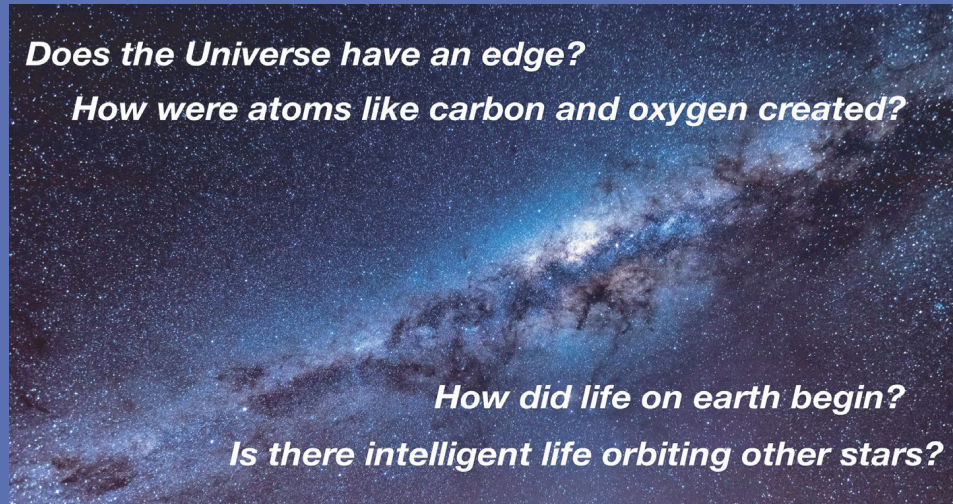


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10. The expanding universe, the Hubble-Lemaître law, the Cosmological Principle, and dark matter.
11. Special and general relativity, gravitational red shift, black holes, and the cosmic microwave background.
12. Does the universe have an edge? How do we know there was a Big Bang? The age of the universe and its fate.
13. Inflation, the 4 forces of nature, string theory, the Anthropic Principle, and women astronomers.
14. Are there extraterrestrial civilizations in the universe? Habitable exoplanets, astrobiology, and the lifetimes of K-type stars.
15. Are there extraterrestrial civilizations on Earth? Have extraterrestrials created unidentified anomalous phenomena?
16. Are there extraterrestrial civilizations on Earth? Have humans observed extraterrestrials on Earth? The Copernican Principle.

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Snap a Shot or Two

MY LOVE OF ASTRONOMY comes thanks in part to images. As a kid, I was enthralled by my dad's old issues of *Sky & Telescope* and his coffee-table books on astronomy. I'd spend hours scouring big portraits of the Andromeda Galaxy and reveling in the magnificence of our cosmic neighbor. I'd study close-ups of the Moon's craters and marvel at the chiaroscuro effect of the blackest of shadows so stark against the blinding lunar surface. I'd lose myself in ethereal nebulae.

But it was the photos of the solar system's planets that really gripped me — the level of detail in Jupiter's clouds, Neptune and its bluish atmosphere, tiny Mercury hopelessly pockmarked with myriad craters. And then there was Saturn, glorious Saturn. Ask most any astronomer what the first telescopic sight was that inspired them, and more often than not the answer will be the king of the rings.



▲ You, too, can photograph the planets.

Back in the day, we had to wait for the next issue of *S&T* or the latest book to get our fix of astronomical delights. Nowadays, the internet serves up a buffet of images every second. There's enough material out there to keep even the most avid consumer of astrophotos happy for a long time. And you know what might be even more satisfying than browsing online for a photo of your favorite planet? Creating your own. Whether you're a seasoned astrophotographer or a novice with a hankering to take your own pictures, this is a great month to start. Saturn comes to opposition and is up all night, giving you ample opportunity to test your newest equipment or your budding skills. (Mars and Jupiter are out, too.) We can help you get started: On page 28, we have Senior Editor Sean Walker's handy guide on how best to photograph the planets. Do consider submitting your photos to our online gallery (skyandtelescope.org/gallery).

You likely won't capture frozen worlds beyond Neptune or the gleam of interstellar ices with your backyard setup, but the articles starting on pages 34 and 62, respectively, give you a look at these fascinating corners of our solar system and galaxy. However, you could try snagging, visually or photographically, some of the reflection nebulae featured starting on page 14. And in case you, ahem, "need" to update your equipment, see our test report of Stellarvue's latest refractor on page 72 — some of you might have even drooled over it at this year's NEAF expo.

There's one planet that backyard astrophotographers can't capture floating in the sky: Earth. But imagining what Earth looks like from space has been a longtime human pursuit — some 2,000 years ago the Roman scholar Cicero first described what our home planet might look like from afar. Turn to page 22 to see how his "word picture" inspired the scientists who helped us fly beyond the sky.

Dimm
Editor in Chief

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Piece Meal

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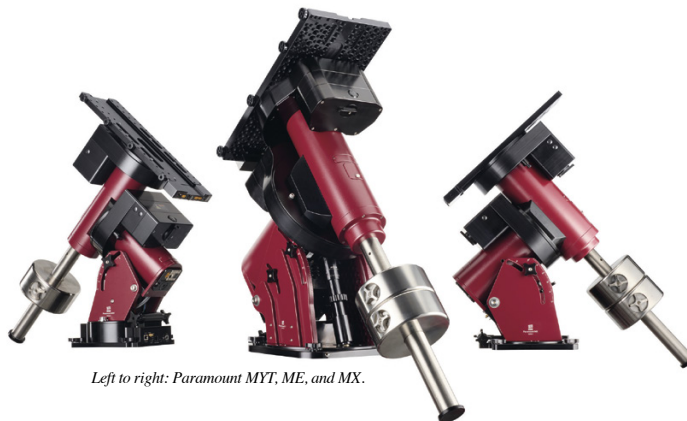


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Freedom's Star

I enjoyed Joe Barry's timely article on Harriet Tubman, "Freedom's Beacon" (S&T: June 2026, p. 14). There is a primary school named after Harriet Tubman in St. Catharines, Ontario. St. Catharines was one of the final stops on the Underground Railroad for escaped enslaved people. Tubman lived here for 10 years, not far from the border with the United States. Last June, my astronomy club had a private star night for 47 seventh-grade students at a local conservation area. After noticing their "Harriet Tubman North Stars" sweatshirts, I asked them if they all knew the Harriet Tubman story. They said yes, so I talked about her and demonstrated where Polaris is, why it's always there, and how she used it to navigate to Canada. I think it was a gratifying moment for all of us.

Philip Downey

St. Catharines, Ontario

Royal Astronomical Society of Canada

Reading the June issue of *Sky & Telescope* was rewarding. As a person of color, I'm pleased to find articles that reflect all aspects of stargazing which demonstrate the natural abilities of

all people. "Freedom's Beacon" by Joe Barry is a testament to the ability of an underrepresented segment of American society. Thank you!

In "Why are there Seven Sisters" (S&T: Nov. 2024, p. 36), Ray Norris suggested that the folklore behind the Seven Sisters, or the Pleiades, originated in ancient Africa and migrated with early *Homo sapiens* into the wider world. Also, the Nabta Playa stones in Egypt are one of the world's oldest observatories, predating Stonehenge by 2,000 years! Needless to say, astronomy began in Africa!

What else has Africa given us that relates to astronomy? If we search the annals of North American history, we find the first Black American astronomer is considered to be the freeman Benjamin Banneker. However, predating him is another educated, free Black man, Francis Williams of Jamaica, who correctly calculated the trajectory of Halley's Comet in 1759. Both these individuals lived in the 18th century. We should also consider Phillis Wheatley, who was educated in astronomy and often wrote about the stars in her poems. And as Joe Barry notes, the Black enslaved communities of the 19th century in America used stargaz-

ing and other navigation techniques to escape slavery. Certainly, history hails those free persons of color who were educated as highly accomplished, but many of those Black people who were denied access to education were resourceful enough to acquire knowledge on their own!

I enjoy reading about those who sought the stars for pleasure and for necessity. The world is a diverse place, and people from all strata of society throughout history have demonstrated a diverse interest in astronomy.

Clarence G. Underwood

Pittsburg, California

Thank you for publishing Joe Barry's excellent "Freedom's Beacon" about the Underground Railroad and the details of the journeys under the stars of 100,000 escaped enslaved people. A very moving story with excellent ties to astronomy and our human family.

Tom Kellogg

Aptos, California

I loved the June issue, especially "Freedom's Beacon" and Javier Barbuzano's "Animal Navigators" (S&T: June 2026, p. 20). It's my top-favorite issue of S&T so far. But when I look at the photo on page 14, I cannot see the Big Dipper. I asked two friends to look at it, too. They couldn't see the Dipper either. Is it a hidden beacon?

Michael Kauper

Minneapolis, Minnesota

“Meg Thacher replies: *It took me a while to find the Big Dipper at first, too! The trees either hide or dim several of the stars. The center of the photo is at an altitude of about 55°, and the zenith is at the top. The Big Dipper appears to be hanging upside down off the top of the central tree by its bowl. The handle is dangling off to the right pointing towards the lower right corner, with Alkaid disappearing behind the text. Alas, most of the Little Dipper stars are hidden, including Polaris.*

◀ This plaque located near the British Methodist Episcopal Church, Salem Chapel in St. Catharines, Ontario, explains why so many fugitive enslaved people fled there.



Hundreds of Hours

I see photos of deep-space objects that list exposure times of tens or even hundreds of hours. That means multiple nights of start-and-stop imaging with changing sky conditions and other variable factors. How is this accomplished?

Robert Bobo

Pullman, Washington

“ Sean Walker replies: *These massive exposures are recorded in small batches, often by taking many 5- or 10-minute exposures over several nights for weeks and even months on end. It's not terribly difficult to return to the same field on multiple nights with telescope mounts capable of extremely accurate pointing, just like the Hubble Space Telescope does. Simply center the telescope on the same celestial coordinates, ensure your pointing matches the previous images, and then start recording. Afterwards, the individual pictures are stacked together in an astronomical image-processing program such as PixInsight.*

Ptolemaic Circles

The diagram of the Ptolemaic geocentric solar system on page 37 of the December 2025 issue unfortunately contains a common misconception: It shows each of the superior planets at a different position on its epicycle.

The line from the stationary Earth to the Sun must always be parallel to the line from the center of the epicycle to the superior planet. This requires a superior planet to undergo retrograde motion only around the time when the superior planet is in opposition.

The motion of an inferior planet on its epicycle is its actual orbital motion around the Sun, and the line from Earth to the center of the epicycle of an inferior planet must always be parallel with the line from Earth to the Sun. This keeps Mercury and Venus from ever straying far from the Sun in our

sky. Correct diagrams are available at tinyurl.com/StackExchPtolemy.

Gerald Newsom

Columbus, Ohio

“ Meg Thacher responds: *Indeed, as most observers know, superior planets exhibit retrograde motion at opposition, and our diagram clearly shows a prograde Jupiter near opposition. The fact that we could not find a diagram anywhere that showed a superior planet traveling retrograde at opposition illustrates our problem pretty well. Thank you for supplying one!*

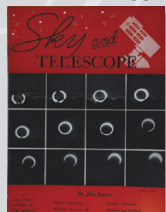
FOR THE RECORD

• In “The Big Role of Small Observatories” (S&T: July 2026, p. 60), we unwittingly lengthened the life of William Parsons, the Third Earl of Rosse. The “Lord Rosse” who visited Lick Observatory in 1891 was Laurence Parsons, the Fourth Earl of Rosse.

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75, 50 & 25 YEARS AGO by Sabrina Garvin

1951



October 1951

Eclipse Convention “Taps of a gavel resounding from door to door brought sleepy conventionites to life in the 4:15 pre-dawn darkness, Saturday, September 1st, to observe the annular eclipse. More than 200 members of the Astronomical League and their friends gathered at Piney Prospect, Chapel Hill, N. C., to greet the rising sun . . .

“[The] previous day found the exhibit room at the Morehead Planetarium building a busy place, with T. W. Stone, of the Richmond Astronomical Society, doing the yeoman task of organizing the displays as quickly as they arrived. More than 40 exhibitors [and] commercial exhibits [made it] the most extensive exhibition at recent league conventions. . . .

“[Elizabeth] Fazekas announced a total registration of 218 persons, representing 35 societies and 22 states, as well as Canada, the Canal Zone, and Cuba.”

1976



October 1976

Air and Space “At long last there is a place to turn the dreams of every would-be astronaut or fighter pilot into thrilling, educational experiences. It is the National Air and Space Museum, situated along the south side of the scenic Mall in Washington, D. C. . . .

“The tri-level glass-and-marble edifice measures 685 feet long, 225 wide, and 85 tall — many times more capacious than the cramped “temporary” quarters that for decades housed an ever-growing number of flight-related exhibits. . . .

“Thus, the overall effect is spacious and uncluttered, even though there are more than 160 major aircraft and spacecraft displays. . . .

“The open interior can accommodate large numbers of visitors, estimated to approach 7,000,000 annually. However, the museum appears to be unexpectedly popular . . . in the 11-week period following the July 1st dedication, more than 3,000,000 people made their way through its carpeted galleries.”

October 2001

Barnard's Planets “One famous ‘discovery’ of the first planet beyond the solar system dates from 1963, when astronomer Peter van de Kamp announced that a planet orbits Barnard's Star every 24 years. . . .

“Several subsequent studies failed to confirm van de Kamp's results. But he stuck to his claims; his last analysis, in 1982, had planets of 0.7 and 0.5 Jupiter mass in 12- and 20-year orbits . . .

“Philip Ianna and Jennifer Bartlett (University of Virginia) recently analyzed . . . 924 images made from 1969 to 1998 — and found no sign of van de Kamp's stellar wobble.

Astronomers are now confident that no such Jupiter-mass planets exist around Barnard's Star, but in 2024 they discovered a world smaller than Earth circling the red dwarf. A few months later, in 2025, archival data confirmed three other planets with less than half Earth's mass orbiting the star.



SOLAR SYSTEM

Evidence for Europa's Water Plumes Vanishes



THE PUTATIVE VAPOR plumes detected escaping from Jupiter's moon Europa might not be real.

In 2013, Lorenz Roth (now at KTH Royal Institute of Technology, Sweden) and colleagues announced the detection of faint ultraviolet emissions from the southern hemisphere of Jupiter's moon Europa using the Hubble Space Telescope. The team interpreted the signal as an escaping plume of water vapor.

The finding was widely accepted as evidence that liquid water was escaping from Europa's subsurface ocean. (A geologically active surface and magnetic readings near the moon offer strong evidence of that ocean, separate from the plumes).

However, subsequent Hubble observations, the latest of which was undertaken in 2020, failed to show the localized emissions again. This lack of confirmation prompted Roth and col-

◀ Multiple lines of evidence suggest Jupiter's moon Europa harbors a subsurface ocean.

GRAVITATIONAL WAVES

Gravitational-Wave Signals Surge with Latest Data

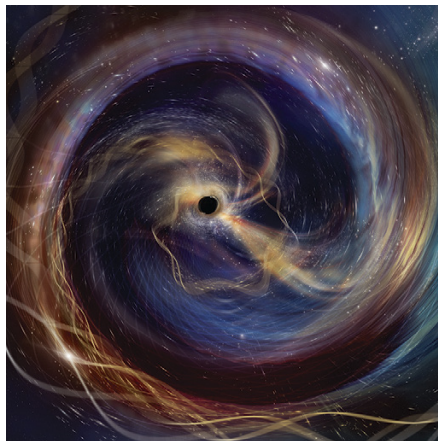
ASTRONOMERS HAVE RELEASED

the newest list of gravitational-wave detections, almost doubling the number of events to a total of 390. Some 161 new sources are detailed in the Gravitational-Wave Transient Catalog 5.0, including several record-breakers.

It has been more than a decade since astronomers first directly detected gravitational waves, ripples in spacetime produced by some of the most violent events in the cosmos. All of the new entries in this catalog come from colliding black holes. Astronomers captured the signals between April 2024 and January 2025 using the Laser Interferometer Gravitational-Wave Observatory (LIGO) in the United States, the Virgo interferometer in Italy, and the

Kamioka Gravitational-Wave Detector (KAGRA) in Japan. The new results were posted on May 26th to the astronomy arXiv preprint server.

The latest achievements include the most precisely located gravitational-wave source yet: Scientists traced GW240615 to a 6-square-degree patch of sky — an impressive feat for a signal originating more than 3 billion light-years away. Such precision makes it easier to identify sources' host galaxies as well as test associated physics.



► This artist's concept imagines the powerful collision between two black holes, depicting the view from one as it spirals toward the other. Vibrations within the gravitational waves are depicted as intertwining threads.

For Ian Harry (University of Portsmouth, UK), who was not directly involved in the catalog's release, the new data hide gems, such as strong evidence of signals from "second-generation" black holes, themselves born from black hole mergers (*S&T*: June 2022, p. 12).

Researchers also reported the first measurement of three distinct vibrational modes of a newly merged black hole, much like the different notes produced by a ringing bell. These vibrations offer a new way to test whether black holes behave as Einstein's general theory of relativity predicts.

"We don't yet see any deviations from Einstein's theory," Harry says, "but who knows what the next decade will bring?"

The new data release makes clear that gravitational-wave astronomy is moving from a fledgling science to a maturing field — one capable of exploring some of the deepest questions about our universe.

■ COLIN STUART

Read more: skyandtelescope.org/GW5.

laborators to conduct a comprehensive reanalysis of available data. In the May issue of *Astronomy & Astrophysics*, the team concludes that the original detection of a watery plume was most likely a statistical fluke.

The team found two main flaws in the previous analysis. The first had to do with uncertainty in the position of Europa's signal on Hubble's detector. The moon occupies only a small fraction of the $1,024 \times 1,024$ -pixel detector. The researchers found that the original alignment was off by just two pixels horizontally and one pixel vertically — a small error that nevertheless created data artifacts, artificially inflating the brightness at the purported location of the plume.

This positioning error was further compounded by a global atmospheric feature unknown a decade ago. More recent Hubble observations have revealed a thin but persistent hydrogen *exosphere* surrounding the moon.

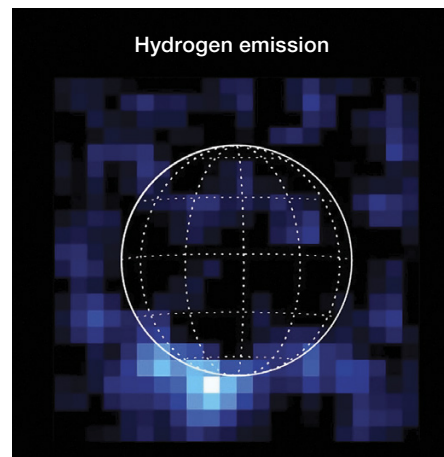
► A single set of Hubble Space Telescope observations taken in 2012 revealed the signature of a possible water plume, shown here. But with reanalysis, that signature has now vanished.

The hydrogen atoms floating above the moon's surface scatter ultraviolet sunlight, producing a natural glow around the satellite. The glow added to the overestimate of the abundance of photons coming from the moon's limb.

Once the researchers corrected for both of these effects, the apparent plume signature dissolved into the background.

"I was very surprised by the finding," says planetary scientist Juan Alday (Institute of Astrophysics of Andalusia, Spain). "I think it's nice in the sense that this is how science should work. The pipelines we use for data analysis are constantly evolving, as we learn over the years of conducting and analyzing new observations."

The research doesn't rule out that there could be transient plumes of



water escaping from geysers or cracks in Europa's surface. But the solid evidence the researchers once thought they had has now disappeared.

Plumes or no, scientists remain deeply interested in Europa's subsurface ocean, which NASA's Europa Clipper orbiter will investigate once it arrives in the Jupiter system in 2030.

■ JAVIER BARBUZANO

NEUTRINOS

"Shadow Blaster" Might Have Sent High-Energy Neutrino Our Way

A HIGH-ENERGY NEUTRINO could have come from a distant, dusty galaxy bursting with newborn stars. If they're right, supermassive black holes are not the only sources of these energetic but elusive particles.

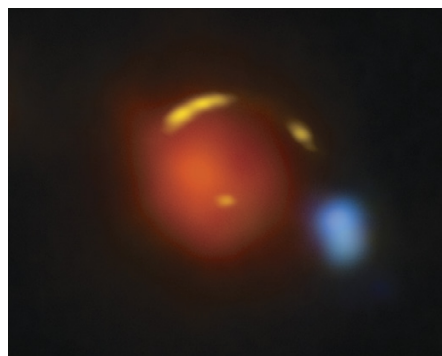
Neutrinos — electrically neutral and almost massless elementary particles — only rarely interact with other matter. But on September 22, 2021, the IceCube Neutrino Observatory registered a neutrino (named IC210922A) with an estimated energy of 750 teraelectron volts (750 TeV), more than 100 times the energy generated in our largest particle accelerators.

Although scientists have traced some high-energy neutrinos back to supermassive black holes in the cores of

distant galaxies, follow-up observations didn't reveal any such counterpart to IC210922A in visible light, X-rays, or gamma rays.

But a team led by Taiwanese astronomers Yuji Urata (MITOS Science Co.) and Kuiyun Huang (Chung Yuan Christian University) did find a submillimeter radio source that coincides with the direction the neutrino came from.

Now, the team details Atacama Large Millimeter/submillimeter Array observations of that submillimeter source on June 17th in *Nature Astronomy*. It turns out to be a gravitationally lensed, dusty, star-forming galaxy, magnified by the



► Shadow Blaster, a star-forming galaxy that might have sent a high-energy neutrino our way, appears as golden, gravitationally lensed arcs around a red foreground galaxy.

gravity of a foreground galaxy. It's so distant that its light has taken 11 billion years to reach us.

The ALMA data indicate that the galaxy has a compact gaseous core about 3,000 light-years across. According to the team, this violent but obscured star-forming region is the likely source of IC210922A. They have nicknamed the galaxy "Shadow Blaster."

"I think the paper provides a good case" for this identification, says Jacco Vink (University of Amsterdam, The Netherlands), who was not involved in the study. But there's still a possibility — at most a 1% chance, by the researchers' calculations — that the two sources just happen to align. Finding additional galaxy-neutrino lineups would help clinch the case.

If Shadow Blaster is indeed the source of IC210922A, then Urata, Huang, and colleagues estimate that up to 20% of all high-energy neutrinos may originate in star-forming galaxies, rather than from around supermassive black holes.

■ GOVERT SCHILLING

SOLAR SYSTEM

Meteorite Evidence of Moon-Size Planetoid

A RARE METEORITE recovered from the Sahara Desert could be a fragment of a Moon-size body that met an early, violent end.

The meteorite, dubbed Northwest Africa (NWA) 12774, was purchased in 2019 from a Mauritanian dealer. It belongs to a rare group called *angrites*, volcanic space rocks that scientists thought originated from a moderate-size asteroid a few hundred kilometers in diameter.

But a new analysis by Aaron Bell (University of Colorado, Boulder) and colleagues, published in the July 1st *Earth and Planetary Science Letters*, reveals that these crystals are rich in aluminum, suggesting the rocks formed at a much greater pressure — and, thus, in a much larger body — than previous studies had indicated.

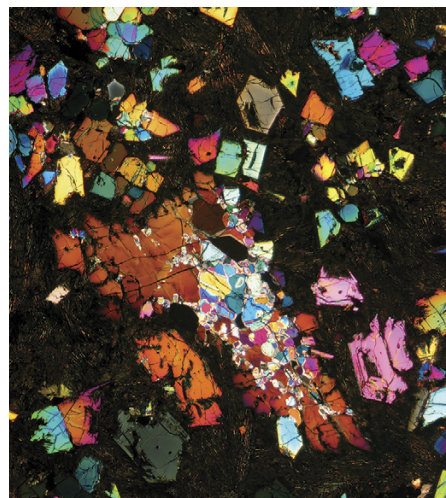
The researchers estimated the crystals formed at a pressure of at least 17.6 kilobars, the pressure found at a depth of about 50 to 60 kilometers

(30 to 40 miles) beneath Earth's continental crust. The angrite parent body therefore had to be a layered world at least 2,000 km wide.

Moreover, the crystals in the rock appear sharp, showing few signs of deformation. This suggests that, while the rock formed in a high-pressure environment, it quickly hitched a volcanic ride to the near-surface, from which it erupted, Bell explains.

The rapid ascent points to an origin in the parent body's upper mantle, likely less than 200 km deep. To achieve the necessary pressures at this relatively shallow depth, the parent body must have been as large as our Moon — spanning about 3,600 km.

The birthdate of this putative baby planet remains a puzzle. Angrites are among the oldest known materials in the solar system, formed just 4 million years after the first solids coalesced from the solar nebula. The presence of angrites suggests the parent body must



▲ Specialized photography reveals minerals in the meteorite Northwest Africa 12774.

have grown surprisingly quickly — challenging traditional planet-formation models, most of which do not predict planetoids of this size roaming the solar system so early on, Bell says. The find is more in keeping with newer theories that result in faster planet formation.

This meteorite provides a rare window to our system's violent early years.

■ JAVIER BARBUZANO

GALAXIES

Little Red Dot Is Cocooned Black Hole

ASTRONOMERS HAVE USED the James Webb Space Telescope to observe a mysterious *little red dot* (LRD; *S&T*: May 2024, p. 20) in unprecedented detail, providing some of the strongest evidence yet that these red-hued fuzzies are supermassive black holes enveloped in dense cocoons of gas.

That conclusion is based on the deepest spectrum of an LRD captured so far. Called GLIMPSE-17775, it exists some 1.8 billion years after the Big Bang. Its light is magnified by a foreground galaxy cluster, which aided Webb observations of its spectrum, collected by Vasily Kokorev

► An image of the galaxy cluster Abell S1063 turned up the “little red dot” known as GLIMPSE-17775.



(University of Texas, Austin) and colleagues. Their results are published in the June 20th *Astrophysical Journal*.

The team observed more than 40 features in the spectrum. Several of the emission lines were thick, broadened in a way that suggests the light is filtered through a gaseous screen. In other words, a dense cocoon of gas shrouds the central source. The spectrum also contains strong features from ionized iron, oxygen, and helium, all pointing to a powerful energy source hidden within that cocoon.

Taken together, the observations are consistent with an actively feeding 5-million-solar-mass black hole surrounded by layers of gas so thick they are opaque. The gaseous cocoon absorbs much of the radiation produced near the black hole, reemitting it at the infrared wavelengths that Webb

sees, creating the unusual red appearance that gives LRDs their name.

One challenge for this interpretation is that the black hole appears to be guzzling gas at a rate almost twice the theoretical threshold, known as the *Eddington limit*.

Sadegh Khochfar (University of Edinburgh, UK), who was not involved in the research, says that while gas-guzzling at this rate isn't physically impossible, it's also not expected based on our understanding of black hole formation and evolution. Observations of other, non-gravitationally-lensed LRDs could help clarify the picture, Khochfar adds, since the lensing effects can create uncertainty.

The findings, if they pan out, are another piece of evidence suggesting that supermassive black holes grew from “heavy seeds.” But exactly how such heavy black hole seeds would form soon after the Big Bang is still debated.

■ COLIN STUART

OBITUARY

Alan Hale (1958–2026)

ASTRONOMER and comet hunter Alan Hale has passed away at 68 years old on June 6th.

Best known for his co-discovery of Comet Hale-Bopp (C/1995 O1) in July 1995, Hale was introduced to cometary observing by an article on Comet Tago-Sato-Kosaka (C/1969 T1) in the February 1970 issue of *Sky & Telescope*. After observing that comet in a 4½-inch Sears refractor, and then seeing Comet Bennett (C/1969 Y1) two months later, Hale was hooked to sweeping the skies.

Hale graduated from the U.S. Naval Academy's physics program in 1980 and served for three years before joining the Jet Propulsion Laboratory, where he worked on the Deep Space Network for another three years. He went on to obtain a PhD in astronomy from New Mexico State University in 1992. During this time (1991), Eugene and Carolyn Shoemaker named the asteroid 4151 Alanale, in recognition of Hale's careful visual comet observations.

Upon graduation, Hale founded the nonprofit Southwest Institute for Space Research (now Earthrise Institute), with the mission of using astronomy to break down intercultural barriers.

After decades of scanning the skies, Hale had given up hope of discovering his own comet by the 1990s. But he still observed every comet he could. One night in 1995, he had just finished observing Comet 71P/Clark and decided to explore globular clusters in Sagittarius while waiting for Comet 6P/d'Arrest to rise above the horizon. As he focused on Messier 70, he noticed a faint, diffuse object — a comet that would place his name in astronomical history books, alongside Thomas Bopp's.

That same night, Bopp, another amateur astronomer, also spied the fuzzy smudge from south of Phoenix, Arizona. The co-discoverers didn't meet in person until years later, but their names are now linked to one of the greatest comets of modern times. Ultimately, Comet Hale-Bopp brightened to around magnitude -1 when it reached perihelion in April 1997.



▲ Alan Hale poses with the 16-inch Meade Starfinder reflector he was using when he discovered Comet Hale-Bopp.

Hale went on to give lectures and interviews, teach online classes, and write many articles as well as three books. As part of the Earthrise Institute's initiatives, he also conducted science diplomacy expeditions to Iran in 1999 and 2000 and Zimbabwe in 2001.

According to the Earthrise website, Hale observed 533 comets in his lifetime. He is survived by his wife, Vickie Stone Moseley Hale; his two sons, Zachary and Tyler; and three grandchildren.

■ SABRINA GARVIN

IN BRIEF

Amazon's Bright Satellites

Amazon's satellites, now known as Amazon Leo (formerly Project Kuiper), are brighter than the limits recommended by the International Astronomical Union (IAU). The average magnitude for these spacecraft is 6.3, based on 1,938 visual and electronic observations posted on the astronomy arXiv preprint server. Amazon is developing brightness mitigation techniques and is an active member in the IAU Centre for the Protection of the Dark and Quiet Sky (CPS). The CPS recommends that satellites never be visible to the unaided eye; observers can see 6th-magnitude objects from dark-sky locations. To avoid impacting research astronomy, CPS also recommends that satellites at the Amazon Leo altitude of 630 km (390 miles) be dimmer than magnitude 7.2. Amazon is competing with SpaceX's Starlink network, with plans to launch a constellation of 3,232 satellites to deliver internet service; so far, only 365 are in orbit. The total would be a significant addition to the space environment: There are more than 17,000 active satellites as of this writing, in-

cluding more than 10,000 in SpaceX's Starlink network. China also has expansive plans for broadband-satellite deployments, expected to number in the tens of thousands.

■ ANTHONY MALLAMA

Read more: skyandtelescope.org/Amazon

NASA's Moon Base Plans

After scrapping the Gateway space station in March, NASA detailed new plans on May 26th for a sprawling Moon Base at the lunar south pole. The agency announced \$700 million in new contracts; by its completion the base is expected to cost \$20 billion. The first mission, Moon Base 1, may launch as early as autumn 2026. Two more missions are targeting launches before the end of the year. Looking ahead, Aerospace companies Astrolab and Lunar Outpost received \$219 million and \$220 million, respectively, to build 1-ton lunar vehicles by 2028, which would ride to the Moon on a Blue Origin lander. Firefly Aerospace, which landed successfully on the Moon in 2025, is also on tap to deliver four drones to the Moon by 2028 for \$75 million, in a project dubbed MoonFall. To be developed by NASA's Jet Propulsion Laboratory,

the MoonFall drones will image the lunar surface ahead of the Artemis program's first crewed landing. Given the tight timelines for all of these missions, "I wouldn't say it's impossible," says lunar scientist Simeon Barber (Open University), "but I do think it's challenging."

■ HANNAH RICHTER

Read more: skyandtelescope.org/MoonBase

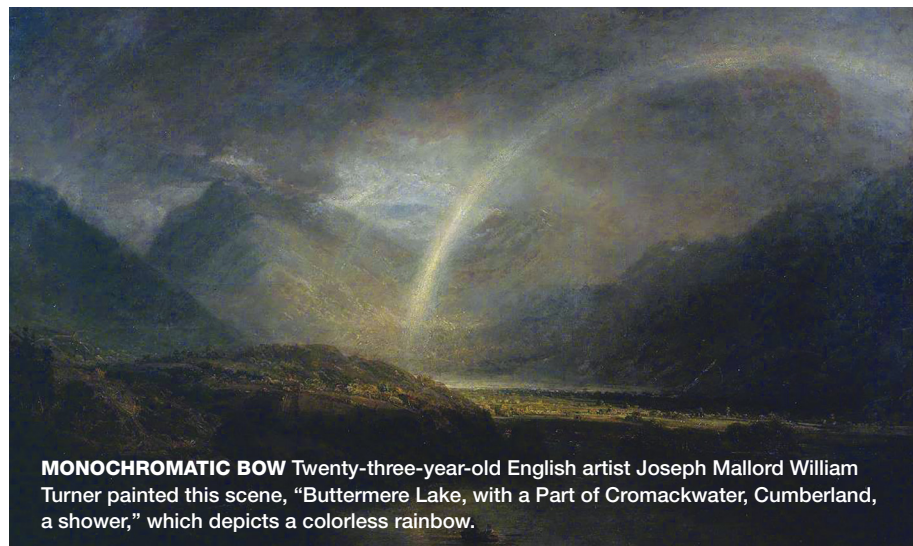
Farewell to MAVEN

The first mission devoted to observing the Martian atmosphere and its evolution, NASA's Mars Atmosphere and Volatile Evolution (MAVEN) mission has ended after more than 11 years in orbit at Mars — a decade longer than its primary one-year mission. Mission control last heard from the spacecraft on December 6, 2025, before it passed behind the Red Planet. In-depth analysis later confirmed that, after MAVEN emerged from behind Mars relative to Earth, it was spinning at an unexpectedly high rate, which drained its batteries. After six months of attempting to recover the mission, NASA officially bid MAVEN farewell on June 3rd.

■ MONICA YOUNG

A "White" Rainbow Mystery

Learn how art, science, and time are linked.



MONOCHROMATIC BOW Twenty-three-year-old English artist Joseph Mallord William Turner painted this scene, "Buttermere Lake, with a Part of Cromackwater, Cumberland, a shower," which depicts a colorless rainbow.

LAST OCTOBER, my wife Deborah Carter and I went to the Towner Eastbourne, an art gallery in Sussex, England, to attend the "Impressions in Watercolour" exhibition, featuring works by English Romantic landscape painter Joseph Mallord William Turner (1775–1851) and his contemporaries. What I was most keen to see was Turner's "Rainbow over a Swiss Lake," as it was but one of the artist's many curious impressions of rainbows in his collection of 2,000 watercolors. Why are the rainbows curious? Because most of them lack color!

I became interested in Turner's "white bows" after reading an article about them in the Atmospheric Optics website (tinyurl.com/white-rainbow). The author primarily focuses on Turner's "Buttermere Lake, with a Part of Cromackwater, Cumberland, a shower," which the then-23-year-old artist exhibited at the Royal Academy of Arts in London in 1798. As noted, the dark and moody scene is bridged by a predominantly white rainbow — though dim traces of color can be seen under careful

observation in parts of the bow. The article suggests that rainbows are "devilishly difficult things to portray in paintings," but all one has to do is see Turner's circa 1824–25 watercolor, "Arundel Castle on the River Arun, with a Rainbow," to see how adept the master was at depicting colors in not only a rainbow but also its reflection on the river.

One could argue then that the Buttermere Lake scene depicts a moonbow or a fogbow, but that may also not be the case. When the painting was exhibited at the Academy, it was accompanied by verses from Scottish poet James Thomson's "Spring," which depicts a scene with the Sun near setting and a "grand ethereal bow" that "Shoots up immense, and every hue unfolds." It would be odd for this poem to appear next to a watercolor with a white rainbow. Besides, why would an artist — renowned for being a color theory pioneer, who, according to the Tate galleries, "shocked with his unique brushwork and use of colour" — intentionally avoid depicting one of the most colorful atmospheric phenomena known

in nature as it truly appears?

The Atmospheric Optics article proffers that Turner likely depicted rainbows as "almost symbolic renditions" that "avoid garishness and solidity." Another theory could be that he was trying to incorporate the burgeoning topic of color theory in his rainbows in an impressionistic way — as white light holds all the colors of the spectrum. While both hypotheses are possible, there's another simpler one that may explain Turner's largely colorless bows.

In the 1909 book *The Water-Colours of J. M. W. Turner* by A. J. Finberg and W. G. Rawlinson, the latter author writes, "May I be permitted here to draw attention to the fact — apparently little known, but none the less true — that, with the exception of some of the darker early works, no Turner drawing can be continuously exposed unprotected to light, without its ruin being eventually only a question of time. The more delicate — the more 'Turneresque' it is — the quicker will that ruin be accomplished." So if Turner was, in fact, delicate in his portrayals of rainbows — "avoiding garishness and solidity" — his rainbow colors would have been subject to expiring over time.

How quickly would the colors have faded? According to the website of Winsor & Newton, manufacturers of artists' materials (including Turner's) since 1832, "Many of the pigments Turner used . . . were known to fade in his lifetime." In addition to exposure to light, factors such as humidity and atmospheric pollution would have affected the rate of deterioration in his paintings. "Turner's desire to experiment with materials and fugitive colour," the site states, "and his passion to achieve an effect rather than care for the finished work, did not help the preservation of his work."

While we'll never know how vibrant Turner's rainbows were when he painted them, we can still admire the unrivaled impressions of Earth's brooding atmosphere and its optical phenomena by the world's greatest watercolorist of his age.

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

High-Performance Cooled Camera with Built-In Filter Wheel

Deep-Sky · Planetary · Photometry

92%
High QE

-45°C
Cooling Delta

CFW
8 Positions

0.76 e⁻
Readout Noise

Linearity
HDR

NIR
Sensitivity

IMX
585

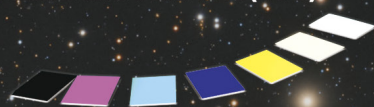
8 MP



Mono Deep-Sky Filter Set

LRGB and 7 nm SHO

LRGB and 3 nm SHO(EVO)



Color Deep-Sky Filter Set

Light Pollution Filter

Heavy Light Pollution Filter

Four-Channel Enhancement
Filter

UV/IR Cut Filter

Planetary Filter Set

LRGB

20 nm Methane Filter

40 nm UV Filter

10 nm Sodium (Na) Filter

Sloan Photometric Filter Set

U'G'R'I'Z'

Special Narrowband Filter

Argon III (Ar III)

Helium II (He II)





Van den Bergh Reflection Nebulae for October Nights

Delve into this batch of neglected visual treats this autumn.

In my earlier article in the January 2026 issue, page 14, I explained how Dutch-Canadian astronomer Sidney van den Bergh compiled a catalog of reflection nebulae in 1966 to help him study the structure of our galaxy's molecular clouds. One of his findings — which was unappreciated at the time — was that most reflection nebulae at intermediate and high galactic latitudes are being illuminated by the com-

▲ **COSMIC BLUE FLAME** In this month's tour, the author introduces a collection of reflection nebulae visible on autumn evenings (in the Northern Hemisphere), beginning with van den Bergh 123, or vdB 123. It appears blue because the nebula's fine interstellar dust is more effective in scattering starlight at shorter (bluer) wavelengths. Visible 7.2' southwest of vdB 123 is the 8.5-magnitude double star Struve 2321, or Σ 2321. Above it is a rare, red reflection nebula that the author managed to observe with his 20-inch telescope. North is up in all images.

WOLFGANG PROMPER

bined light of the Milky Way. These particular dust clouds, called *integrated flux nebulae* (S&T: Apr. 2017, p. 30), are some of the most challenging objects to see visually.

Since then, professional and amateur astrophotographers alike have revealed reflection nebulae in nearly every corner of the sky. But despite such wide coverage, this type of deep-sky object is still one of the few that amateur astronomers can discover. Take for example Sazhen 30, a small cloud surrounding a 12th-magnitude star in northern Orion. Vlad Sazhen, a University of Missouri graduate student who hails from Ukraine, discovered it while scouring survey images in 2023. I was thrilled when I managed to glimpse Sazhen 30 in my 10-inch Schmidt-Cassegrain telescope last winter.

Obviously, I have yet to get tired of the challenges that reflection nebulae offer. Thus, I'm once again excited to showcase another selection of targets I've plucked from van den Bergh's neglected catalog. And like the objects in my first article, they'll be ones that deserve to be better known even though they didn't make it into the NGC or IC catalogs.

Easy as 1, 2, 3!

Originally discovered by German astronomers Johann Dorschner and Joachim Gürtler three years prior to the publication of van den Bergh's catalog, **vdB 123** isn't what I'd call an "easy" find. But with a little determination, I located it 4.7° north-northeast of 3.3-magnitude Eta (η) Serpentis. A 10th-magnitude main-sequence star designated HD 170634 illuminates the cloud.

In my 6-inch f/5 Dobsonian at 37 $\times$, I saw a soft gray quality to the sky around the star, while an 8th-magnitude sun, HD 170545, lies 7.2' southwest. At 112 $\times$, that brighter star resolved into a 6.7"-wide double (designated Struve 2321, or Σ 2321), while vdB 123 appeared as a soft glow more visible off HD 170634's western side. Long-exposure images reveal the nebula is just a small piece of an intricate dark cloud running up from the south known as the Serpens Molecular Cloud. They also show a very red, bipolar reflection nebula above Σ 2321 that I had glimpsed in my 20-inch scope and is being illuminated by a pre-main-sequence star.

A Celestial Bungle

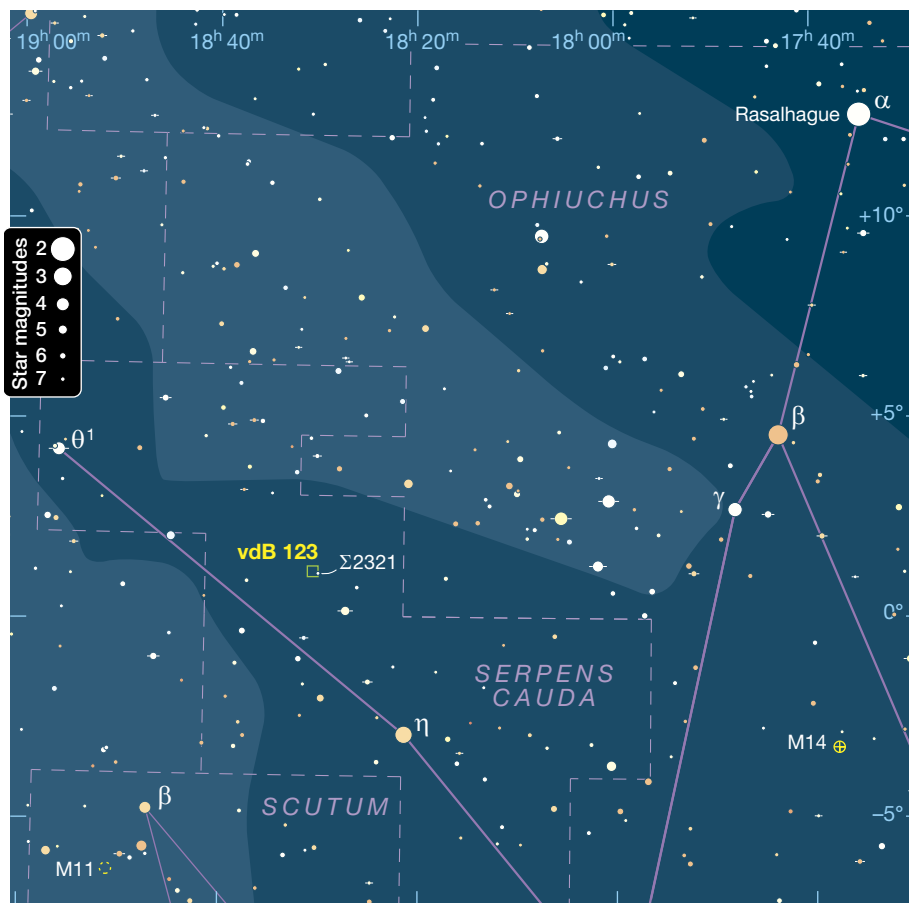
Cygnus is home to many reflection nebulae, including a complex con-

► **EXPLORE THE SERPENT** Use this and the other accompanying finder charts to aid you in your celestial navigation. You can refer to the text for additional star-hopping instructions. The charts have north up and east to the left. Stars are plotted down to magnitude 7.

taining **vdB 132** and **vdB 131**, which lie more than 3,000 light-years away and are located 2.3° north-northeast of 2.2-magnitude Gamma (γ) Cygni, or Sadr. French astronomer Édouard Jean-Marie Stephan discovered the brightest part of the complex, NGC 6914, using a 31.5-inch silvered-glass reflector. He noted "two stars attached on west side." However, in his 1922 article entitled "A General Study of Diffuse Galactic Nebulae," Edwin Hubble ignored Stephan's find and instead applied the NGC 6914 designation to two smaller, fainter reflection nebulae a little farther south that surrounded brighter illuminating stars. His error was made worse when Swedish astronomer Sven Cederblad compiled his list of galactic nebulae in 1946 and inadvertently switched the "a" and "b" sub-designations that Hubble had used.

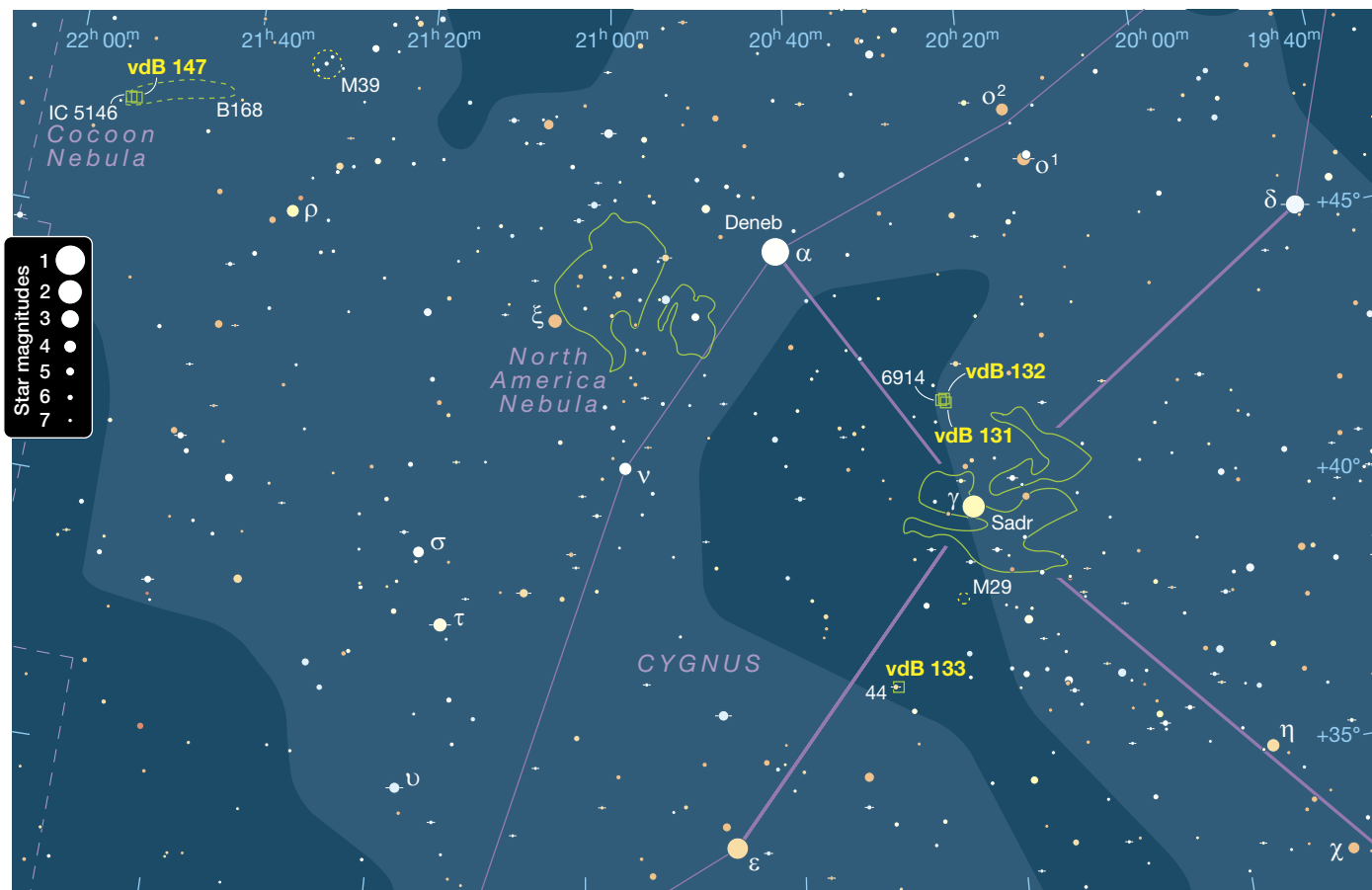
Two decades later, van den Bergh included Hubble's two nebulae in his catalog but left out NGC 6914. This puzzled me until I realized that van den Bergh couldn't include it — for his study, he had chosen to cover only those nebulae around stars in the *Bonner Durchmusterung Catalog*, and NGC 6914's illuminating star was simply too faint to be added.

Using my 5.1-inch reflector at 59 $\times$, I could detect the glow of NGC 6914 to the eastern side of a wide, equal-magnitude pair of stars that are aligned north to south. Though small, NGC 6914 is distinct if you know what you're looking for and can't be mistaken for vdB 132 a mere 6' south. Why? Because at 59 $\times$ it's a very faint glow on the western side of





PAOLO MORONI



▲ **CYGNUS STAR FIELD** Use 2.2-magnitude Gamma (γ) Cygni, or Sadr, and the open cluster M39 to locate the vdB reflection nebulae highlighted in the constellation. The author also gives details about the other celestial attractions found in this rich, star-filled region of the Milky Way.

another wide but unequally bright stellar pair aligned north to south. As for vdB 131, it evaded me until I turned my 16-inch Dobsonian at 191× toward it. Even then, it was only a faint but distinct glow around a 10th-magnitude star.

Flight of the Celestial Swan

Along the leading edge of Cygnus's eastern wing lies a difficult naked-eye star. Known as 44 Cygni, the yellow supergiant shines at magnitude 6.2 and is surrounded by **vdB 133** — which I'm happy to note is plotted on *S&T*'s popular *Pocket Sky Atlas*. Modern images reveal a whitish nebula spanning more than 10' across and roughly centered on 44 Cygni.

In my 5.1-inch reflector at low power, I suspected a large glow around the star, but it's at 59× that I had no doubts. In fact, at 72×, the nebula was an obvious pale glow ballooning out from the cream-colored star some 4' to the northwest.

A dive into old scientific journals reveals that vdB 133's

◀ **RICH NEBULA COMPLEX** This remarkably intricate collection of bright and dark clouds is located at the heart of Cygnus, about 2.3° north-northeast of Gamma Cygni. Its showpieces include the three blue reflection nebulae vdB 131, vdB 132, and NGC 6914, as well as a few relatively rare yellow reflection nebulae. You can detect the faint glow of the trio in backyard telescopes under clear, dark, transparent skies.

discovery was first published in 1939, after astronomers using a 150-foot spectrograph at McDonald Observatory in Texas established the nebula's spectrum. But I believe they only investigated the star after finding it looking soft and swollen on Plate 17 in Frank E. Ross and Mary R. Calvert's 1934 *Atlas of the Northern Milky Way*.

Reflection nebulae are almost always found in association with dark nebulae, and **vdB 147** is no exception, as it lies at the eastern extremity of the impressive dusky streamer Barnard 168, or B168 (*S&T*: Aug. 2026, p. 14). But vdB 147 is rarely sought after visually as it takes double-digit aperture to see, and it's overshadowed by IC 5146 — a unique, bright emission/reflection nebula and open cluster discovered photographically but which is visible in handheld binoculars.

American astronomer George Herbig discovered vdB 147 in the late 1950s while looking for pre-main-sequence stars "that both lie in obscured regions and illuminate nearby nebulosity." Today, it's understood that the nebula's illuminating sun — 10.2-magnitude V1578 Cygni — is a multiple-star system with likely five physical companions.

I always start my searches for IC 5146 and vdB 147 by first finding the 4.6-magnitude open cluster M39, as northern Cygnus is a confusing place! Once that's done, a quick jaunt



▲ **COSMIC COCOON** IC 5146, a glowing sphere of gas in Cygnus also known as the Cocoon Nebula as well as Caldwell 19, is a combination of an emission nebula (red), a reflection nebula (blue), and a dark nebula (dusky lanes) plus a loose open cluster. It's a favorite target of visual observers and astrophotographers alike. The bluish patch to its southwest (lower right) is vdB 147, which is illuminated by the 10.2-magnitude star V1578 Cygni. The nebula lies about 2,500 light-years away.

3.7° southeastward with my 16-inch at 100× revealed a large, distinct glow around a 9.6-magnitude sun, BD +46°3474. This is IC 5146's illuminating star, and an ultra-high-contrast (UHC) filter showed dark chunks in the nebula that I could still detect even after I removed the filter and increased the power to 150×. At this magnification, I could now also discern the soft glow of vdB 147 on the eastern side of V1578 Cygni. Increasing to 300× made the nebula even more apparent.

The King and His Ghosts

About 3.4° southwest of 3.2-magnitude Beta (β) Cephei, or Alfrk, lies NGC 7023, the Iris Nebula. At 7th magnitude, it's the brightest reflection nebula in the constellation Cepheus, the King. I first saw it in 2014 in my 10-inch Schmidt-Cassegrain, but it wasn't until 2021 that my eye spied **vdB 141** for the first time — in my 5.1-inch, no less — even though it lies only 1.4° east of NGC 7023. With the 5.1-inch at 59×, vdB 141 appeared as a small, soft glow around BD +67°1300, a G-type star of magnitude 10.8. Switching to my 10-inch

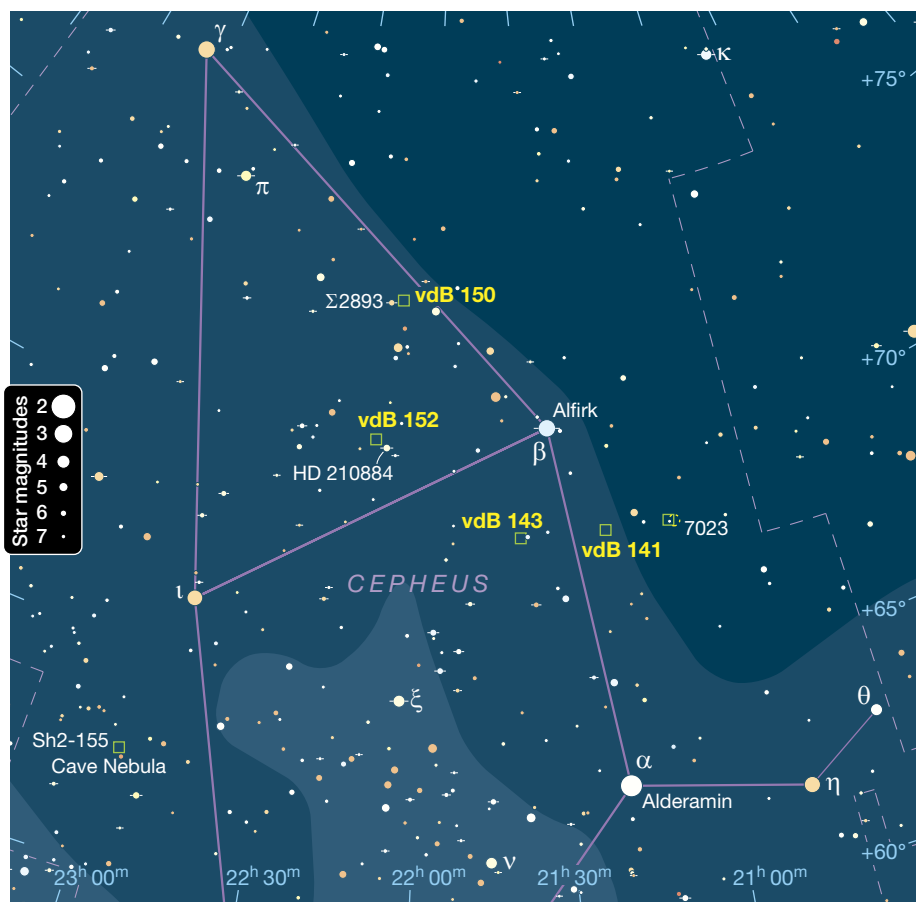


▲ **HEAVENLY SPECTER** The bright, glowing patch at upper left, vdB 141, also designated Sharpless 2-136 and nicknamed the Ghost Nebula, is situated in Cepheus. You can find it by first locating the blue reflection nebula NGC 7023, the Iris Nebula (at right), which lies 1.4° west. Looking at the image, it's easy to understand why vdB 141 earned that moniker, owing to its eerie form and appearance. It looks pale yellow because its illuminating star has the same spectral type as our Sun.

at 260×, the nebula appeared to fan out from the star in all directions except to the south-southeast, while the brightest part was on the northwestern side, where it extended out 40". Having an illuminating star with the same spectral type as our Sun, I was disappointed to find that BD +67°1300, only appeared off-white in my 16-inch at 233×, while a brighter (by more than a full magnitude) G-type star, BD +67°1302, just 3.1' south-southeast of it was yellow.

Astrophotographers love vdB 141 because it distinctly looks like a specter. But long-exposure images reveal that it's merely the brightest of several ghostly waves of oddly shaped nebulae in the area. While van den Bergh listed the object in his 1966 compilation, its first catalog designation is actually Simeis 260, after Russian astronomers Grigory Shajn and Vera Gaze discovered it during a photographic survey for nebulae in the early 1950s. But their only comment was "faint nebula around BD +67°1300."

If your telescope mount isn't motorized and you were to take a 20-minute break after viewing vdB 141 to, say, scan the



skies with binoculars, you'd find that **vdB 143** had slipped into your eyepiece. But that doesn't mean it would be visible, as it was such a challenge in my 10-inch — I was only confident after making multiple attempts on cool, dry, autumn evenings. Even then, my telescope optics at 200× created a glow around vdB 143's 8th-magnitude illuminating star, HD 206135, when I used averted vision. So, how did I know that I'd actually seen it? By closely watching the star with averted vision as I moved it to and fro in the eyepiece, I could detect that the glow pushed out southward. Images confirm this and even show that HD 206135 illuminates the southeastern end of a thin, dark cloud.

I'm always fascinated by how objects are discovered, but those facts can be hard to pin down. In this case, my research indicates that it was Swedish astronomer Knut Lundmark who found vdB 143 on photographs of the Milky Way taken by Edward Emerson Barnard while attempting to measure the parallaxes of stars involved with nebulosity.

I believe the first time I learned of **vdB 150** was when I saw an image taken of the bright cloud LBN 535. Dubbed the Dark Shark, it does bear an eerie resemblance to that animal, with its left eye consisting of the double star Σ2893 (with components of magnitudes 6.2 and 7.9 only 29" apart) and the reflection nebula a small, bluish patch near its dorsal fin.

To find vdB 150, first look for Σ2893 about 4.4° northeast of Beta Cephei. This double star, at 200× in my 10-inch,

▲ **REALM OF THE KING** This finder chart will help you find your way across northern Cepheus. You can use Beta (β) Cephei, or Alfirk, as a stepping stone in tracking down the four vdB nebulae showcased in the constellation. Bring the chart with you when star-hopping.

reminds me of Beta Cygni, or Albireo, with its bright gold and blue members. To see vdB 150, move 12' west-northwest to the 8.4-magnitude blue subgiant HD 210806, which is vdB 150's illuminating star. A faint glow, which isn't seen around nearby stars of similar brightness, was slightly more prominent on HD 210806's northeastern side — but not before I spent 20 minutes on it! As for the shark's dark nostril (marked by the nebula LDN 1235), I saw it only as a void in the star field northeast of the double star.

German astronomer August Kopff discovered our next nebula, **vdB 152**, on the night of October 21, 1908. He was using the 16-inch Bruce refractor at the University of Heidelberg's observatory in Germany to expose plates when he noticed the swollen image of the 9.3-magnitude star BD +69°1231 in central Cepheus. His former teacher, Max Wolf, photographed it soon after and described the new nebula as "a good example of the singular phenomenon of cave-formation amongst Milky Way stars" in a paper entitled "A New 'Cave-Nebula' in Cepheus." Thus, historically, the Cave Nebula moniker belongs to this nebula and not Sharpless 2-155, another diffuse nebula in Cepheus, which was discovered 30 years later!



Autumn Sky’s Dusty Reflections

Object	Original Discovery ID	Constellation	Distance (l-y)	Illuminating Star (Mag)	Size	RA	Dec.
vdB 123	Dorschner-Gürtler 152	Serpens Cauda	1,450	HD 170634 (9.9)	4' × 2'	18 ^h 30.4 ^m	+01° 14'
vdB 132	LBN 274	Cygnus	3,200	BD +41°3737 (9.3)	3' × 3'	20 ^h 24.7 ^m	+42° 23'
vdB 131	—	Cygnus	3,200	BD +41°3731 (9.8)	3' × 3'	20 ^h 24.3 ^m	+42° 18'
vdB 133	McDonald 78	Cygnus	4,250	44 Cygni (6.2)	13' × 11'	20 ^h 30.9 ^m	+36° 57'
vdB 147	Herbig 24	Cygnus	2,500	V1578 (10.2)	2' × 2'	21 ^h 52.6 ^m	+47° 14'
vdB 141	Simeis 260	Cepheus	1,100	BD +67°1300 (10.8)	3' × 2'	21 ^h 16.4 ^m	+68° 16'
vdB 143	Cederblad 194	Cepheus	2,950	HD 206135 (8.3)	7' × 6'	21 ^h 36.9 ^m	+68° 11'
vdB 150	Dorschner-Gürtler 178	Cepheus	1,100	HD 210806 (8.4)	7' × 4'	22 ^h 09.8 ^m	+73° 23'
vdB 152	Cederblad 201	Cepheus	1,200	BD +69°1231 (9.3)	4' × 3'	22 ^h 13.4 ^m	+70° 15'
vdB 2	Cederblad 1	Cassiopeia	2,350	BD +64°0013 (10.2)	2' × 3'	00 ^h 13.4 ^m	+65° 37'
vdB 1	LBN 578	Cassiopeia	1,300	HD 627 (8.3)	5' × 4'	00 ^h 10.7 ^m	+58° 46'

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, and the distances are in light-years, based on Gaia data.

◀ **SHARK BITE** The bright cloud LBN 535 dominates this region of Cepheus rich in dark molecular clouds. It's nicknamed the Dark Shark (others call it the Shark Nebula) owing to its resemblance to the shape of the fish. The double star $\Sigma 2893$ marks the shark's left eye, while its nostril is represented by the dark nebula LDN 1235. The small, bluish patch near the dorsal fin is vdB 150, which is illuminated by the 8.4-magnitude blue subgiant HD 210806, some 1,100 light-years away. Also visible to the south is the blue reflection nebula vdB 149.

Like the previous nebulae we've visited in Cepheus, getting to vdB 152 is straightforward — begin once again at Beta Cephei. From there, a 3.5° jaunt to the east-southeast will land you on the 5.5-magnitude star HD 210884, with the nebula another 18' northeast. I was excited to find that even in my 5.1-inch at just 27×, vdB 152's illuminating star (BD +69°1231) had a subtle, soft, not-quite-stellar appearance. Increasing to 59× made the glow around the star distinct, while HD 210884 gained a companion 15" from it.

Modern images tend to overexpose vdB 152's cave feature, which stands out well as a dark void on the southwestern side in Wolf's 2.5-hour exposure through thin clouds. However, at 93× I could see that the glow extended out from the star in all directions except to the south-southwest. Remarkable! Switching to my 10-inch at 135×, the increase in light-gathering power revealed that the nebula's brightest part extended more than 1' to the northeast from the illuminating star. It faded out into a dark nebula (designated LDN 1217) that I easily saw due to a distinct lack of stars during my sweeps across it.

Back to the Beginning

With an area of almost 600 square degrees, Cassiopeia, the Seated Queen, covers more celestial real estate than neighboring Cepheus. Despite that, it contains fewer entries in van den Bergh's catalog. So, have you ever seen vdB 2? It's situated 6.5° north of 2nd-magnitude Beta Cassiopeiae, or Caph, and surrounds a hot, 10.2-magnitude blue main-sequence sun designated BD +64°0013.

Using my 5.1-inch at 59×, the view reminded me of vdB 141, except that the illuminating star of vdB 2 is brighter and the nebula fainter. It's a simple-looking cloud that was discovered photographically more than a century ago.

Like most astronomical catalogs, van den Bergh's is arranged by right ascension. And since reflection nebu-

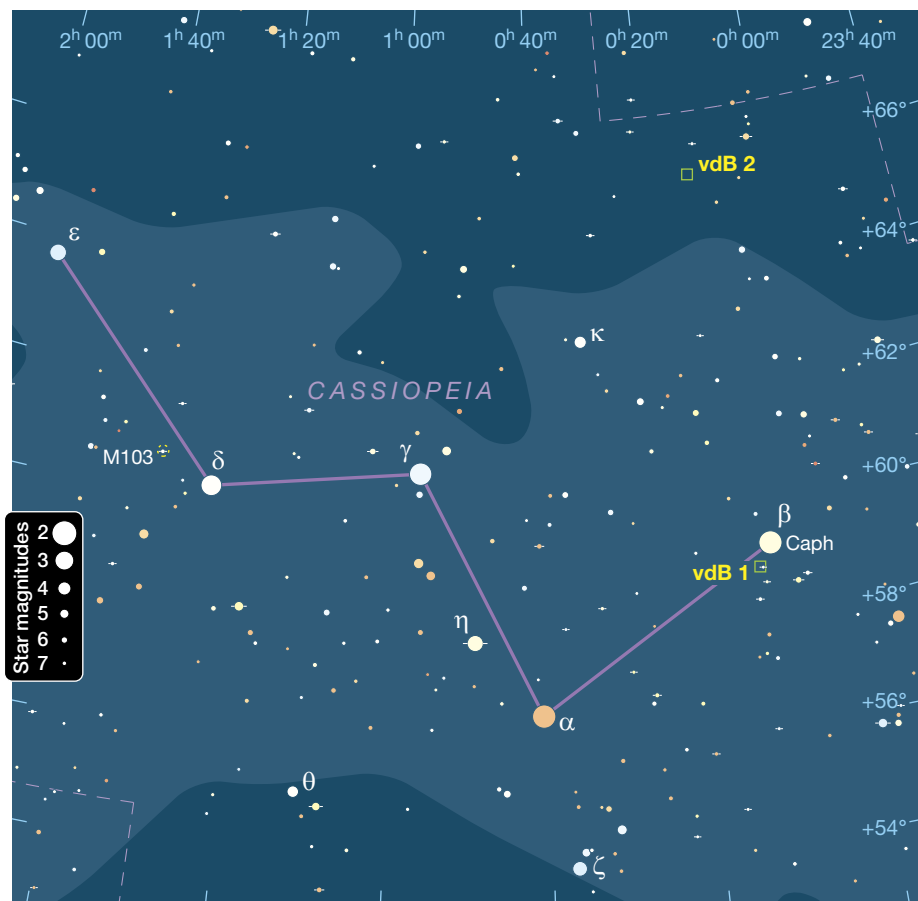
▶ **CASSIOPEIA STAR FIELD** The 2nd-magnitude star Beta Cassiopeiae, or Caph, can be your signpost in locating the first two objects listed in the van den Bergh catalog. The faintest stars shown are at magnitude 7.

lae are typically found in the dust-laden disk of the Milky Way, it's no surprise that vdB 1 lies in Cassiopeia, a bit less than 0.5° south-southeast of Caph. Using my 5.1-inch at 93×, I could just detect a glow around vdB 1's illuminating sun, HD 627, an 8.3-magnitude blue main-sequence star. However, unlike in images, I didn't see the glow extending southwest to a pair of similar-magnitude stars. And though the duo has the appearance of being associated with the nebula, recent precise measurements by the Gaia spacecraft actually place the pair some 100 light-years in the background.

George Herbig first mentioned vdB 1 in a 1960 article as a side attraction to a much more interesting nebula around 14th-magnitude V633 Cassiopeiae, 6' to the northeast. Known today as Herbig 1A, I could see this compact nebula in my 10-inch at 200× as a fat but faint glow protruding out from the dim star. And my 16-inch at 440× revealed V376 Cassiopeiae just above it, looking soft and nebulous with averted vision.

Well, that concludes our tour. I hope it inspires you to observe more of the objects you see in astrophotos, since many more are, in fact, visible in the eyepiece. And who knows, maybe you'll discover a reflection nebula of your own along the way!

■ Contributing Editor SCOTT HARRINGTON may love reflection nebulae, but he's glad the Sun isn't buried inside a humongous one that blocks his view of the Milky Way.



Birth of the Space Age

The 20th century's pioneering rocket scientists can trace
their lineage back 2,000 years.



EARTHRISE The three astronauts aboard the 1968 Apollo 8 mission were the first people to leave Earth's immediate vicinity. They flew to the Moon and orbited it 10 times before returning to Earth, capturing this iconic image on their third orbit. The view of Earth from a distance was a life-changing experience for many of the Apollo astronauts.

Many astronauts have orbited Earth, but few have seen it from a great distance. None described the experience better than Michael Collins, who piloted the Apollo 11 Command Module around the Moon while Neil Armstrong took humanity's first extra-terrestrial footsteps below. In Collins's autobiography, *Carrying the Fire*, he writes:

I really believe that if the political leaders of the world could see their planet from a distance of, let's say, 100,000 miles, their outlook would be fundamentally changed. That all-important border would be invisible, that noisy argument suddenly silenced.

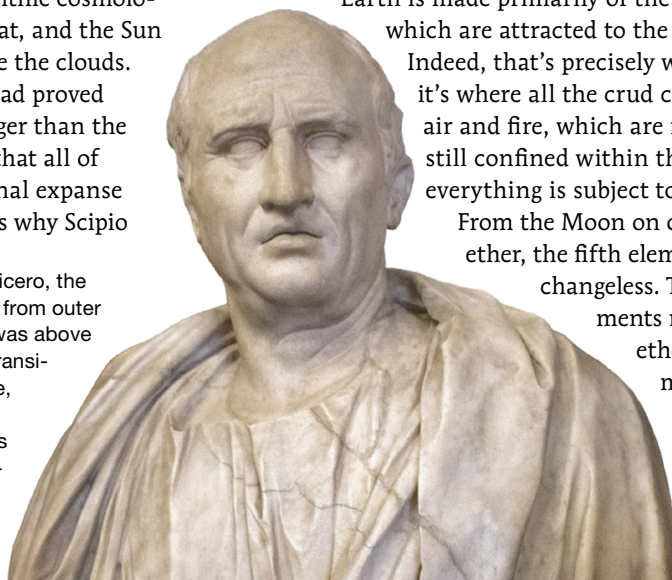
Two millennia earlier, the renowned Roman orator and author Marcus Tullius Cicero (106–43 BC) expressed a similar idea in a work now known as *Somnium Scipionis* (*Dream of Scipio*). His main character, a fictionalized version of the Roman general Scipio Aemilianus dreams that he's floating in the Milky Way together with the spirit of his dead adoptive grandfather, the famous general Scipio Africanus. Here's young Scipio's reaction when he looks at his surroundings:

I saw stars brighter and more numerous than we can see from the ground . . . and each star was much bigger than Earth. As for Earth itself, it appeared so small that Rome's empire was just a pinpoint.

The passage starts with Africanus telling his grandson that he will have an illustrious career as a Roman general and statesman, which makes young Scipio feel mighty pleased with himself. But Scipio Aemilianus realizes the folly of his pride when he sees how minuscule Rome is in the cosmic scheme.

This is arguably the earliest known description of our planet as seen from outer space. Mythological stories from many places and times describe gods looking down on Earth, but these assume traditional, pre-scientific cosmologies. Earth is typically envisioned as flat, and the Sun and Moon float just out of reach above the clouds. By Cicero's time, however, scientists had proved that Earth is a sphere significantly larger than the Moon but smaller than the Sun, and that all of these bodies occupy a three-dimensional expanse that dwarfs the objects inside it. That's why Scipio

► **A FEARLESS PATRIOT** Marcus Tullius Cicero, the first person to describe Earth's appearance from outer space, had wide-ranging interests. But he was above all a politician. He played a key role in the transition from the Roman Republic to the Empire, eloquently defending the power of the Senate against the rising populist dictator Julius Caesar. He was executed after Caesar's assassination, and his head and hands were placed on public display as a warning against anyone tempted to speak or write against the ruling regime.



and the Apollo astronauts perceived Earth so similarly.

A story written today featuring historical figures in an outer-space setting would be classified as science fiction, and *Dream of Scipio* has indeed had a profound effect on that literary genre. Latin, the language of Rome, was an essential part of higher education well into the 20th century. Cicero is widely considered the greatest of all Latin prose writers, and *Dream of Scipio* is one of his best-known works. So most of the early science-fiction writers likely read it somewhere along the line. Its direct and indirect influence is easy to trace.

Science fiction, in turn, has shaped the development of spaceflight. Many of the rocket pioneers were inspired by reading science fiction as children, and it remains a shared secular mythology for engineers and scientists today. In retrospect, the Apollo program seems like an inevitable outcome of spaceflight fantasies.

Cicero's Cosmos

Dream of Scipio is a parable on a familiar theme: the reward for virtue in the afterlife. It's modeled on the *Myth of Er*, a similar parable told more than three centuries earlier by the foundational Greek philosopher Plato. Both works posit that human souls are immortal, but they're periodically reborn into different bodies. Between incarnations, virtuous souls live blissfully in heaven, while evildoers are punished.

For Plato, the souls of the dead exist on a different plane from everyday reality, though the two worlds do share many things in common. For Cicero, by contrast, the heaven of the afterlife is one and the same with the physical, scientifically observable cosmos. Using Scipio Africanus as his mouthpiece and Scipio Aemilianus as auditor and witness, Cicero describes the glories of cosmos in loving detail.

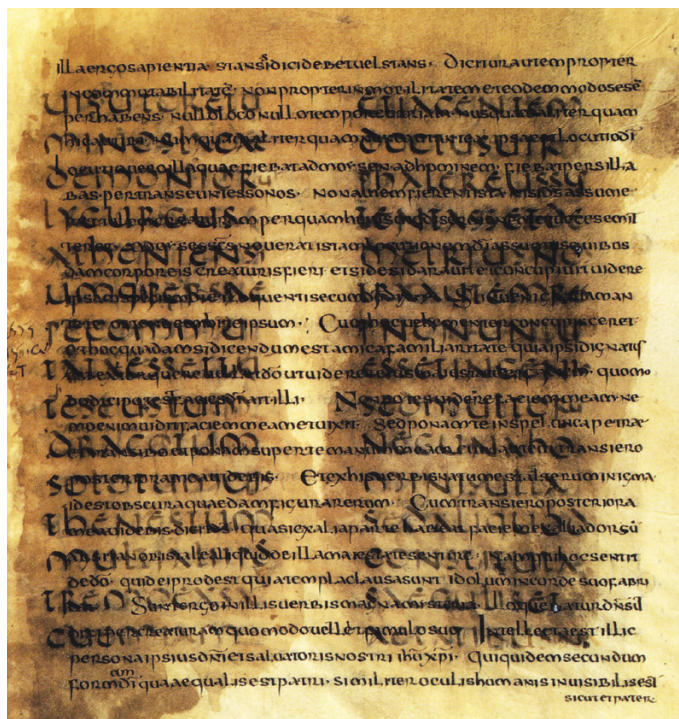
For the most part Cicero follows the cosmology laid out by Plato's student Aristotle. Earth lies motionless at the center, while everything else rotates around it at various speeds.

Earth is made primarily of the elements earth and water, which are attracted to the center of the universe.

Indeed, that's precisely why Earth is at the center — it's where all the crud collects. Earth also contains air and fire, which are repelled by the center but still confined within the orbit of the Moon, where everything is subject to corruption and decay.

From the Moon on out, everything is made of ether, the fifth element, which is perfect and changeless. The four terrestrial elements

move in straight lines, but ether moves in circles, the only motion that can continue indefinitely. Grandpa Scipio enumerates all the circles from the outside in: first the stars, then Saturn, Jupiter, Mars, the Sun, Venus, Mercury, the



▲ **RECOVERING A CLASSIC** *Dream of Scipio* was originally the last chapter of a book called *On the Republic*, which was thought to be lost until 1819, when a heavily obscured copy was found in the Vatican Library. Cicero's text (larger lettering) had been scraped off the original parchment and overwritten with a treatise by the great Christian theologian Augustine of Hippo (AD 350–430), but chemical treatment rendered most of the original text readable.

Moon, and finally the sphere of Earth. He describes the appearance and significance of each object briefly but beautifully.

Scipio Aemilianus witnesses all this with his ears as well as his eyes. The universe is full of the music of the spheres, with each body contributing its own unique note as it follows its orbit. Only Earth, being motionless, fails to participate in the celestial symphony.

When young Scipio first meets his grandfather, he's baffled that he can be conversing with a dead man. Africanus tells him that human souls are immortal, and to prove the point Paulus, our hero's dead birth father, joins the conversation. Paulus tells his son that human souls, being eternal, are also made of ether, and their natural home is in the heavens. But they're periodically sent down to Earth, chained to human bodies until they have completed the tasks allotted to them by the supreme God. If they do those tasks well and selflessly, their souls are set free again upon death. But if they pursue the pleasures of the flesh, their souls remain chained on or near Earth until all their earthly impurities have been purged.

Then, to reiterate Rome's minuscule size, Cicero turns to geography. All of Rome's domains are just a tiny part of the known world, which is in turn a small fraction of Earth's surface. And Rome is small not only in space but in time. Earthlings reckon time in years — the time it takes the Sun to make a full cycle through the stars. But Rome has lasted

barely one-twentieth of a Great Year, the time required for everything in the heavens to return to its original position.

Therefore, says Africanus, you should not seek glory, which is petty and ephemeral, nor material self-interest, which binds you to lowly Earth. Instead, you should serve your city-state selflessly. And if you do, your soul will be set free after your death to roam the glorious cosmos.

Dream of Scipio introduced the idea of viewing Earth from a distance, but it's not about spaceflight in the modern sense. To Cicero, traveling the cosmos was possible only in spirit, not in body. During the Scientific Revolution of the 16th and 17th centuries, however, an author who did espouse bodily spaceflight wrote a work modeled partly on Cicero's parable.

Kepler's Dream

The great astronomer Johannes Kepler (1571–1630) worked intermittently throughout most of his life on a story about a journey to the Moon. He wrote the first draft as a university dissertation in 1593 and was still tweaking the final version when he died. His heirs published it in 1634 under the title *Somnium*, or *Dream*.

According to Kepler, the original dissertation was an oblique defense of the controversial Sun-centered model of the universe introduced 50 years earlier by the German-Polish astronomer Nicolaus Copernicus. Copernicus showed that the periodic fluctuations observed in the planets' apparent motions can be explained by our shifting perspective due to Earth's orbit around the Sun. To make this idea more palatable to mainstream astronomers, who believed that Earth is stationary, Kepler described how the motions of the planets would appear to an observer standing on the Moon as it orbits Earth.

The most vivid part of *Somnium* is the description of Earth as seen from the Moon. To someone on the farside, Earth is a rumor; it's never directly visible. To someone on the nearside, Earth dominates the night sky; it stands still in one spot but shows different features as it rotates. It appears four times wider than the Moon does from Earth and is vastly brighter, ensuring that no part of the nearside is ever truly dark.

The strictly astronomical aspect of *Somnium* stands up well to the test of time. Some of the details are wrong, but it's based on solid evidence and reasoning. Not so with Kepler's theories on the Moon's weather, its inhabitants, and the possibility of actually traveling there. These were hard to justify rationally, so Kepler instead adopted Cicero's device of presenting his speculations as eyewitness accounts while maintaining plausible deniability by having the discussion take place in a dream. Kepler also presumably chose the title to give the work credibility; together with the astronomical subject matter, it's an obvious reference to *Somnium Scipionis*.

In Kepler's *Somnium*, the dream-self never actually makes it to the Moon; he's on the verge of being escorted there by a magical spirit when he wakes up. The description of the Moon is instead put into the mouth of a tour guide, who's telling Kepler what to expect when he arrives. But we know that Kepler really did believe that spaceflight was possible,



ECLIPSE SCIENCE Sometime before 400 BC, Greek astronomers concluded that the Moon shines by reflected sunlight, that its phases are caused by the orientation of the lit half, and that lunar eclipses occur when the Moon passes through Earth's shadow, as shown in this skillful montage. This realization made it possible for the first time to measure distances to astronomical objects. By comparing the size of the Moon to Earth's shadow (and knowing its angular size), Greek scientists deduced correctly that the Moon is about one-quarter Earth's diameter and 30 Earth-diameters distant. Their estimates of the Sun's size and distance (found using other methods) varied but were typically about 5 and 600 Earth-diameters, respectively — unimaginably vast by everyday standards, but just one-twentieth of the actual values.

thanks to a passage in a public letter that he wrote in 1610 to his great contemporary, Galileo Galilei. He argues that both the Moon and Jupiter are inhabited and says that even if they're not now, they soon will be — by humans:

But as soon as somebody demonstrates the art of flying, settlers from our species of man will not be lacking. . . . Given ships or sails adapted to the breezes of heaven, there will be those who will not shrink from even that vast expanse. Therefore, for the sake of those who, as it were, will presently be on hand to attempt this voyage, let us establish the astronomy, Galileo, you of Jupiter, and me of the moon.

As far as I can find, this is the first declaration that humans can and will colonize worlds beyond our own. Kepler's confidence is remarkable considering that he had no idea how such a feat could be accomplished. His vision of sailing cosmic breezes evokes the modern concept of solar sails, but he likely meant it metaphorically — he argues elsewhere in the same letter that space must be a vacuum.

It would be more than three centuries before humans achieved the spaceflight Kepler foretold.

Goddard's Cherry Tree

Remarkably, Kepler started fantasizing about traveling to outer space before Galileo's telescopic observations proved that the Moon and planets are worlds much like Earth. Several other literary discussions of spaceflight appeared in the decades following Galileo's revolutionary discoveries, increasing dramatically with the advent of motorized transportation

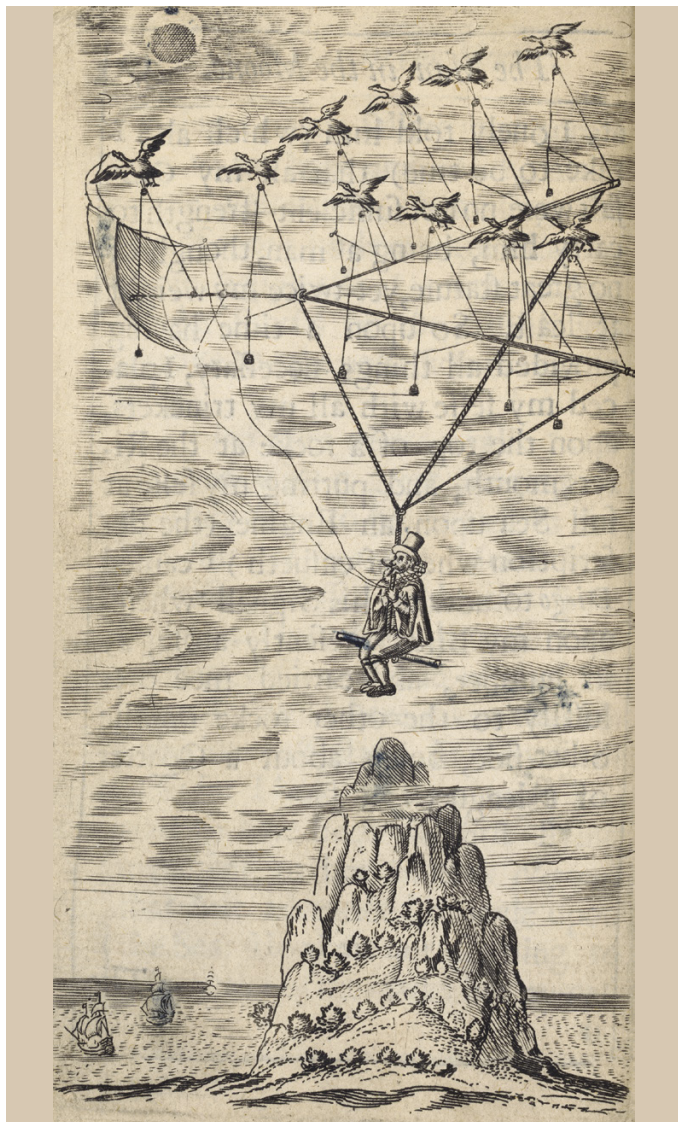
in the 19th century. Finally, the modern science-fiction genre, with spaceflight as a major component, evolved out of the works of two wildly popular authors, Jules Verne (1828–1905) and H. G. Wells (1866–1946).

There's no reason to think that Verne was strongly influenced by Kepler, though he did allude to Kepler's theories in his 1870 novel *Around the Moon*. Wells, by contrast, used a quotation from Kepler about alien civilizations as the epigraph of his 1898 novel *The War of the Worlds*. Three years later he borrowed Kepler's idea of an underground lunar civilization (with attribution) in *The First Men in the Moon*.

Wells, in turn, inspired a 16-year-old boy named Robert Goddard to devote his life to spaceflight. As Goddard told the story, he experienced an epiphany after climbing a cherry tree with his head full of stories from *The War of the Worlds*. He suddenly decided that it really was possible to fly to Mars, and that he would be the one to make that possible.

After a few false starts, he realized that rockets were the key to space travel. In 1919 he published a mathematical analysis of the requirements for sending a rocket to the Moon, unaware that he was replicating work published 16 years earlier by the Russian Konstantin Tsiolkovsky. But unlike Tsiolkovsky, Goddard was a gifted engineer; he flew the world's first liquid-fuel rocket a century ago in 1926, cementing his status as the father of American rocketry.

Goddard's science-fiction inspiration was typical of the rocket pioneers, enthusiastic young men from many countries who formed clubs to work on space rockets. They didn't get very far on their own; the technical challenges and costs proved far greater than they had imagined. But when national



▲ **FLYING IN STYLE** The first English spaceflight fantasy was Francis Godwin's *The Man in the Moone*, published under the pseudonym Domingo Gonsales in 1638, just four years after Kepler's *Somnium*. This illustration shows Gonsales being transported to the Moon by a cleverly harnessed flock of geese. Although the device is clearly comical, it's also half in earnest; the fact that Earth's atmosphere stops short of the Moon was not well established at the time of publication.

governments with deep pockets became interested in spaceflight for its military applications, the rocket pioneers formed the experienced core of the engineering teams.

Striving for the Stars

There are striking similarities and differences between modern and ancient notions of Earth's place in the universe. One is scale: Two centuries after Cicero, the astronomer Ptolemy estimated the universe's diameter to be about 20,000 times bigger than Earth's — which is huge enough by ancient Roman standards. Modern astronomers, on the other hand, estimate the observable universe to be roughly 100 billion light-years across, or 70 quintillion times Earth's diameter, an



▲ **SPACEFLIGHT IN THE INDUSTRIAL AGE** Jules Verne's 1865 novel *From the Earth to the Moon* ushered in the era of pseudo-realistic spaceflight stories. Verne's notion of traveling to the Moon in a cannon shell is impractical for many reasons, but he accurately understood the concentrated power required to escape Earth's gravitational field.

entirely different dimension of vastness. The other difference is situation: According to mainstream Greco-Roman cosmology, Earth was unique not only in its central location but also in its composition, being the only body made of earth, water, air, and fire. Now we know it's just one of many large rocky bodies in our solar system, and one of countless trillions in our galaxy. But that arguably makes it seem more special.

Both Cicero and astronaut Collins saw Earth in political terms, but they brought home very different lessons. To Collins, it appeared infinitely beautiful, precious, and fragile. He came back from outer space no less a patriot — he had been, after all, a U.S. Air Force test pilot — but newly devoted to Earth as the common heritage of humankind. Collins was culturally prepared to think in those terms; the idea of



EXPANDING UNIVERSE Although we can now travel much faster and farther than the ancient Romans could, the size of the known universe has increased much faster still. In ancient times, most astronomers thought that the stars lay just beyond Saturn's orbit, and the edge of the universe just beyond that. Even as late as 1920, most astronomers thought that our own Milky Way was the entire universe. We now know that it's just one of countless billions of galaxies, as shown in this Hubble Ultra-Deep Field image. Humanity's place in the cosmic scheme seems smaller today than ever before.

common goals for humanity as a whole dates back at least to the 18th-century Enlightenment, though it certainly was not universally accepted in Collins's time, nor is it now.

By contrast, global humanism was completely alien to Roman culture, at least before the advent of Christianity. To Cicero, city-states might be small in size and short in duration, but they were the highest possible form of society. Conquest was fundamental to the identity of his own city-state. Scipio Aemilianus, Cicero's chosen hero, was most famous for defeating Rome's arch-rival, Carthage, leveling the city, slaughtering most of its inhabitants, and selling the rest into slavery. To Cicero and his readers, this represented the epitome of virtue.

When I set aside my differences with Cicero about what constitutes righteous behavior, I find *Dream of Scipio's* message quite compelling. Outer space is humanity's birthright, says Cicero. Reclaiming that birthright isn't easy; the pitfalls are many. But it's worth all the struggle, because reaching outer space will allow us to transcend our earthly bonds.

Those twin ideas, destiny and transcendence, are the

essence of the ideology that drove the rocket pioneers. Tsiolkovsky stated it beautifully: "Earth is humanity's cradle, but one cannot live in a cradle forever." The critical difference is that for Cicero, childhood's end meant using correct thought and virtuous behavior to leave the corrupt, fallible human body behind. Modern spaceflight evangelists, by contrast, want to use technology to colonize outer space in the flesh.

■ Contributing Editor **TONY FLANDERS** thanks his Latin 1 professor for teaching him to appreciate Cicero's prose style. Tony's translation of the passage from *Dream of Scipio* is meant to be faithful to the spirit rather than the letter of the original.

FURTHER READING: Many English translations of *Dream of Scipio* are available in print and online. The passage from Kepler's letter to Galileo is from a translation by Edward Rosen, who also published the standard English translation of *Somnium*. Marjorie Hope Nicolson's *Voyages to the Moon* is a delightful summary of spaceflight literature before the first human balloon flight in 1783.

Resolving Our Neighboring Worlds



MOMENTS OF CLARITY

With practice and patience, you too can record highly detailed closeups of the major planets. This montage shows some of the best results the author has recorded from his backyard observatory in southern New Hampshire.

ALL IMAGES ARE COURTESY OF THE AUTHOR

Capturing high-resolution pictures of the major planets has never been easier.

The planets in our solar neighborhood have long been a major pursuit of both amateur and professional astronomers alike. But it wasn't until the end of the 20th century that amateurs' work really started to be taken seriously. The advent of digital cameras and powerful home computers and software provided backyard observers with the tools to achieve the resolution and clarity needed to produce world-class images of these distant worlds. And that prompted professional astronomers to seriously consider their work.

Today, amateurs using high-speed digital video cameras and innovative processing techniques regularly produce pictures of the major planets on par with those obtained at professional, mountaintop observatories. And it doesn't take a lot to get involved yourself. Here's how.

Aperture Is Key

The planets might be nearby (astronomically), yet they're still an immense distance away, and resolving details on their tiny disks requires a lot of magnification. Almost any type of telescope can produce pleasing views of our neighboring worlds, but you'll need an aperture of at least 8 inches to clearly record swirling clouds inside Jupiter's Great Red Spot or small storms in the atmospheres of Saturn and even Uranus.

The type of scopes best suited for planetary imaging are either a Newtonian reflector or a Cassegrain instrument. Refractors provide the greatest contrast due to their unobstructed aperture, but large refractors are very expensive, with long, heavy tubes compared to the alternatives.

The most economical approach is the Newtonian, which costs the least amount per inch of aperture. But the design's biggest weakness is that its tube can be prone to flexure, requiring frequent collimation to ensure consistent optical performance throughout the night as the instrument tracks your target across the sky. Additionally, using the scope on an equatorial mount frequently places the Newtonian's focuser at an awkward angle. Furthermore, determining which direction is up can be tricky, an important factor when using an atmospheric dispersion corrector, discussed later.

Perhaps the best compromise between aperture and tube size is a Cassegrain system that folds a long optical path into a tube some one-third the length of a comparable-aperture Newtonian and produces

the image at the rear of the scope through a central perforation in its primary mirror. The Schmidt-Cassegrain telescope (SCT) is the most common Cassegrain variant that utilizes a front corrector plate to produce a wide, corrected field. Other optical designs such as the Maksutov-Cassegrain or Dall-Kirkham optics are also suitable but less common.

Cameras and Magnification

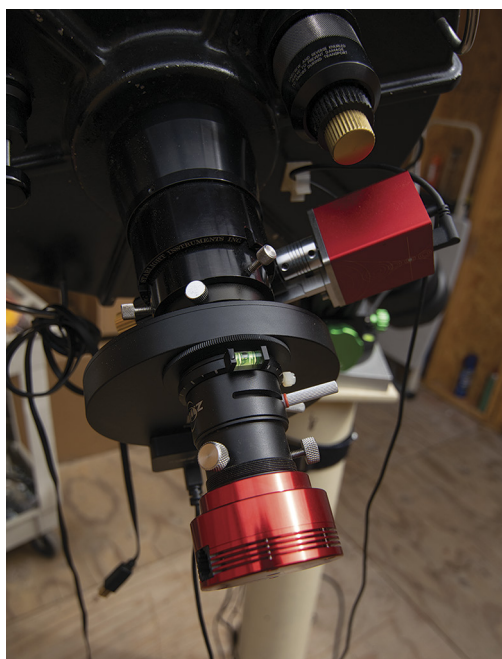
Regardless of which telescope you choose, there are some other accessories you'll need. The two primary ones are the camera and an amplification device like a Barlow lens. Resolving the smallest planetary details requires a long focal ratio, and commercial telescopes are typically offered with f-ratios of f/4.5 to f/11, so you'll likely need a quality Barlow lens, eyepiece-projection adapter, or other means of amplification (like Tele Vue's Powermates) to achieve the desired magnification. However, some of the cameras designed specifically for planetary imaging these days may have such small photosites (typically referred to as pixels) that additional magnification might not be needed in your particular setup. The optimum pixel scale to resolve small-scale features is about 0.1 arcsecond per pixel. To calculate this value, enter your telescope's focal length (*F*, in millimeters) and your camera's pixel size (*P*, in microns) into this equation:

$$\text{Pixel Scale} = 206.265 \times (P / F)$$

For example, a camera with 2.76-micron pixels paired with an 8-inch f/10 SCT having a focal length of 2,032 mm produces a pixel scale of 0.28 arcsecond per pixel, which may be fine on most nights, though it will benefit from a 2× Barlow to get up to 0.14 arcsecond per pixel on particularly steady nights.

Speaking of cameras, planets are bright and typically

require an exposure of just a fraction of a second to achieve adequate signal without much noise. This means you don't need a camera with active cooling, which requires additional power. However, due to Earth's turbulent atmosphere moments of steady seeing are few and far between, so it's nearly impossible to record all the small-scale detail visible in quick snapshots. To work around this issue, planetary imagers



◀ **HANDS-OFF** Manually focusing a telescope at extremely high magnification is much easier with an electronic focuser. The author uses a Feather Touch secondary focuser with a ZWO EAF stepper motor with his Celestron C14 that's controlled through a laptop. Also seen is a color filter wheel and ZWO Atmospheric Dispersion Corrector (ADC). The ADC tunes out prismatic dispersion introduced by Earth's atmosphere, leading to even-sharper results.



use the *lucky imaging* technique, in which you record a short video sequence of your target, then process the file using a computer program that selects and combines the sharpest individual frames.

There are many compact planetary cameras on the market today capable of recording hundreds of frames per second. These cameras are designed around Sony low-noise CMOS sensors and come in either monochrome (black-and-white) or one-shot color formats. Color cameras are great if you're interested in capturing images of the planets in their natural color. Monochrome models need an additional filter wheel with red, green, and blue (RGB) filters to produce color images.

Until fairly recently, monochrome cameras used with RGB filters produced the very highest-resolution images. That was because unlike the color version, monochrome cameras don't incorporate a *Bayer color filter array*, which is a grid of tiny filters layered over the detector that divides it into a pattern, with 50% of the pixels having green filters, 25% blue, and 25% red. Software then interpolates these pixels into a color image. This matrix used to produce inherently lower-resolution color images than a monochrome camera using separate color filters, but improvements in the interpolation algorithm (known as *debayering*) have made the difference negligible. But if you're trying to record planetary details in wavelengths beyond the visible spectrum, such as ultraviolet, near infrared, and the methane band that reveals features deep within Jupiter's atmosphere, then a monochrome camera is a better choice.

Besides its sensitivity characteristics, you should pay careful attention to the size of the pixels when choosing a video camera, as they're a key factor in determining the resolution of your results as noted earlier. The other feature to look for is how many frames it can record per second. You'd want to capture as many as you can in the shortest amount of time to ensure you get enough frames taken under steadier moments for stacking later.

Planetary cameras record video in AVI or SER formats, and most have the option of creating individual FITS files. Be aware that these cameras produce massive amounts of data — it's not uncommon to collect several hundred gigabytes of image data in an evening! These large files require a computer with substantial hard-drive memory space and an ultrafast write speed. When shopping for a computer, look for one with USB 3.0 ports and a high-capacity, solid-state drive (SSD), as these are capable of write speeds of hundreds of megabytes

◀ **BEYOND THE VISIBLE** A monochrome camera equipped with color filters isolates individual wavelengths of light, which is particularly desirable for imaging in specific spectral regions. Certain planets, including Jupiter, Venus, and Uranus, reveal interesting details at wavelengths beyond the visible spectrum. Venus shows light and dark bandings in its cloud tops in ultraviolet light (top), which are only hinted in visible light under excellent seeing conditions (second from top). Jupiter recorded on February 3rd shows the planet in natural color (third from top) and in the methane (CH₄) absorption band at 889 nanometers (bottom), where features deeper into the planet's atmosphere appear bright.

per second. Avoid budget models that rely on cloud storage, as it's simply too much data to pass through an internet connection. If you're using an older laptop or one with a slower write speed, many planetary cameras now include onboard DDR3 RAM memory buffers, which help prevent dropping frames when operating the camera with slower write speeds.

While your camera may come with its own control software, there are a few free or inexpensive programs designed specifically for planetary imaging that feature additional capabilities, including controls for electronic focusers and filter wheels. Some also allow you to preprogram the exposure length and gain settings for each filter. *SharpCap* (sharpcap.co.uk) for PCs supports a wide range of camera models. Both PC and Mac users can operate their cameras and accessories with *FireCapture* (firecapture.de), which is perhaps the most popular and versatile program for capturing planetary data, and there's a version for Mac users. There's also *oaCapture* (tinyurl.com/oacapture) just for Macs.

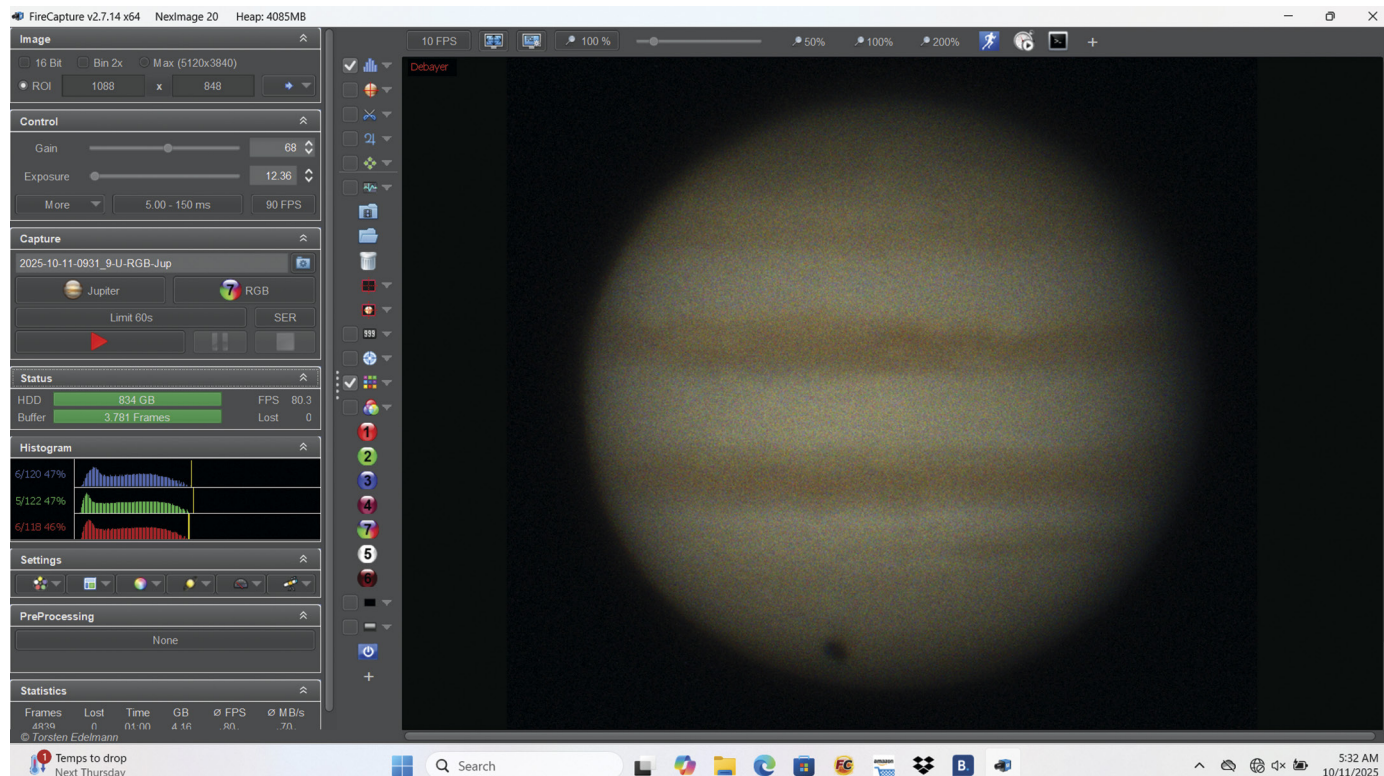
Imaging with extremely long focal lengths requires an electronic focuser. Attempting to manually focus will magnify the vibrations from your hand, producing an unsteady view that's virtually impossible to focus accurately. Also consider that you'll be refocusing many times during the night as the ambient temperature drops and seeing conditions change.

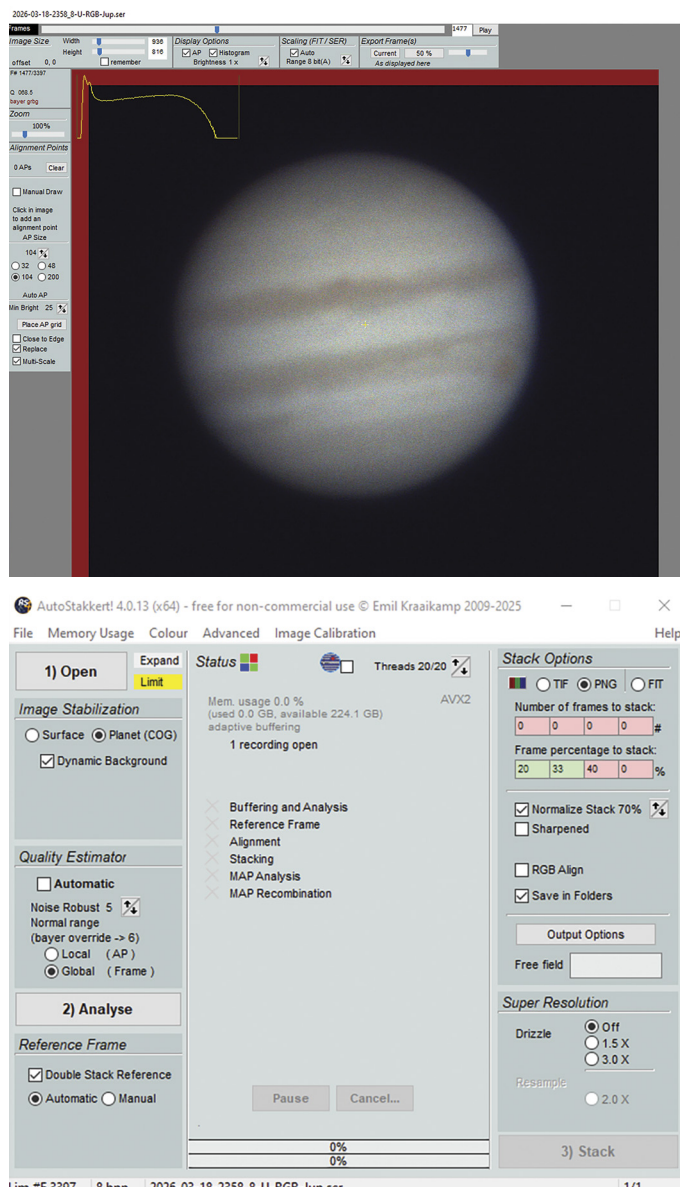
One other useful accessory is the atmospheric dispersion corrector (ADC). This device resembles a short Barlow that contains two weak prisms placed in the optical path. Earth's atmosphere is loaded with water vapor, which smears light into its component rainbow colors, a process known as *atmospheric dispersion*. The effect appears as red and blue fringing on the



▲ **PIXEL POWER** Some newer cameras are built around detectors with smaller pixels than ever before, which, in some cases, eliminates the need for additional image amplification like using a Barlow lens. The author recorded this shot of Jupiter on the evening of March 19th this year using a Celestron NexImage 20 paired with his C14 at prime focus. With its 1.4-micron-square photosites, the camera produces an image scale of 0.07 arcsecond per pixel — a bit too much magnification for this scope, though a good match for a C8 with its 2,032-mm focal length.

▼ **COMPLETE CONTROL** While some cameras come with their own software, other third-party options are available that offer much more features. *FireCapture* (firecapture.de), shown above, as well as *SharpCap* (sharpcap.co.uk) both can also operate electric focusers and filter wheels.





▲ **AUTOMATED STACKING** *Autostakkert! 4* is a popular free program that stacks videos or individual frames with very little user input.

top and bottom of your target planet, which becomes more pronounced the closer the planet is to the horizon. By adjusting the ADC, you can cancel out this chromatic smear and noticeably improve the sharpness of the image. An ADC is a worthwhile investment, particularly at more northerly locations, where the planets arc across the sky at lower elevations. It needs to be aligned with the horizon to work properly, making it challenging to use with Newtonian reflectors.

At the Telescope

Once you've put together your planetary imaging setup, you'll need to ensure all your equipment is operating as best as it can starting with collimation. Because you're imaging at an extremely long focal length, even a slight misalignment in your optics will significantly degrade the quality of your

images. Be sure to check your collimation before starting an imaging run by using a bright star in the same region of the sky as your target planet. Another important step is to give the telescope ample time to reach thermal equilibrium. If your telescope is warmer than the surrounding air, it radiates heat, which can significantly blur the image. Give your telescope about an hour to cool down before starting to image.

The biggest limiting factor in the quality of your images will be the atmospheric seeing conditions at your location. It's best to monitor weather conditions using websites that cater to astronomers, such as *Astrospheric* (astrospheric.com), *Meteoblue* (meteoblue.com), or *Clear Sky Chart* (cleardarksky.com/csk) to see how the night may progress. Keep in mind, though, that meteorology isn't an exact science. You might end up with some great moments on a night forecast to be mediocre, so it's always worth trying to image on a clear night.

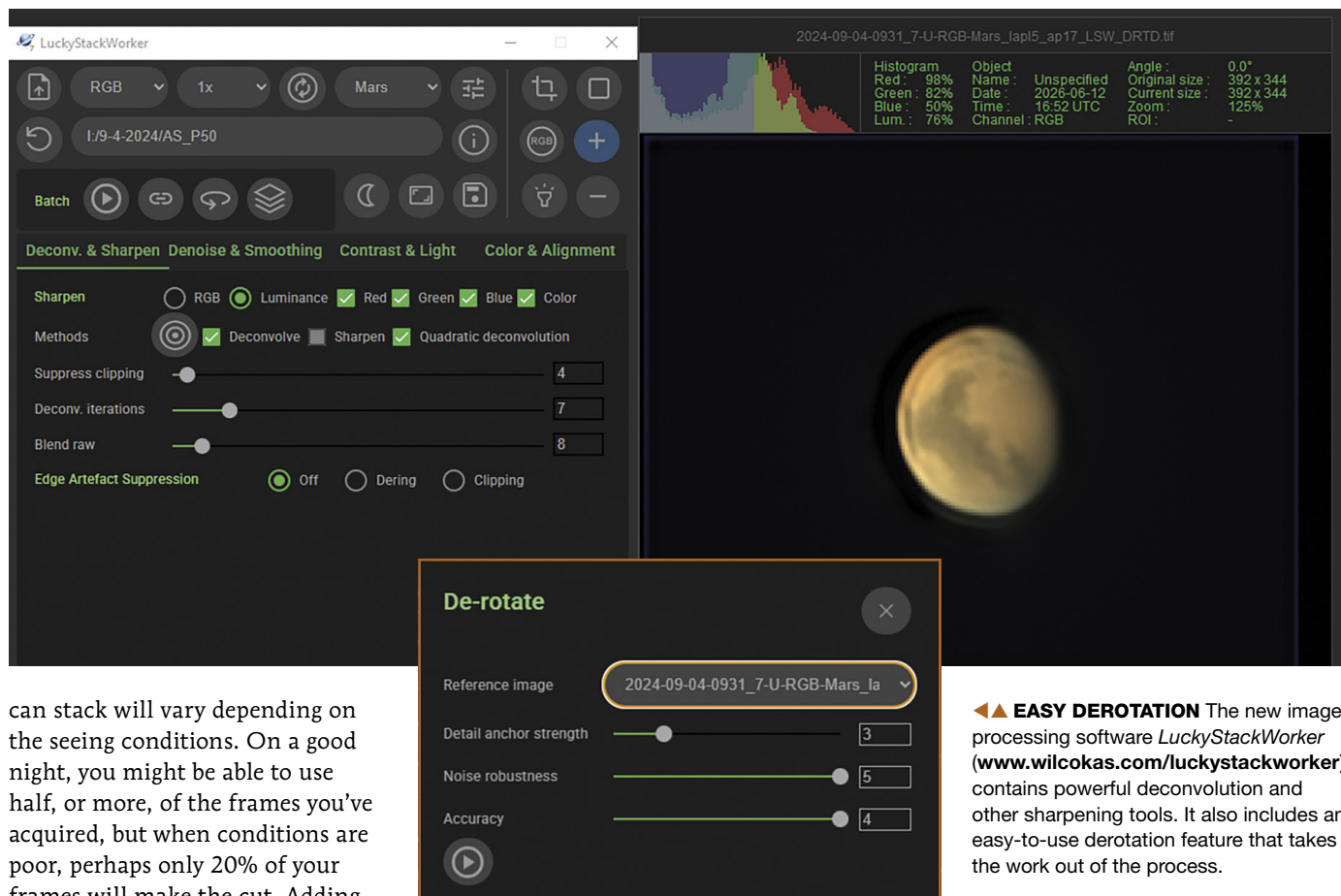
The last thing you'll need to do before hitting the record button is to focus the image. Achieving perfect focus is pretty easy under steady seeing conditions. More likely, though, is you'll end up racking the focuser back and forth, trying to find a good approximation of focus on a less-than-optimal night. It may take several minutes of trial and error to achieve sharp focus, but take as long as you need. I often refocus frequently throughout the night as the temperature falls and seeing conditions change.

With everything ready, start recording. Keep in mind that your target is a rotating planet, so there's a limit on how long your recording can be before that rotation begins to smear the fine details you're trying to capture. For example, Jupiter rotates quickly, so I limit my videos to between 45 seconds to a minute when the seeing conditions are excellent. Saturn is noticeably smaller, fainter, and a bit slower, so I can go about 90 seconds or so before its rotation begins to affect image quality. With Mars, the limit is closer to 3 minutes. Neither Venus nor Mercury rotates fast, so you can record longer videos of each.

Video Sorting and Stacking

Once you've recorded your videos, there are several programs that make quick work of sorting and stacking them. Current PC options include *AutoStakkert! 4* (autostakkert.com), *AstroSurface* (astrosurface.com), and *RegiStax 6* (astronomie.be/registax). Each one will distill your video or image files into an image suitable for sharpening. Mac users also have several options, including *Lynkeos* (lynkeos.sourceforge.io) and *Planetary System Stacker* (tinyurl.com/psstacker), and *Planet Stacker X* (tinyurl.com/planetstackerx).

All stacking programs function similarly: They first evaluate and order the images or video frames, then you choose how many to include in the resulting stack. Generally, the more frames you stack, the better the signal-to-noise ratio is in the resulting image, allowing you to aggressively sharpen it, though it's not quite that simple. How many frames you



can stack will vary depending on the seeing conditions. On a good night, you might be able to use half, or more, of the frames you've acquired, but when conditions are poor, perhaps only 20% of your frames will make the cut. Adding more frames to a stack taken under poor seeing produces a smoother but blurrier result. If you're unsure of how many to stack, some programs like *AutoStak-ker!* 4 permit you to create several custom stacks at a time so you don't have to go back and redo the often-lengthy process.

With your data all stacked, it's time to sharpen the results using the tools in most of the programs listed above. (I prefer using wavelets and deconvolution tools in *Wave-Sharp*.) An additional way to get even more detail out of your planetary images recorded on a single evening is by using the technique of *derotation*, in which many stacked images taken over a long period of time are aligned on a specified longitude. This is a feature found in the freeware *WinJUPOS* (jupos.org/gh/download). You can find a tutorial on the technique in the May 2013 issue, page 70. There's also a new program that performs derotation on multiple images that's even easier to use than *WinJUPOS* called *LuckyStackWorker* (www.wilcokas.com/luckystackworker). This program automates all the manual work needed in *WinJUPOS* and also includes its own sharpening routines, though it still has some bugs to fix.

Contribute to Science

After you're done with your images, you can share them online or with any publications (we'd love to receive yours for our Gallery department). But these pictures are more than

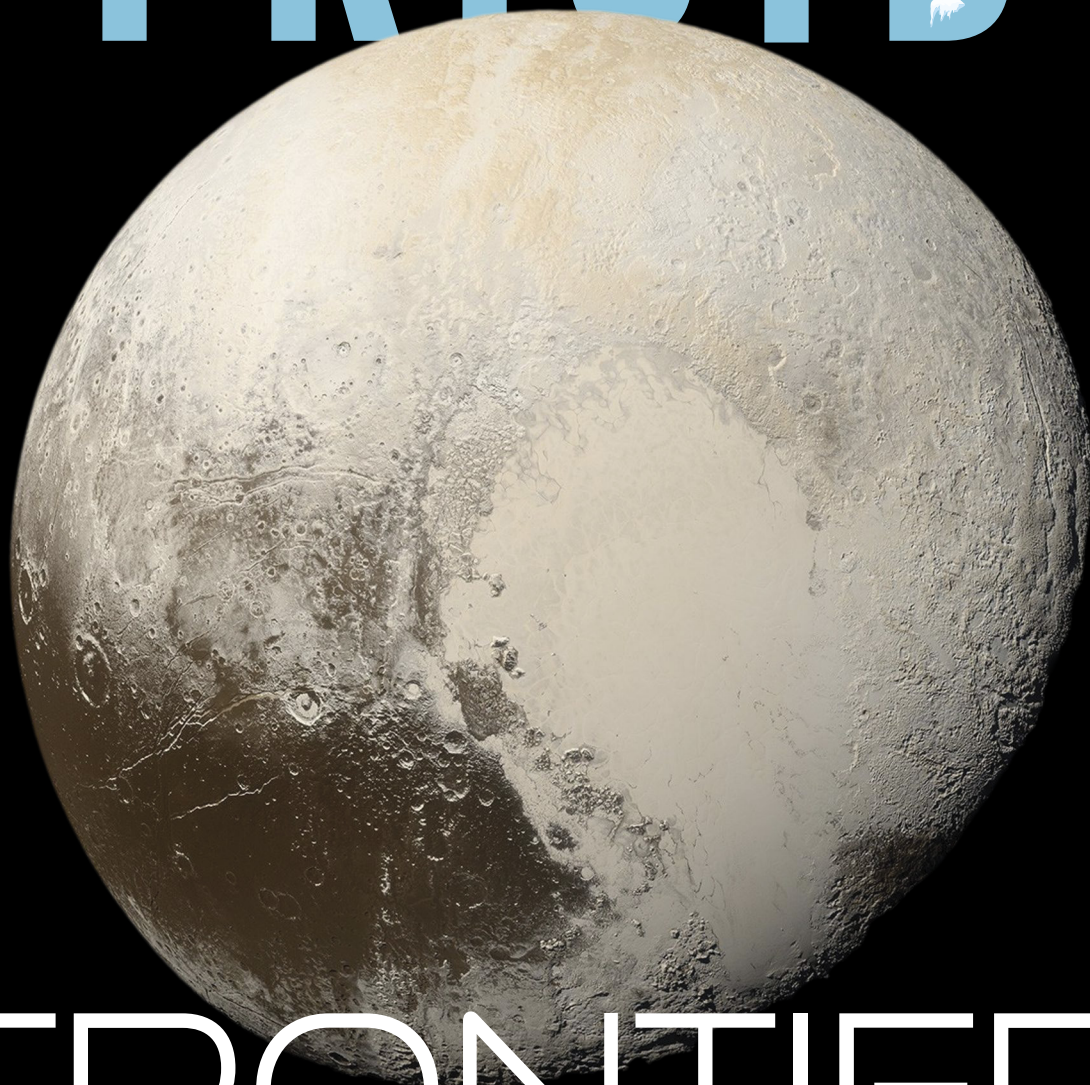
▲ **EASY DEROTATION** The new image-processing software *LuckyStackWorker* (www.wilcokas.com/luckystackworker) contains powerful deconvolution and other sharpening tools. It also includes an easy-to-use derotation feature that takes the work out of the process.

simply nice photos — they're an accurate record of a planet's appearance at a specific time and can contribute to historical records. The images you produce are of interest to professional astronomers, who cannot monitor the planets on a full-time basis. Instead, they rely on networks of dedicated amateurs in organizations such as the British Astronomical Association (britastro.org), the Association of Lunar and Planetary Observers (alpo-astronomy.org), and ALPO Japan (alpo-j.sakura.ne.jp/indexE.htm). These groups welcome new members and together provide almost continuous monitoring of the major planets throughout each apparition. Additionally, they provide good forums where you can discuss unusual observations with fellow imagers such as an asteroid impacting Jupiter or other transient events that you might serendipitously record.

It's a great time to start imaging the planets. While other types of astrophotography have to contend with problems like light pollution and the growing population of orbiting satellites, neither of these issues affect your pictures at all. Additionally, the major planets are just as visible from the city as they are under a dark sky. And with Saturn just past opposition, it's a great target to start honing your technique on in the early evening.

■ Senior Editor SEAN WALKER has observed the planets for a full Saturnian year and hopes to keep doing so for another.

THE FRIGID



FRONTIER

New observations are revealing the nature of the solar system's six largest trans-Neptunian objects in intriguing detail.

Venus, Mars, Saturn. Mere points of light a millennium ago, but telescopic views and spacecraft visits have transformed each of these names into an actual world we can vividly visualize: Venus, our torrid, cloud-enshrouded neighbor; Mars, a ruddy planet with polar ice caps and dried-up riverbeds; and Saturn, glorious Saturn, an amber globe with spectacular rings.

But Makemake, Gonggong, Quaoar? They too revolve around our Sun, but how many of us know anything about these worlds that reside beyond the orbit of Neptune?

New observations are changing that, converting these *trans-Neptunian objects* from nondescript entities lurking in the void into real places.

"None of them are really like each other," says William McKinnon (Washington University in St. Louis). "They all have their own individual characteristics and quirks, each with its own story to tell."

Recent observations have unveiled these quirky characters via three different approaches. First, every now and then, a distant world passes in front of an even more distant star. This *occultation* reveals the object's diameter and thus its volume — and sometimes even an atmosphere or ring (*S&T*: Sept. 2023, p. 34).

Second, the largest trans-Neptunian objects all have at least one satellite, whose orbital motion depends on the mass of the world it circles. Dividing mass by volume gives the world's mean density. Density in turn can indicate what each world is made of — in this case, how much rock and how much water ice, the two chief ingredients in the outermost solar system.

Third, in 2022, the James Webb Space Telescope (JWST) began peering into the trans-Neptunian realm. "It's blown the doors off the outer solar system in terms of figuring out what's on the surfaces of all these mysterious worlds," McKinnon says. The telescope's large mirror glimpses faint and faraway objects, and its near-infrared spectrometer detects wavelengths as long as 5.3 microns, reaching a range where key molecules such as methane and molecular nitrogen readily betray their existence.

Using the latest observations, we can now explore each of the six largest trans-Neptunian worlds in detail, proceeding from largest to smallest.

Pluto

Despite the plethora of other trans-Neptunian worlds (*S&T*: June 2025, p. 22), Pluto remains superlative in four ways. First, with a diameter of 2,377 kilometers (1,477 miles) —

◀ **BEHOLD, PLUTO** The New Horizons spacecraft snapped this natural-color image of Pluto during its 2015 flyby. The nitrogen-ice-filled basin Sputnik Planitia forms the left lobe of the world's iconic heart.

49% that of Mercury — Pluto is the largest known member of the solar system beyond Neptune's orbit. Pluto is so large and its early interior so hot that it underwent a process called *differentiation*: Its rock sank, leaving Pluto with a rocky core beneath a water-ice mantle.

Second, Pluto boasts five moons, one of which — Charon — is half its diameter. The moons likely arose after a giant object hit Pluto's icy mantle and kicked up debris. In order of distance from Pluto, the moons are Charon, Styx, Nix, Kerberos, and Hydra. (Here's a handy mnemonic: Crosby, Stills & Nash Keep Harmony.)

Third, Pluto is the only trans-Neptunian world in the solar system that definitely possesses an atmosphere. Though tenuous, with a surface pressure only $1/100,000$ that of our planet, this distant atmosphere's composition is strangely earthly. The nearest planets to us, Venus and Mars, have carbon dioxide (CO₂) atmospheres, but the air on both Earth and Pluto consists mostly of the same gas: molecular nitrogen (N₂).

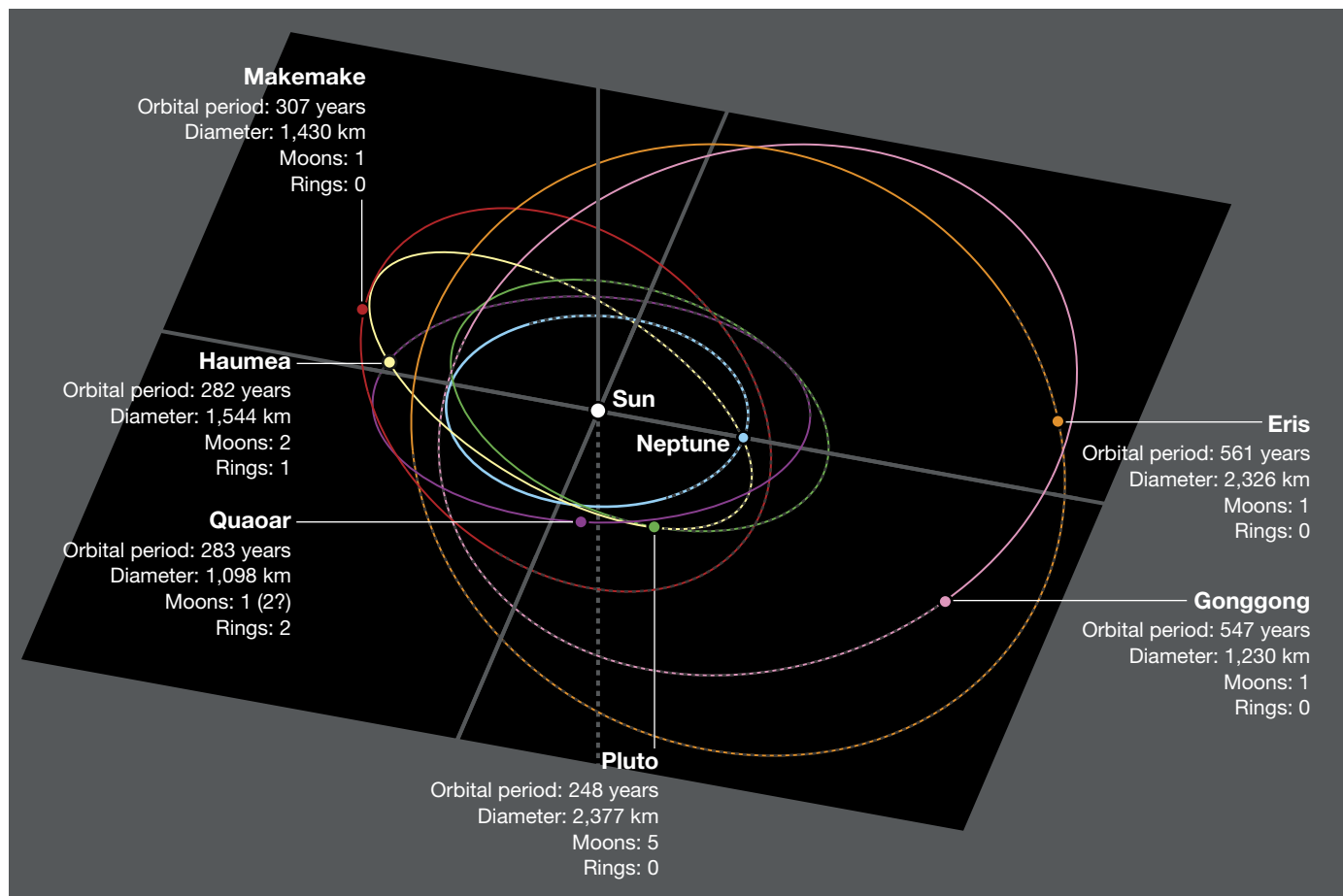
Fourth, Pluto is the only big world beyond Neptune's orbit that we've seen close-up. In 2015, the New Horizons spacecraft sped past it and spied tall mountains of water ice, rock-hard at Pluto's frigid surface temperature; signs of an ocean beneath that surface; and a bright white heart.

In initial images, Pluto's iconic heart looked like a fuzzy trapezoid. But the images grew sharper as the spacecraft neared its target. "One day I walked into our science room, and somebody says, 'You're never going to believe this: It's not a trapezoid; it's a heart,'" recalls Alan Stern (Southwest

VAPOR-PRESSURE EQUILIBRIUM

Mars and Pluto both have atmospheres in *vapor-pressure equilibrium*, which means that molecules travel back and forth between air and ground, changing phase as they do so, as the seasons shift and surface temperatures rise and fall. On Mars, when winter comes to one of the poles, the air there becomes so cold that some of the atmosphere's carbon dioxide gas freezes out, reducing the atmospheric pressure. On farther and far more frigid Pluto, similar seasonal effects occur, intensified by its greatly varying distance, but they involve molecular nitrogen rather than carbon dioxide.

Earth is different. Although our planet's water can be gas, liquid, or solid, water vapor makes up no more than a few percent of the air. Earth's dominant gases — molecular nitrogen, which constitutes 78% of the dry atmosphere, and molecular oxygen, which constitutes 21% — never freeze, because Earth is thankfully much too warm.



▲ **WORLD JUMBLE** The six TNOs described in the text follow orbits of various sizes, shapes, and inclinations. For nonspherical worlds, the diameter given corresponds to the width that a sphere of the same volume would have. The largest world, Pluto, is two-thirds as wide as Earth's Moon, the diameter of which is just shy of 3,500 km. Dotted lines indicate where an orbit dips below the ecliptic plane.

Research Institute, Boulder), the mission's principal investigator. "They showed me this picture and my jaw hit the ground. You couldn't draw a better heart if you tried."

Full of frozen nitrogen, the region actually constitutes the heart of Pluto's atmosphere, too. "In many ways, Pluto behaves like Mars," McKinnon says. "It has a thin atmosphere, and that atmosphere is in vapor-pressure equilibrium with the ices on its surface — carbon dioxide ice in the case of Mars, nitrogen ice in the case of Pluto." During a Martian year, up to 25% of the Red Planet's atmosphere temporarily disappears as carbon dioxide freezes onto one polar cap or the other. Because of Pluto's elliptical orbit, its atmosphere may vanish altogether when it is farthest and coldest, covering the ground with fresh ice.

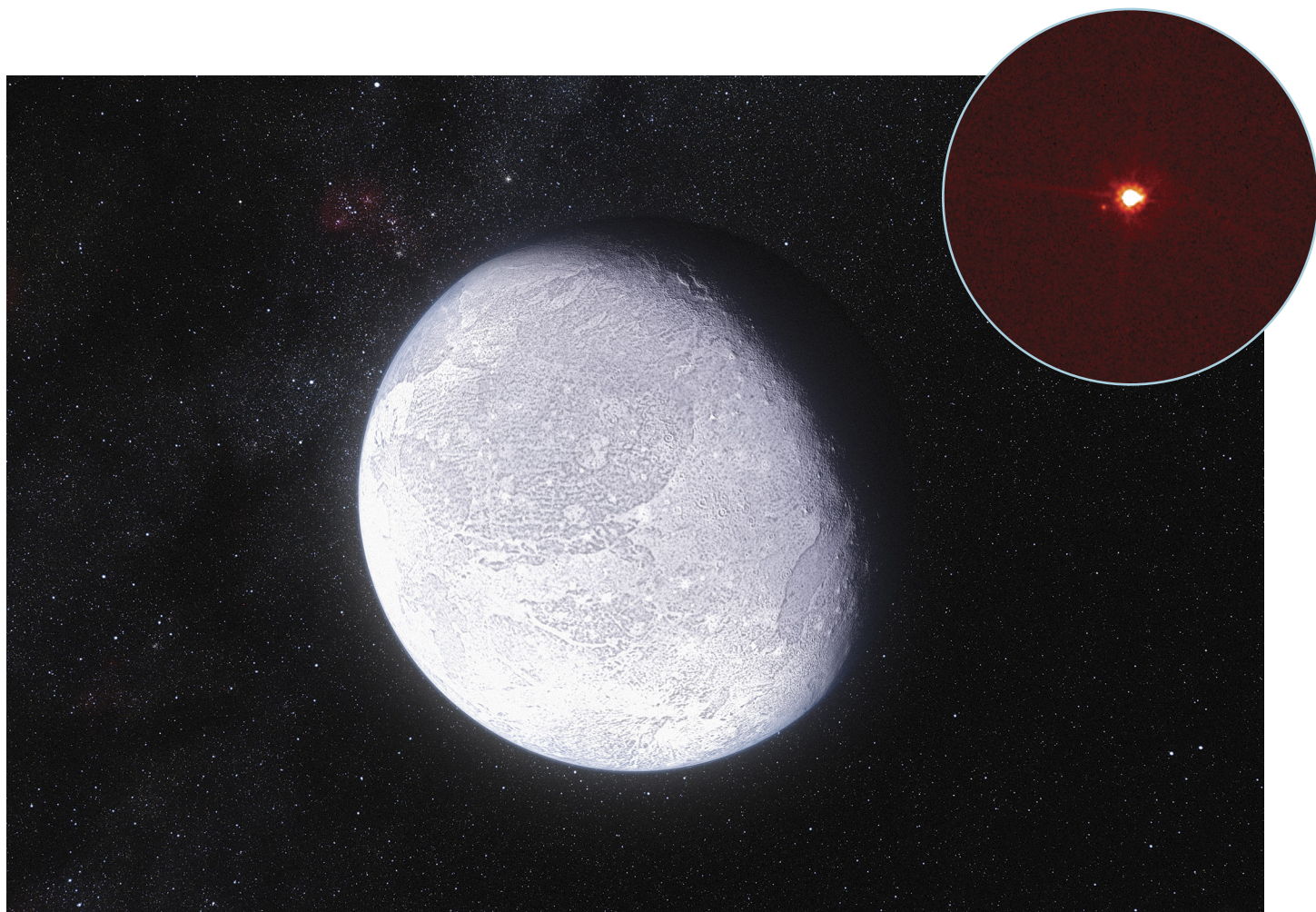
Unlike Mars, whose ice caps occupy the poles, Pluto wears its icy heart on its equator. That's because of its odd axial tilt. Like Uranus, Pluto lies on its side as it spins. Uranus's axial tilt is 98°; Pluto's, 122°. Both therefore have literally unearthly climates. Earth's equator is warmer than its poles because the equator receives more sunlight, but Pluto is the opposite: Its equator receives less sunlight than the poles and is therefore on average colder.

The heart's western half is likely an impact basin, causing nitrogen to collect there. If not for that long-ago impact, McKinnon suspects, a white band of nitrogen ice would gird Pluto at its equator rather than accumulating in that one spot.

Like Mars, Pluto is orange. But the Martian color arises from iron oxide, whereas Pluto's hue starts with methane (CH_4) ice. Unlike its moons, Pluto has enough gravity to retain lots of methane and nitrogen ices, which are what planetary scientists call *volatiles*: substances prone to vaporizing. Methane is colorless, but radiation strips off its hydrogen atoms, typically creating first ethane (C_2H_6), then ethylene (C_2H_4), then acetylene (C_2H_2), and finally more complex organic molecules that can be yellow, orange, and even black.

In contrast, Pluto's largest moon, Charon, is pale gray. Its surface is mostly water ice, which stays solid in the deep freeze. Carbon dioxide ice is there, too, though New Horizons didn't see it because its spectrometer cut off at 2.5 microns.

"Thanks to the extended wavelength coverage, Webb provided a far more complete view of the moon's surface chemistry," says Silvia Protopapa (Southwest Research Institute, Boulder). "In particular, it revealed a thin veneer of carbon



▲ **ERIS** This artist's impression shows Pluto's airless cousin with its highly reflective icy surface. *Inset:* Eris (large dot) appears with its moon, Dysnomia (small dot), in this Hubble Space Telescope image.

dioxide, likely excavated from Charon's interior by impacts." Carbon-dioxide ice makes up about 2% of the satellite's surface. (Although Webb has also observed Pluto, scientists are still analyzing its complex spectrum.)

Webb discovered another substance previously unseen on Charon: hydrogen peroxide, whose chemical formula — H_2O_2 — resembles water's, H_2O . On Earth, we use hydrogen peroxide for disinfection and as a bleaching agent. Hydrogen peroxide also exists on Jupiter's icy moon Europa, where charged particles from the Jovian magnetosphere create the compound by bombarding water molecules.

But Pluto is no Jupiter. "We didn't think, honestly, that we would find evidence of hydrogen peroxide," Protopapa says. "We just didn't think about it." The compound arises on Charon when ultraviolet photons from the Sun, as well as charged particles in the solar wind and from the galaxy, strike the moon's water-ice surface.

Eris

Eris is a world of extremes. It's extremely remote, 95 times farther from the Sun than we are, or more than twice Pluto's mean distance. It takes 561 years to orbit the Sun once.

A 2010 passage in front of a star revealed that Eris is slightly smaller than Pluto (*S&T*: Sept. 2024, p. 23). The occultation began and ended abruptly; therefore, unlike Pluto, Eris lacks an atmosphere.

Incredibly, Eris reflects 96% of the sunlight striking it. "Absurdly high," says Will Grundy (Northern Arizona University). It's not as absurdly high as Saturn's hyperactive moon Enceladus, where water-spewing geysers coat the surface with glittering ice. But like Enceladus, Eris owes its shine to ice.

Eris has both methane and nitrogen ice, as Pluto does. "It doesn't take long for methane to darken if just exposed to space radiation, so Eris is refreshing itself somehow or other," Grundy says.

That refreshed surface is not only bright but also nearly uniform. Pluto's terrain is varied; its brightness waxes and wanes as light and dark regions rotate into and out of view. In fact, astronomers used these variations to measure Pluto's rotation period back in 1955, before those of Mercury, Venus, Uranus, or Neptune. In contrast, Eris's uniformly white surface made pinning down this key parameter a struggle, until astronomers were able to do so in 2023. They reported that Eris spins every

15.8 days — the same period its one known moon, Dysnomia, takes to revolve. In like fashion, Pluto rotates in the same time that Charon takes to revolve, 6.4 days.

Eris's orbit around the Sun is even more elliptical than Pluto's. When at its closest, Eris is just 38 times farther from the Sun than Earth is, closer than Pluto's average distance. Eris reaches perihelion in 2257. Around that time, sunlight may vaporize some of the methane and nitrogen ice, giving Eris an atmosphere. Such cycles might explain Eris's high reflectivity: Every time Eris recedes from the Sun, its air freezes and blankets the surface with fresh ice.

But JWST has uncovered a telltale piece of evidence that Eris is like Enceladus in more ways than one. The telescope measured how much of the heavy hydrogen isotope deuterium exists in Eris's methane ice. The answer: not much.

"That result was shocking, actually," says Christopher Glein (Southwest Research Institute, San Antonio). He had expected a higher level of deuterium, because the frigid temperatures inside interstellar clouds, which forge primordial ice, favor chemical reactions that put deuterium into methane. Moreover, a decade ago, the Rosetta spacecraft measured a much higher deuterium level in the methane of Comet 67P/Churyumov-Gerasimenko, a primitive object that presumably resembles the building blocks of Pluto and Eris.

The low deuterium level in Eris's methane suggests that the molecules were heated above the boiling point of water, perhaps within geysers, cryovolcanoes (S&T: Aug. 2020, p. 32), or anywhere that hot water touched deeply buried rock.

And Eris abounds with rock. "It has a higher density than Pluto, so we know it has more rock," Stern says. Although it's smaller than Pluto, Eris is more massive, with a density 2.4 times that of water, versus 1.85 for Pluto. These numbers suggest that Pluto's interior is 66% rock and 34% water ice; Eris is 85% rock and 15% water ice.

Rock bears radioactive uranium, thorium, and potassium-40, which generate heat. Since Eris has more rock, it would have generated more radioactive heat in the early days, Stern says. "So it might have had a more active geology early on, driven by that heat from the rock," Stern says.

A MNEMONIC FOR PLUTO AND ITS MATES

You can memorize the solar system's six largest trans-Neptunian worlds — Pluto, Eris, Haumea, Makemake, Gonggong, and Quaoar — by using the phrase "Please Excuse How My Goose Quacks."

What's that? Think you can do better? Tell us! Send your suggestion to letters@skyandtelescope.org.

And while you're at it, let us know: Given the five choices of Eris, Haumea, Makemake, Gonggong, and Quaoar, where would *you* send a spacecraft?

On Pluto, New Horizons discerned cracks in the crust, as though an ocean of water was freezing and expanding beneath the surface. "If Pluto has an ocean," McKinnon says, "Eris almost certainly does." Thus, in the depths of space far beyond Earth, Europa, and Enceladus, Eris might even harbor our solar system's most remote abode of life.

Haumea

What would Pluto and Eris, the solar system's two largest trans-Neptunian worlds, be like if something smacked into them and obliterated their volatile-rich crusts? Meet the *third* largest trans-Neptunian world, Haumea: a roughly egg-shaped oddity.

Observations have revealed at least two small moons and a narrow ring around this world. Shepherd moons, not yet seen, may keep the ring thin.

Haumea spins fast, every 3 hours and 55 minutes. It probably owes its spin, shape, moons, and ring to a giant impact. "It blew off whatever crust of volatile ices or dark material that might have been there and exposed what we presume to be a deeper water-ice mantle," McKinnon says. Indeed, Haumea's surface consists mostly of water ice, like Pluto's mantle. Thus, Haumea could be a naked Pluto.

Variations in brightness as the world spins reveal that Haumea sports a dark spot, the composition of which is currently unknown.

A family of small, water-ice-rich objects orbit the Sun on paths like Haumea's, probably all former pieces of Haumea's mantle. "It's a crime scene kind of thing," Grundy says. "A lot of violence must have been here once upon a time."

Makemake

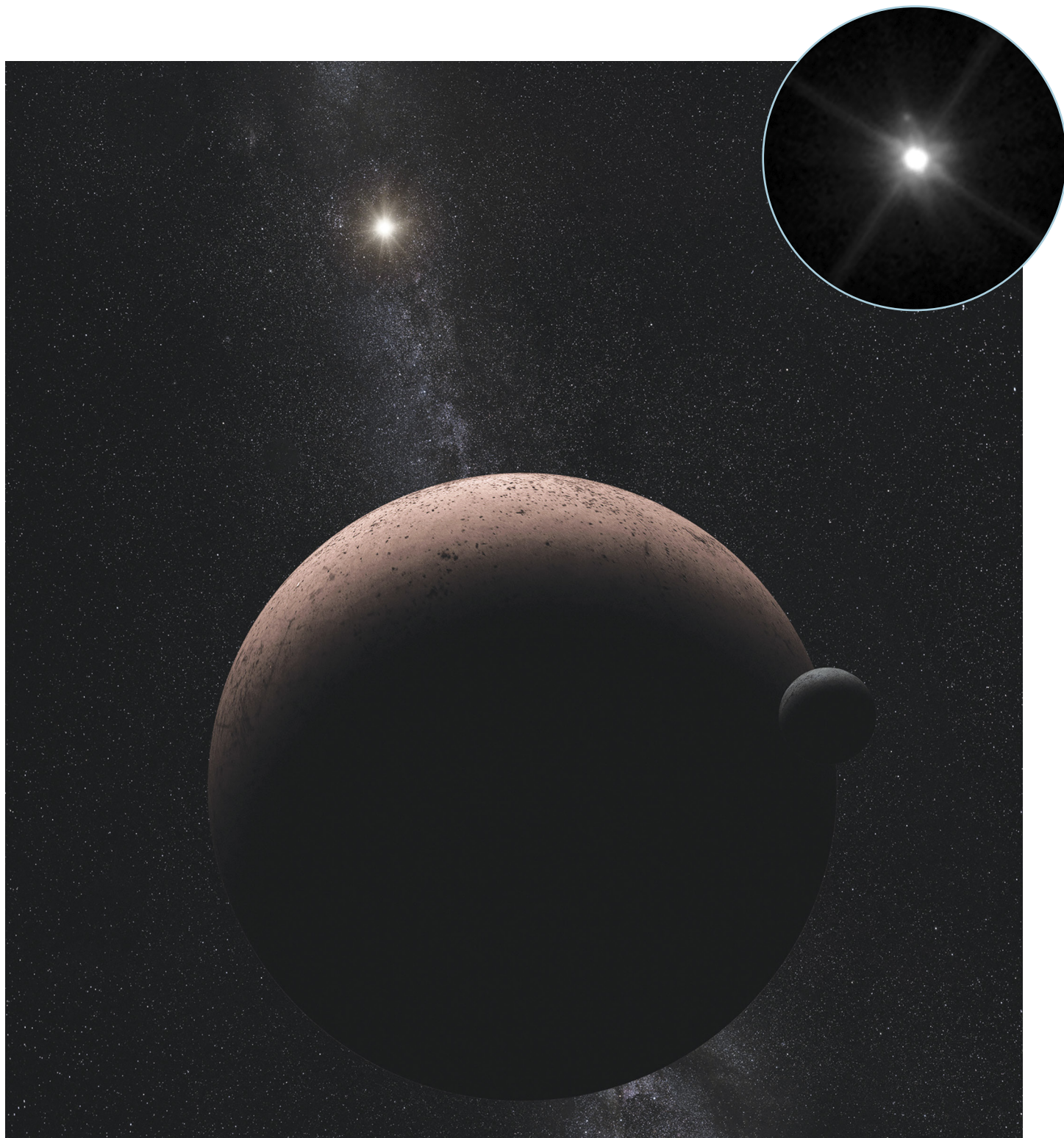
Unlike Haumea, the surfaces of Pluto, Eris, and Neptune's big moon Triton all have lots of methane ice. But "Makemake is *the* most methane-rich of the bunch," Grundy says. "When you look at Makemake's spectrum, you're like, 'Oh my goodness, that thing is methane everywhere.'"

All that methane ice is shiny, making Makemake reflect 80% of the sunlight hitting it. Like Pluto, Makemake is orange, because radiation has converted some of the methane into complex organic molecules. "The methane is probably a little older and a little less mobile" than the ice on Pluto and Eris, Grundy says, so the methane hasn't buried the colorful material.

Yet JWST has uncovered tantalizing signs of activity. First, Makemake's methane ice has the same deuterium-to-hydrogen ratio as Eris, suggesting that heat has altered Makemake's methane, too. Second, JWST discovered a warm spot. What it is, no one knows, but it could be a cryovolcano, gushing liquid water and methane gas.

Third, in 2025, Protopapa and her colleagues reported that JWST spectra had revealed methane *gas* — the farthest gas ever seen in our solar system. This far from the Sun, methane should be so cold it's frozen solid.

"It was a beautiful surprise," she says, because Makemake



▲ **TANNED TRANS-NEPTUNIAN** This artist's impression shows Makemake, where radiation has converted some of the surface methane into orange-ish complex organic molecules. *Inset:* Distant Makemake and its moon, currently nameless, appear in this composite Hubble image.

had earlier occulted a star and shown no sign of an atmosphere. The gas may constitute an extremely tenuous global atmosphere, its surface pressure only a millionth of Pluto's and 100 billionth of Earth's. The gradual vaporization of methane ice could create such an atmosphere, or the gas may arise more dramatically, from geysers and cryovolcanoes. The

latter possibility dovetails with both the deuterium level and the warm spot.

"We don't really know what, but clearly there's something going on on Makemake," Grundy says.

JWST found no nitrogen ice, which is more volatile than methane at Makemake's surface temperature. Over time, the

nitrogen ice may have turned to gas and fled to space, barely hindered by Makemake's weak gravitational pull.

The world has one small moon. "It is pretty darned faint compared to Makemake," Grundy says. Ongoing observations with the Hubble Space Telescope should refine the moon's orbit; until then we don't have a firm mass or density for Makemake itself.

Gonggong

Of the six worlds on our tour, Gonggong remains the most obscure. It is small, dim, and distant, making it difficult to observe. Still, we know Gonggong is dark orange and differs from its four larger brethren. Whereas Pluto, Eris, Haumea, and Makemake reflect most of the sunlight striking them, Gonggong reflects just 14%, because radiation has converted so many of its simple hydrocarbons into dark compounds.

Observers had earlier found signs of water ice on this world. JWST added to our knowledge, spotting ethane but little to no methane. "The methane's been processed into the next step of chemistry, into ethane," says Joshua Emery (Northern Arizona University). "The fact that we still see ethane suggests that it's relatively recent." If the ethane had all formed long ago, radiation would already have turned it into complex organic molecules. Ongoing internal activity may be producing the methane that leads to ethane.

"Methane is more volatile than ethane, and so there's a possibility that some of the methane is also sublimating away" and escaping into space, he says, because Gonggong is as small as Charon and thus has a weak gravitational grip.

Gonggong's orbit is even more elliptical than Eris's. When farthest from the Sun, at 101 astronomical units, Gonggong is three times more remote than when at its closest. At times Gonggong probably ventures beyond the protection of the *heliosphere*, the Sun's magnetic bubble, exposing itself to the full brunt of cosmic rays streaming through our galaxy.

DIFFERENTIATION

The largest rocky objects orbiting the Sun are *differentiated*, which means that their crusts and mantles differ in composition from their cores. Once warm mixtures of metal, rock, and/or ice, these worlds subsequently sorted their molten interiors thanks to gravity: The heavier materials sank to the center, leaving the lighter materials in the upper layers.

Differentiation might have occurred only partially or not at all on objects as small as Gonggong and Quaoar. If the differentiation process was partial, rock still sank, but its infall may not have generated enough heat to fully erase the primitive surface. And if differentiation didn't happen at all, the surface could preserve primordial materials, letting us observe them directly.

Quaoar

Unlike Gonggong, our final world, Quaoar, follows a remarkably circular orbit around the Sun. In fact, its path is more circular than those of every planet except Venus, Earth, and Neptune.

"Compositionally, Quaoar seems pretty similar to Gonggong," Emery says. Quaoar is closer to us, so ground-based observers had detected its water ice, ethane, and methane long before JWST. Relative to Gonggong, Quaoar has less ethane — probably because it's closer and warmer, so methane vaporizes faster and escapes before it can create ethane.

"Quaoar keeps springing surprises on us as we keep looking at it," Grundy says. By good luck, it's coursing through Scutum, the Shield, which provides a rich backdrop of stars for the world to occult. Recent occultations revealed two unusual rings around Quaoar (*S&T*: Mar. 2026, p. 14).

Hubble has spotted one moon, Weywot, and a 2025 occultation showed a dropout in light that may signal a second. But "you could always have a bird fly in front of your telescope," Grundy says. "We certainly looked for the moon in all of the Hubble data that we've got, and we couldn't see it." Since the putative moon is small and on a tight orbit, Quaoar's glare may have swamped it.

Future Voyages

The New Horizons spacecraft gave us our first close-up view of Pluto. Which of its five near-peers should receive the next such mission? Scientists each have their favorite.

"I would go to Eris," Stern says. "I think it's the better comparator to Pluto in terms of the volatiles. But it's different: It's obviously rockier; it didn't have the giant impact." What would we discover? "I'm only going to predict something I'm certain is true: We will find something wonderful."

McKinnon says, "I would go to Haumea, because it's obviously the most different and the most unique amongst all these bodies. Eris is a good one, but I like Haumea better. And it has a ring. It's got lots of goodies."

"Makemake," Protopapa says. "Definitely Makemake. It's a fascinating world that could tell us a lot about the physics that is occurring on these large bodies in the outer solar system."

Says Grundy, "I might actually choose one of the smaller ones," such as Gonggong or Quaoar. "Pluto is probably fully differentiated, and I would be surprised if Eris wasn't. But if you pick something that's only partially differentiated, that might offer some clues about the differentiation process."

Meanwhile, from afar, we glean what we can about these worlds, distant dots that exhibit tremendous variety. "Each and every one of them is different," Stern says. "We would learn a lot more by going to all of them."

■ Contributing Editor KEN CROSWELL's life was transformed the morning his first-grade teacher told his class about the planets and had each student make a color map of the solar system from Mercury to Pluto. Since then, he's been especially intrigued by the Sun's farthest and most mysterious worlds.



3–4 ALL NIGHT: Saturn arrives at opposition, where it gleams in western Cetus.

4 DAWN: High in the east-southeast, the waning crescent Moon is in Gemini with Pollux about $3\frac{1}{2}^\circ$ upper left. Mars and Jupiter, arranged in a line extending toward the eastern horizon, complete the scene.

5 DAWN: Face east-southeast to see the crescent Moon visiting the Beehive Cluster (M44) in Cancer, bracketed by Mars above and Jupiter below. You'll need binoculars to tease out the cluster stars. Turn to page 46 for more on this and other events listed here.

6 MORNING: The lunar crescent and Jupiter rise above the east-northeastern horizon in tandem. Viewers in the eastern half of the U.S. and Canada will see the Moon occult the planet. See page 48 for details.

14 DUSK: Low in the southwest, the waxing crescent Moon hangs around $1\frac{1}{2}^\circ$ lower left of Antares, the smoldering heart of the Scorpion.

14 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:03 p.m. PDT (see page 49).

17 EVENING: Algol shines at minimum brightness for roughly two hours centered at 9:52 p.m. EDT.

19 EVENING: Algol shines at minimum brightness for roughly two hours centered at 6:41 p.m. EDT.

21–22 ALL NIGHT: The Orionid meteor shower is expected to peak. The waxing gibbous Moon shouldn't interfere with viewing. Go to page 50 for details.

27 EVENING: The Moon, two days past full, is in the Pleiades as they rise above the east-northeastern horizon. As they climb higher, the Moon pulls away from the star cluster, heading lower left.

31 DAWN: Face southeast before sunrise to spot the waning gibbous Moon with Pollux about 5° to its right. Jupiter and Mars shine farther to the lower left.

—DIANA HANNIKAINEN

▲ An Orionid streaks across the sky above Arches National Park in Utah. BABAK TAFRESHI

OCTOBER 2026 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

- Galaxy
- Double star
- Variable star
- Open cluster
- Diffuse nebula
- Globular cluster
- Planetary nebula

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

LAST QUARTER
October 3
13:25 UT

NEW MOON
October 10
15:50 UT

FIRST QUARTER
October 18
16:13 UT

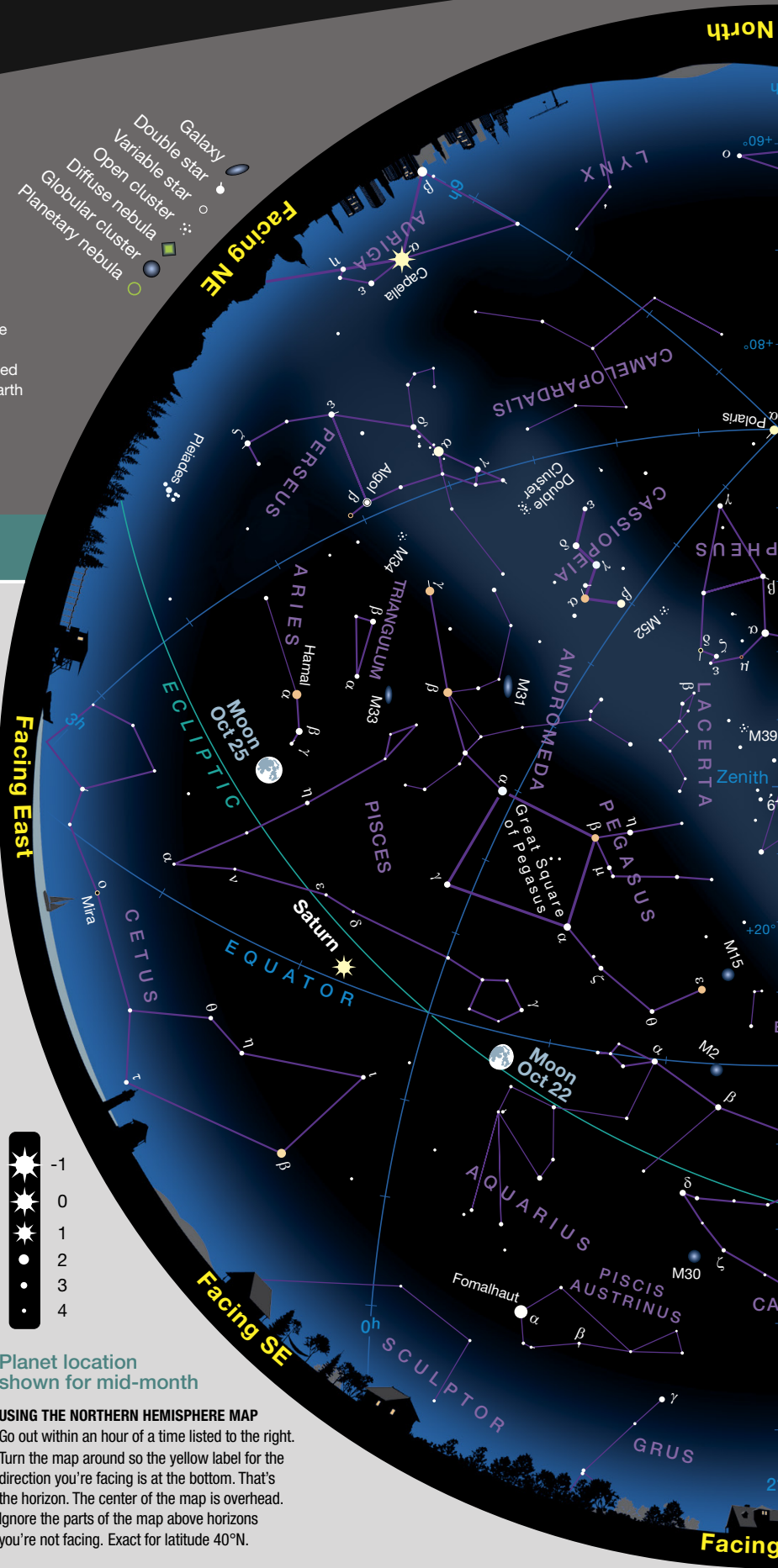
FULL MOON
October 26
04:12 UT

DISTANCES

Perigee	October 1, 21 ^h UT
369,335 km	Diameter 32' 21"
Apogee	October 16, 23 ^h UT
404,642 km	Diameter 29' 32"
Perigee	October 28, 18 ^h UT
364,407 km	Diameter 32' 47"

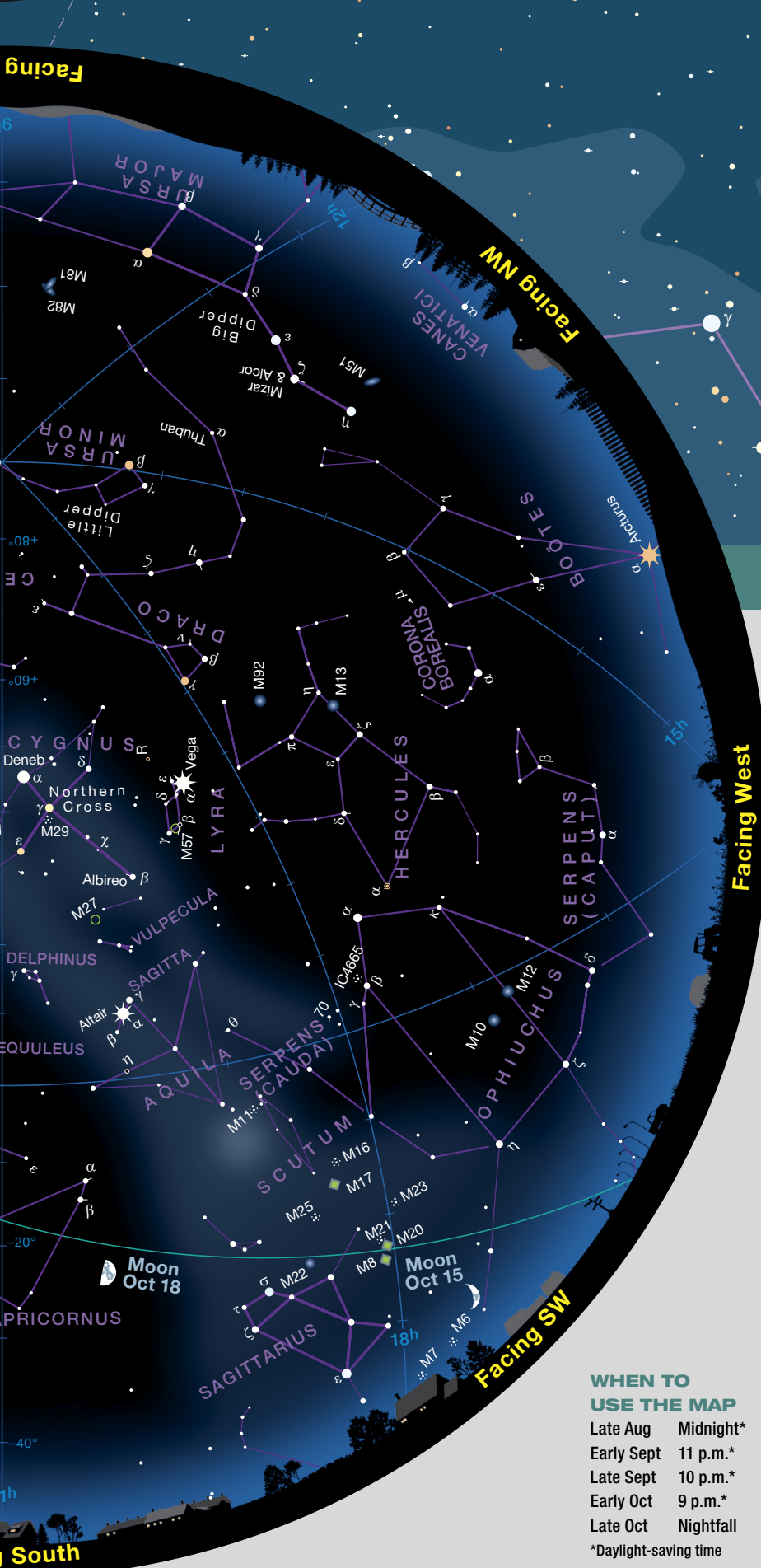
FAVORABLE LIBRATIONS

• Drygalski Crater	October 1
• Hayn Crater	October 14
• Yakovkin Crater	October 26
• Hausen Crater	October 27



Planet location shown for mid-month

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



Binocular Highlight by Mathew Wedel

A Very Old Favorite

Cassiopeia, named for the mythological queen and mother of Andromeda, has long been my favorite constellation. When I started stargazing, Cassiopeia was the first constellation I explored, and my launching point to all the others. This month I'm going back there to check in on an old friend, the open cluster **M52**.

Cassiopeia is stacked with open clusters that, it seems, could easily have been Messier objects. That crowd of could-have-beens shouldn't overshadow what a fine object M52 is — big, bright, and easy to find. From Alpha (α) Cassiopeiae, or Schedar, scan 5° northwest to Beta (β) Cassiopeiae, or Caph, and then another 6° along the same line. M52 will be the 7th-magnitude knot of brighter stars in an already rich section of the Milky Way. The cluster is roughly $\frac{1}{4}^\circ$ across and vaguely bean-shaped. Like many Messier open clusters, I see it as an unresolved glow in my 7×50 binos, showing hints of resolution in 10×50 s, and as a dense field of stars like sand grains in 15×70 s. Of course, big binos resolve more, but don't miss the wide, low-power view, which puts M52 into context among the neighboring clusters and star fields.

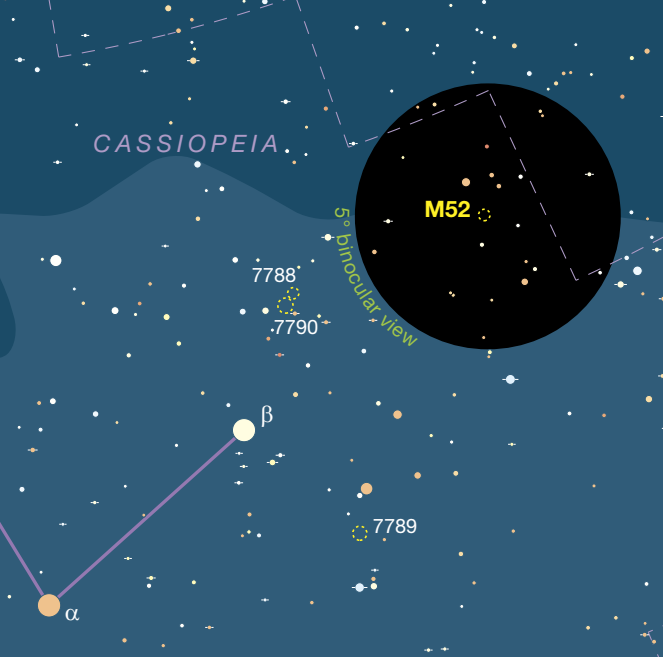
Recent studies put the age of M52 at about 150 million years old. That's a resonant number for me, just barely older than the Late Jurassic dinosaurs I study in Oklahoma, Colorado, and Utah. Dinosaur country tends to have dark skies, and I've had many memorable views of the cosmos out in the boonies. Cassiopeia and its neighbors are similarly rich hunting grounds, where even modest binoculars reveal the structure of the nearby galactic arms. Go ramble through this cosmic wilderness and I'm certain you'll discover favorites of your own.

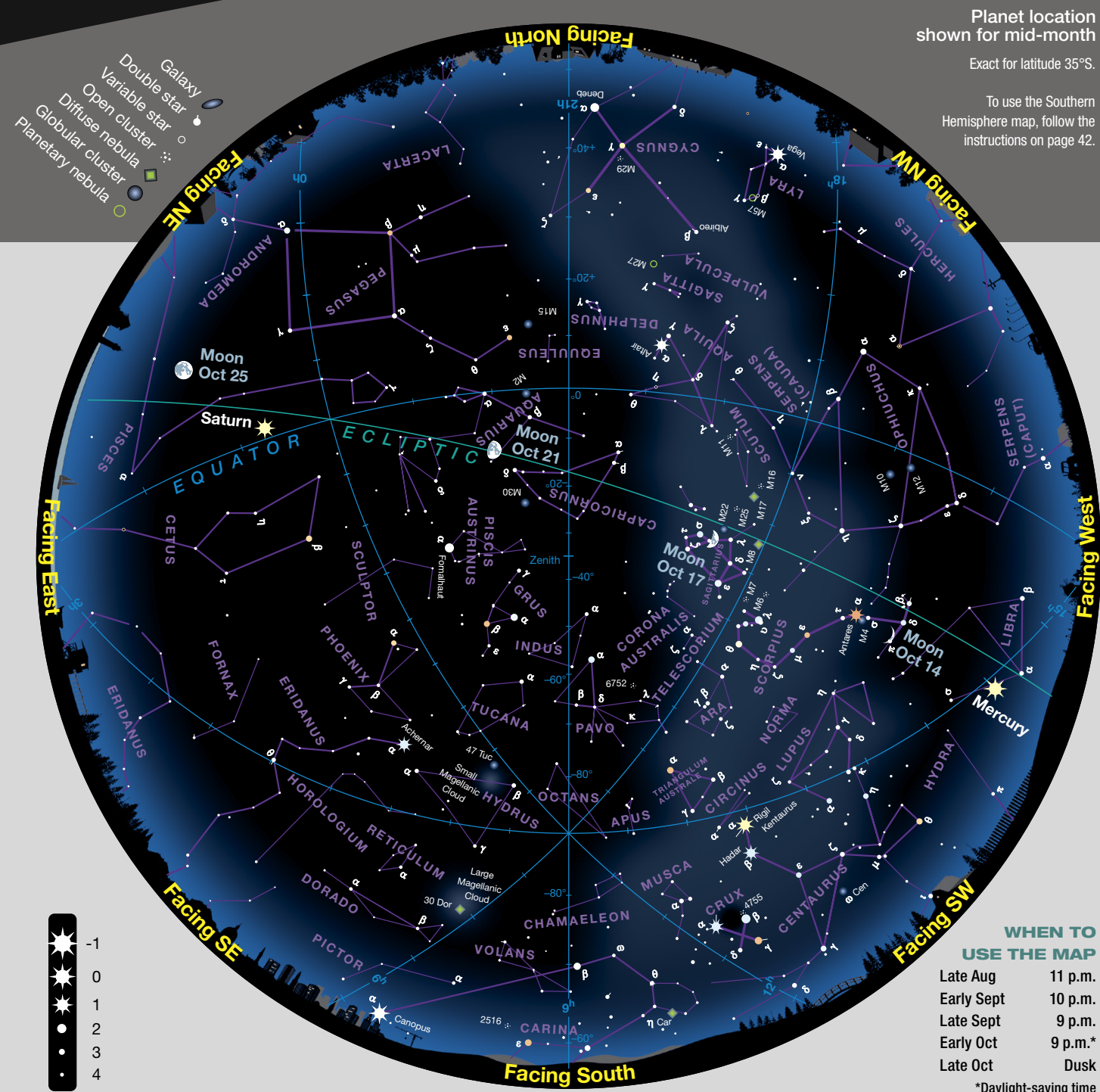
■ So, is **MATT WEDEL** a paleontologist, an astronomer, or what? That depends — is it dark out?

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	Nightfall

*Daylight-saving time





YOU'RE PROBABLY FAMILIAR with the constellation Corona Borealis, the Northern Crown, but have you ever taken note of its twin in the southern sky? Corona Australis, wedged between Sagittarius and Telescopium, is one of the smallest constellations by area — 80th out of 88 — but its distinctive arc of stars makes it stand out quite prominently.

Looking at the chart above, the four stars in the arc,

from top to bottom, Gamma (γ), Alpha (α), Beta (β), and Delta (δ) Coronae Australis; their magnitudes are 4.2, 4.1, 4.1, and 4.6, respectively. Alpha is a slightly bluish A-type star like Vega, while orange Beta is a K-type giant almost 40 times the size of the Sun. Gamma is a binary system comprising almost identical white F-type main-sequence stars, and Delta is a smaller K giant just a bit more than 10 times the Sun's size. ■

Perseus and the Eternal Journey of Stingy Jack

Follow a tricky con man and his turnip lantern across the sky this Halloween.

Perseus, the Hero, plays an important role in what is arguably the most famous myth of the heavens, that of the fate of princess Andromeda, the Chained Maiden. Her father, King Cepheus, chained Andromeda to a rock as a sacrifice to Cetus, the Sea Monster, after his wife, Queen Cassiopeia, boasted that she was more beautiful than the exquisitely ravishing sea nymphs — a good way to get into trouble in Greek mythology. The Hero saves the day by flying down on his winged sandals and rescuing Andromeda, after showing Cetus the severed head of the serpent-haired Gorgon Medusa, which turns the monster into stone. But this month, we're going to look at Perseus in a different light: not as a hero, but as a piteous fictional character named Stingy Jack, whose tale traces back to Irish folklore. In time, his story was woven with that of the jack-o'-lantern, which predates Stingy Jack and likely originates with ancient Samhain celebrations. Let's look now at how we can, for fun, link Stingy Jack's tale to the constellation Perseus.

Jack was a miserly, inhospitable man who liked to imbibe and play tricks on everyone. One day, the Devil came to claim the man's soul, but Jack struck up a bargain that gained him 10 more years of life. When that time was up and the Devil returned, Jack managed to trap Satan, only to release him when he agreed never to take the drunkard's



soul. The stingy man continued in his vile ways until he died a natural death, only to find himself unfit for heaven, and barred from hell. What happens next varies among sources. But in some accounts, the Devil gave Jack a burning ember to help light his way through the eternal darkness. Jack placed the ember in a hollowed-out turnip to use as a lantern in his endless search for a final resting place. Our jack-o'-lantern means "Jack with the lantern."

Most depictions show Perseus holding the severed head of Medusa, marked principally by Algol. Also known as the Demon Star, Algol is the Gorgon's winking eye, as the star varies in brightness from magnitude 2.1 to 3.4. It doesn't take a stretch of the imagination to replace Perseus with Jack and Medusa's head with a jack-o'-lantern — Algol representing its flickering flame.

Now look at this month's Northern Hemisphere star chart on pages 42–43. Note how Perseus (now seen as Stingy Jack) lies just above the northeastern horizon. As the year progresses, our newly imagined constellation will climb ever higher toward the heavens, reaching the zenith (the point directly overhead) in January. Then, as if being turned away, it sinks ever lower until it all but dips below the northern horizon in June, where Jack is rejected from the celestial underworld, only to repeat his wanderings for all eternity.

▲ In a 1939 version of the Stingy Jack tale, "Jack" is a notorious gambler. This scene shows Death coming for the gambler.

For those interested in reading Stingy Jack's tale in more detail, multiple versions exist — some under different titles and some using different names for the main character. An early version of the tale starring "Jack" authored by an E. W. appeared in the January 16, 1836, *Dublin Penny Journal* as "Jack O' the Lantern." Another popular edition is William Carleton's article in the 1845 book *Tales and Sketches, Illustrating the Character, Usages, and Traditions, Sports and Pastimes of the Irish Peasantry*, titled "The Three Wishes; An Irish Legend" with Billy Duffy as the principal player. The same story credited to Carleton but appearing in *Fairy and Folk Tales of the Irish Peasantry* edited by W. B. Yeats has Jack as Billy Dawson. And in the 1894 *Welsh Fairy Tales and Other Stories*, editor P. H. Emerson names the story "Billy Duffy and the Devil." These tales and others like it all appear to stem from an 1812 Brothers Grimm Tale "The Blacksmith [or Smith] and the Devil," But the legend has likely been passed by word-of-mouth for centuries. Beware: Once you begin looking, the search is endless.

■ Cosmic Mythographer **STEPHEN JAMES O'MEARA** has been studying the constellations and their lore for more than 50 years.

The Moon and Mars Visit the Beehive

October skies offer a bountiful harvest of eye-catching conjunctions from dusk to dawn.

THURSDAY, OCTOBER 1

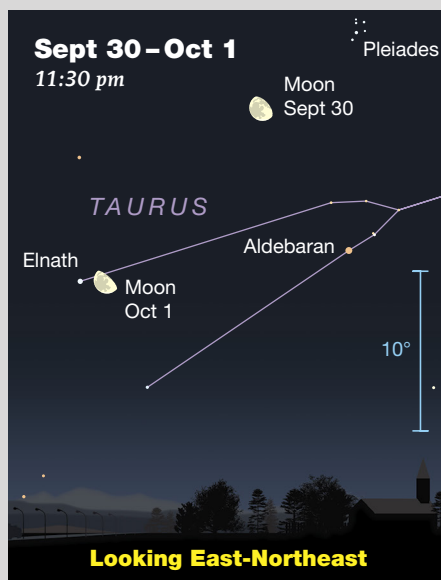
Remember the lunar standstill? We've mentioned it a couple of times in the past. It's when the **Moon** is positioned farther north or south of the *ecliptic* — the plane defined by Earth's orbit around the Sun — than usual (S&T: Apr. 2025, p. 49). Although the 18.6-year cycle reached its peak a year and a half ago, its effects are still in play, bringing the Moon close to stars it normally doesn't encounter. This evening the 66%-illuminated waning gibbous is positioned near 1.7-magnitude **Elnath**, also known as Beta (β) Tauri. As the duo rises in the east-northeast at around 10 p.m. local daylight time, the Moon is about 2° right of the star. However, the gap between them narrows as the night goes on. A little after 3 a.m. EDT (October 2nd), just $\frac{3}{4}^\circ$ separates Elnath from the northern edge of the lunar disk. At this moment, the Moon's declination is $+27.6^\circ$, which is only 1° shy of its maximum northerly position during the standstill. Although Luna will continue to visit Beta Tauri on a monthly basis, it won't get this close again until January 2043. That's a bit of a wait!

MONDAY, OCTOBER 5

Early this morning, the **Moon** and **Mars** rise in tandem in the east-northeast. The Red Planet shines at

► 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.

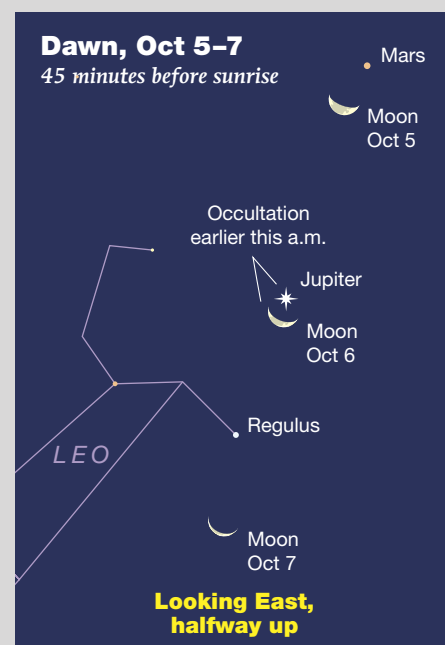
magnitude 1.1 and sits about 1° upper right of the 30%-illuminated waning lunar crescent. (The Moon's southern limb actually covers Mars as seen from the remote Canadian Arctic and northern Alaska.) The Moon is already east of Mars by the time they clear the horizon, which means the separation between the two planets increases with each passing minute — the earlier you look, the closer they'll be. But there's another reason you should continue watching even as the lunar crescent drifts away from Mars. It turns out that this is only the first meeting on the Moon's schedule for tonight. If you use binoculars or a small telescope, you can also watch it skim the northern edge of the **Beehive Cluster** (M44), in Cancer, as dawn approaches. None of the stellar bees in the hive are brighter than 6th magnitude, which is why you'll need the optics to watch this meetup.

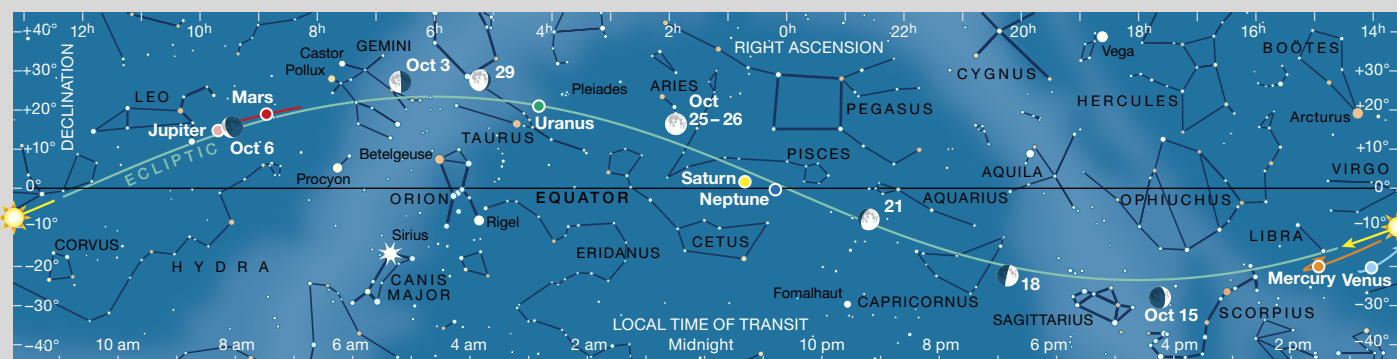


TUESDAY, OCTOBER 6

The month's most exciting event takes place this morning as the **Moon** closes in on **Jupiter** and then occults the planet. As detailed on page 48, the spectacle is visible for much of the eastern half of the U.S. and Canada. This is the second occultation in a sequence that began on September 8th and wraps up next May. As it turns out, this morning's encounter is the only one in the series visible from North America at night.

Even if you view the night sky from a location outside of tonight's occultation zone, you're still going to see a wonderfully close conjunction between the 20%-illuminated waning lunar crescent and the solar system's biggest planet. Usually, a conjunction such as this would qualify as a "don't miss it!" level occurrence — it's only because of





▲ 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.

the occultation that this part of the show might not seem quite so grand. Jupiter gleams at a magnitude of -1.9 , so it'll be readily visible to the naked eye even next to the Moon's bright, leading limb.

SUNDAY, OCTOBER 11

This morning Cancer's **Beehive Cluster** hosts its second October visitor when **Mars** passes through the heart of the hive. Once again, you'll need binoculars or a small telescope to enjoy the sight. The cluster is so big it'll take Mars roughly 45 hours to cross its entire expanse, so it's worth another look on the 12th. The Red Planet's color and brightness (magnitude 1.1) make it appear distinctly out of place among the swarm of dimmer cluster stars.

Indeed, Mars outshines the brightest bee, Epsilon (ϵ) Cancri, by more than 100 times!

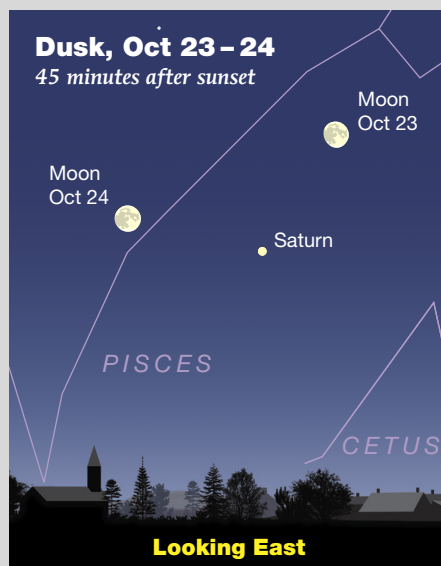
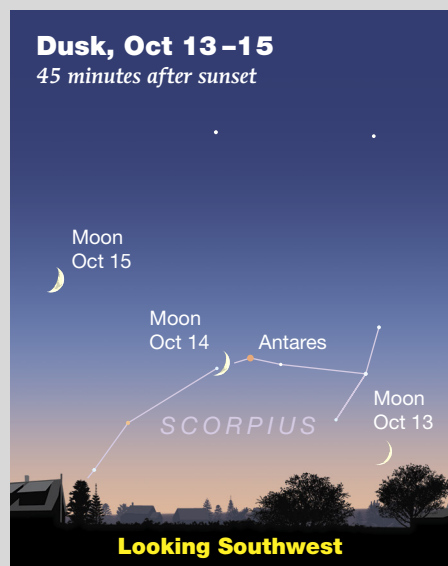
WEDNESDAY, OCTOBER 14

At dusk today we get our second lunar standstill event of the month, this time featuring the **Moon** dipping toward its southernmost position on the celestial sphere. Because it's well south of the ecliptic, the Moon is traveling a little off the beaten path. Look to the southwest in fading twilight to see the 18%-illuminated lunar crescent sitting between **Antares** and neighboring **Tau (τ) Scorpii**. Binoculars help fish out 2.8-magnitude Tau from twilight's glow, but 1st-magnitude Antares should be pretty obvious even to the unaided eye. The Moon is roughly $1\frac{1}{4}^\circ$ left of

Antares and a bit less than $\frac{1}{4}^\circ$ from Tau. All three easily fit into a single binocular field of view. Last month, observers in eastern Europe got to watch the Moon occult Tau — something that won't happen again until 2043, when the next lunar standstill gets underway.

SATURDAY, OCTOBER 31

If you're looking for motivation to get up a little early, the last dawn of the month provides some potent incentive. High in the sky, the waning gibbous **Moon** (one day shy of last-quarter phase) forms a tidy right triangle with Gemini's leading lights, **Castor** and **Pollux**. Pretty nice. To the left of the Moon you can't help but notice **Regulus**, **Jupiter**, and **Mars** arranged in a slightly lopsided (but attractive) three-in-a-row line. Also nice. But the real "star" of the show is **Venus**, hanging low in the east-southeast with **Spica** less than 4° upper left of it. The Morning Star had its conjunction with the Sun just one week ago and is now starting a fresh apparition that will reach its climax in mid-December. This morning Venus gleams gamely at magnitude -4.2 , outshining everything in the morning sky except for the Moon. All that luster is certainly worth setting an early alarm for!



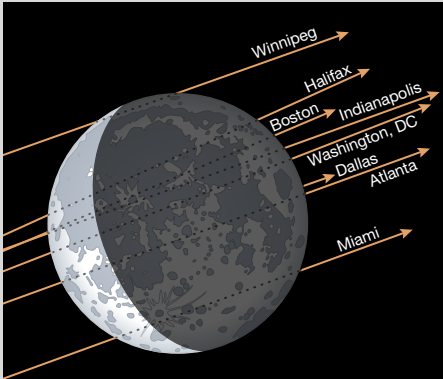
■ Senior Contributing Editor **GARY SERONIK** keeps tabs on the night sky from his home in British Columbia's Okanagan Valley.

Spectacular Cover-Up

This Jupiter occultation is not to be missed!

Skywatchers in eastern and central North America, including parts of the Mountain states, are in for a rare treat. On Tuesday morning, October 6th, the waning lunar crescent covers Jupiter and its four Galilean moons in a stunning occultation near dawn. The Moon's bright limb eclipses the planet (magnitude -1.9), which reappears at the dark limb minutes to about an hour later, depending on your location. Like a row of ducklings, Europa, Callisto, and Io precede their mother planet, with Ganymede bringing up the rear. After the cover-up, each rises in succession above the Moon's semi-dark, earthlit edge.

You can enjoy the spectacular game of hide-and-seek any way you like, whether by naked eye, binoculars, or through a small telescope. Or all of the above. To make sure you don't miss it, consider changing location if the weather's bad. Apps like *Zoom Earth* (zoom.earth), *Windy* (windy.com), and *Astrospheric* (astrospheric.com) offer free versions that use up-to-the-minute satellite imagery to plot clouds and their movements.



▲ This diagram shows the entry and exit points of Jupiter at the Moon's bright and dark limbs for a selection of cities in North America. Event timings are listed in the table below.

Jupiter and the Moon are located in Leo, 9.5° to the upper right of Regulus and stand highest in the sky as seen from the East Coast. The farther west you are the lower their altitude, so be sure to scout out a location with an unobstructed eastern sky in advance. From Boston, the duo is 23° high at first contact at 4:27 a.m. local time and climbs to 35° at its conclusion at

5:30 a.m. For Chicagoans the event begins at 3:22 a.m., with the Moon's altitude at 9.5°. Farther west in Austin, Texas, the Moon rises with the occultation already underway. Observers there will witness Jupiter's reappearance at 4:10 a.m., 9° above the horizon.

The occultation's northern limit, where the planet grazes the Moon's limb, slopes across eastern and central Canada and down into northern Montana. The southern limit cuts across southern Mexico and Cuba. For more details and graze-limit maps, check out Eberhard Riedel and David Dunham's dedicated page at tinyurl.com/Graze2026.

Outside the occultation zone, skywatchers see one of the most compelling conjunctions ever of a bright planet and the Moon. This is especially true for North and Central America, which are adjacent to the region. Las Vegas, a city that never sleeps, sees the duo just 1° apart around 4 a.m. For Seattleites, Jupiter floats less than ½° above the Moon when the two reach 5° altitude.

Other sights to watch for include Io and Callisto, which pair up tightly just before their disappearance behind the Moon and open up at reappearance. After the occultation is complete, Ganymede casts its shadow on Jupiter starting at 9:37 UT (5:37 a.m. EDT). And if that's not enough frosting on the cake, the Great Red Spot transits Jupiter's central meridian at 10:36 UT and should be obvious an hour before. Clearly, the cosmos is pulling out all the stops for this event!

Visit the International Occultation Timing Association's (IOTA) special event page at tinyurl.com/IOTAjupiter for a map and listing of times for many cities. Disappearance times are when the Moon's limb first touches Jupiter. Reappearance times are when the first bit of the planet shows at the dark limb. The next Jupiter occultation visible in North America won't be until (yikes!) September 28, 2034. I hope you're all able to get out and see this amazing bit of gravitational clockwork. It could become one of your most memorable observing experiences.

Occultation of Jupiter on October 6, 2026		
City	Disappearance (UT)	Reappearance (UT)
Winnipeg	8:45.5	9:03.9
Halifax	8:35.0	9:36.2
Boston	8:26.8	9:29.9
Indianapolis	8:19.5	9:18.1
Washington, DC	8:20.5	9:24.5
Dallas	—	9:11.5
Atlanta	8:15.7	9:16.7
Miami	8:20.8	9:09.0

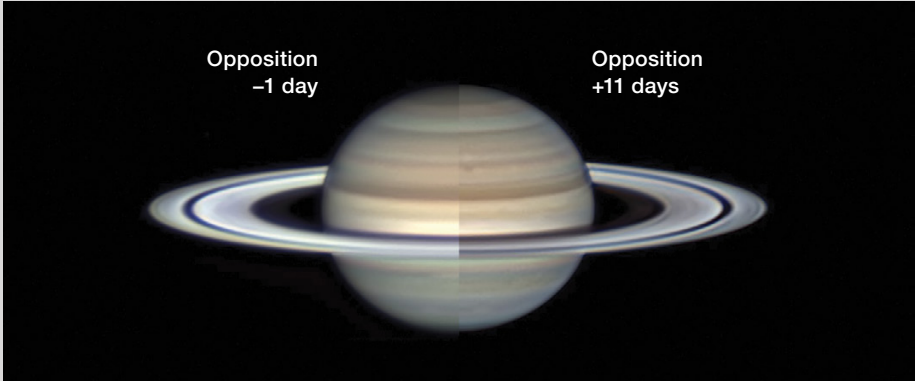
Ring King Never Disappoints

LAST MARCH, SATURN'S rings were edgewise and remained narrowly tilted the entire year. But when the most glamorous planet reaches opposition on October 4th, the rings' south face is tipped by 7.5°. Saturn is starting to look like Saturn again. The extra light they reflect boosts its magnitude to 0.3, a few tenths brighter than the previous opposition.

The ring plane is still narrow enough to make hunting the planet's fainter moons fair game. If you're a veteran Saturn-watcher, you've probably tracked down Titan, Rhea, Dione, and Tethys. But if you have access to a 10-inch scope with clean optics, leave your comfort zone and try seeking the inner moons Enceladus and Mimas. The challenge will become greater in the next few years as the tilt — and glare — increases.

Earth, the faster inner planet, laps sluggish Saturn about every 12.4 months at opposition. Since both planets are paired on the same side of the Sun, we're closest on October 3–4, at a distance of 1.26 billion km (784 million miles) or 1.2 light-hours. By the way, Saturn abandons the zodiac this season. You'll find it in Cetus crawling westward in retrograde motion.

Opposition is also the best time to view the *Seeliger effect*. For two to three days centered on October 4th, the rings undergo a brightness surge before fading back to their pre-opposition appearance. Shadow-hiding and *coherent backscatter* work in tandem to cause the spike. In shadow-hiding, the ring particles — which range in size from dust grains to large boulders — hide their own shadows and reflect sunlight directly back to our eyes. Coherent backscatter occurs when multiple reflections from trillions of small particles combine to produce a single (coherent), brighter reflection



▲ The Seeliger effect is apparent in this split image of Saturn made during its August 27, 2023, opposition. The left half shows the planet on August 26th; the right, September 6th. The rings are noticeably brighter near opposition.

pointed back at the observer. Photographs show the effect well, but it's also obvious visually through the telescope. Observe the rings a week on either side of the big night and compare their brightness to what you see at opposition. How fascinating that we can perceive the make-up of Saturn's rings from more than a billion kilometers away with our eyes and a basic telescope.

Now that the rings are opening up again, we should get a clear view of the outer A ring; the bright, wide B ring; and even the diaphanous C ring, also called the Crepe Ring. The last is the most challenging because of its translucence. Use high magnifica-

tion on a night of excellent seeing and look for a filmy, gray presence interior to the B ring that borders the black, “empty” space adjacent to Saturn's globe. You'll also want to look for the thread-thin Cassini Division that separates the A and B rings. Advanced observers with 10-inch and larger scopes and excellent seeing can attempt the more difficult Encke Gap, located just within the outer edge of the A ring.

Whenever Saturn is well placed for observation, I feel relieved because I know that no matter what, I'll have something wonderful to share on public observing nights. The Ring King never disappoints.

Minima of Algol			
Sep.	UT	Oct.	UT
2	4:53	3	17:48
5	1:42	6	14:37
7	22:30	9	11:26
10	19:19	12	8:15
13	16:08	15	5:03
16	12:56	18	1:52
19	9:45	20	22:41
22	6:34	23	19:30
25	3:22	26	16:18
28	0:11	29	13:07
30	21:00		

These geocentric predictions are from the recent heliocentric elements Min. = JD 2457675.72 + 2.867343E (where E is any integer), as listed in the AAVSO Variable Star Index. For a comparison-star chart and more info see skyandtelescope.org/algol.



▲ Perseus reaches the zenith during the pre-dawn hours in October. Every 2.87 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Estimate its brightness with respect to the comparison stars, whose magnitudes are shown in this chart without the decimal point (e.g., 29 = 2.9).

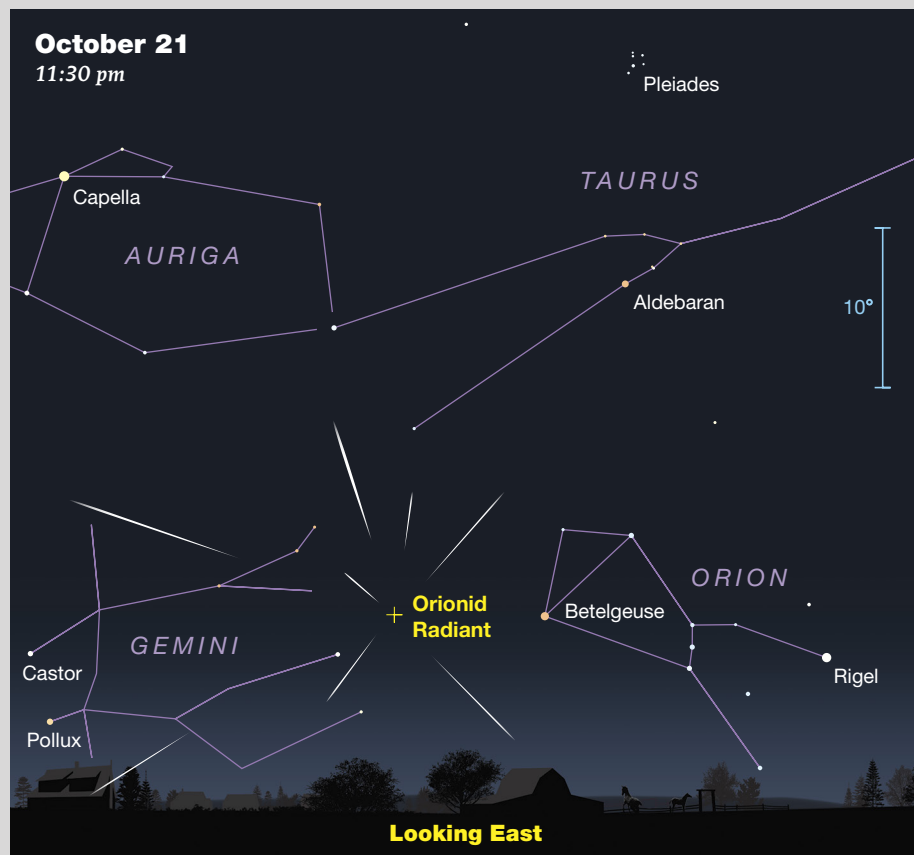
Orionids Delight after Moonset

WANT TO SEE Halley's Comet? Or at least its castoffs? Get up early on the morning of October 22nd, when pieces of the famed comet shoot from Orion's upraised club from around 3:30 a.m. local time till dawn. During that approximately 3-hour span, observers with access to a dark sky can see some 20 meteors per hour tear past the silent stars. Each flash results from a sand-grain- to pea-size fragment slamming into the upper atmosphere at more than 235,000 km per hour (146,000 mph).

Every year, Earth traverses the trail of debris left by Halley's Comet twice: first in May through the stream's outbound

leg, which gifts us with the Eta Aquariid meteor shower, and in October across the inbound leg. To watch the Orionids in comfort, bundle up and ease back into a reclining chair. Face about 90° away from the radiant, for example to the east or west, for the best view of both short- and long-trailed meteors.

The Orionids often toss in a few fireballs to keep things interesting. My favorite part of watching meteor showers is what I call the Just-One-More effect. You might plan to spend just an hour with the shower but find it impossible to call it quits until you see *just one more*.



▲ While not a strong shower like the Perseids or Geminids, the Orionids are swift and reliable. Originating from Halley's Comet and streaming from a radiant in Orion's upraised club, the shower reaches maximum on the night of October 21–22. If it's cloudy, one night on either side of maximum will still provide good views.

Action at Jupiter

JUPITER CONTINUES to dominate the early morning sky, rising around 3:00 a.m. at the beginning of the month and 1:00 a.m. by Halloween. You've got a good 3 hours of observing before sunrise as the gas giant climbs nearly straight up from the horizon. The eastern and central U.S. are treated to an occultation on the 6th (see page 48), when our tiny Moon blocks a planet 40 times its size.

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

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

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

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

20:31; **19:** 6:26, 16:22; **20:** 2:18, 12:14, 22:09; **21:** 8:05, 18:01; **22:** 3:57, 13:52, 23:48; **23:** 9:44, 19:40; **24:** 5:35, 15:31; **25:** 1:27, 11:23, 21:18; **26:** 7:14, 17:10; **27:** 3:06, 13:01, 22:57; **28:** 8:53, 18:48; **29:** 4:44, 14:40; **30:** 0:36, 10:32, 20:27; **31:** 6:23, 16:19.

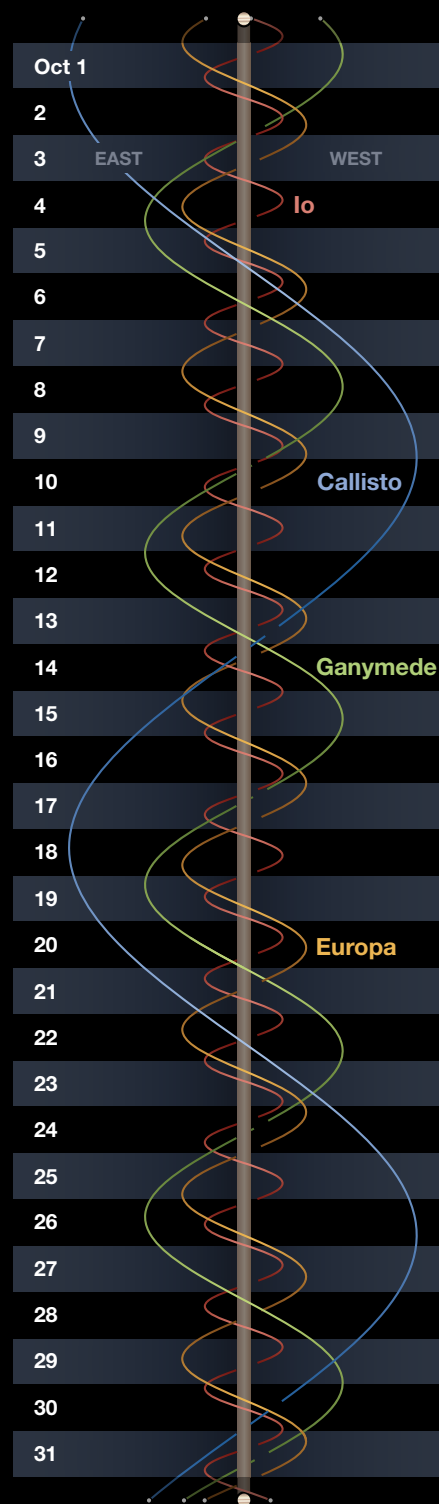
These times assume that the spot will be centered at System II longitude 92° on October 1st. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 92° and 1²/₃ minutes later for each degree more than 92°.

Phenomena of Jupiter's Moons, October 2026

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

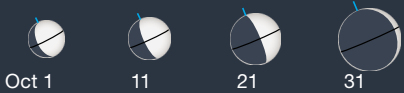
Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, 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

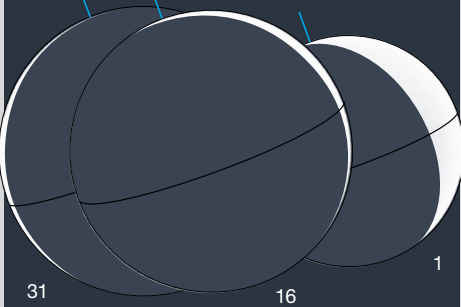


The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites'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

Mercury



Venus



*Size reduced to 75%

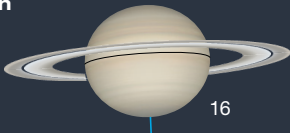
Mars



Jupiter



Saturn



Uranus



Neptune



10"

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

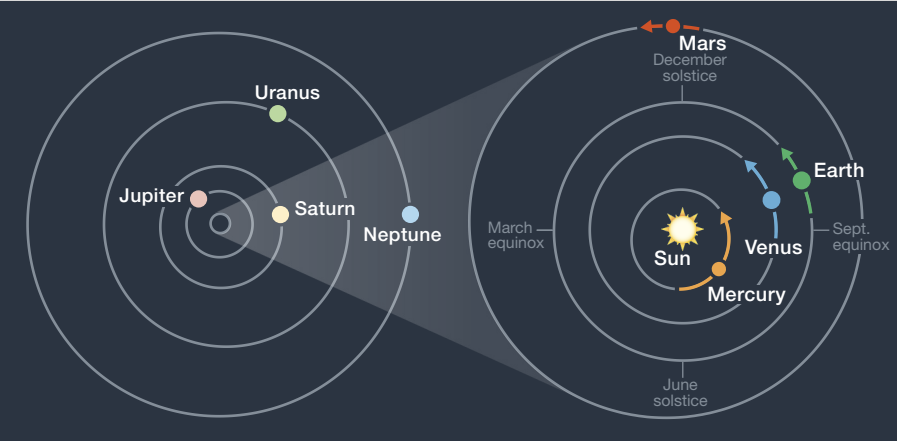
► **ORBITS OF THE PLANETS**
The curved arrows show each planet's movement during October. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** lost in the Sun's glare all month • **Venus** visible at dusk until the 4th and then at dawn starting on the 29th • **Mars** and **Jupiter** rise in the early morning and visible to dawn • **Saturn** visible all night.

October Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	12 ^h 27.4 ^m	−2° 58′	—	−26.8	31′ 57″	—	1.001
	31	14 ^h 19.4 ^m	−13° 55′	—	−26.8	32′ 13″	—	0.993
Mercury	1	13 ^h 50.3 ^m	−13° 13′	23° Ev	−0.1	5.7″	77%	1.176
	11	14 ^h 35.8 ^m	−18° 11′	25° Ev	−0.1	6.5″	64%	1.027
	21	15 ^h 06.3 ^m	−20° 47′	23° Ev	+0.2	7.9″	41%	0.846
	31	14 ^h 57.3 ^m	−18° 46′	10° Ev	+2.7	9.7″	7%	0.690
Venus	1	14 ^h 12.9 ^m	−20° 51′	31° Ev	−4.7	48.0″	15%	0.348
	11	14 ^h 07.9 ^m	−20° 59′	21° Ev	−4.5	55.5″	6%	0.301
	21	13 ^h 50.3 ^m	−18° 49′	9° Ev	−4.2	60.6″	1%	0.275
	31	13 ^h 30.3 ^m	−14° 56′	12° Mo	−4.2	60.0″	2%	0.278
Mars	1	8 ^h 15.1 ^m	+20° 51′	66° Mo	+1.1	5.6″	90%	1.666
	16	8 ^h 50.5 ^m	+19° 02′	72° Mo	+1.0	6.0″	90%	1.558
	31	9 ^h 22.7 ^m	+17° 01′	79° Mo	+0.9	6.5″	90%	1.441
Jupiter	1	9 ^h 27.3 ^m	+15° 37′	48° Mo	−1.9	33.3″	100%	5.921
	31	9 ^h 45.5 ^m	+14° 14′	73° Mo	−2.0	35.7″	99%	5.515
Saturn	1	0 ^h 45.4 ^m	+1° 56′	175° Mo	+0.3	19.7″	100%	8.436
	31	0 ^h 37.2 ^m	+1° 05′	152° Ev	+0.5	19.5″	100%	8.540
Uranus	16	4 ^h 11.6 ^m	+20° 57′	137° Mo	+5.6	3.8″	100%	18.692
Neptune	16	0 ^h 09.9 ^m	−0° 29′	160° Ev	+7.8	2.4″	100%	28.940

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



Getting the Correct Exposure for Nightscapes

Here's a great way to improve your Milky Way night scenes.

Photographers shooting nightscapes for the first time ask the obvious question: “What’s the best exposure to use?” Beginners soon encounter several exposure rules to guide them when capturing a starlit landscape. One technique I teach at every workshop I present is Expose to the Right, or ETTR. It’s a concept I learned from the photo website Luminous-Landscape.com many years ago.

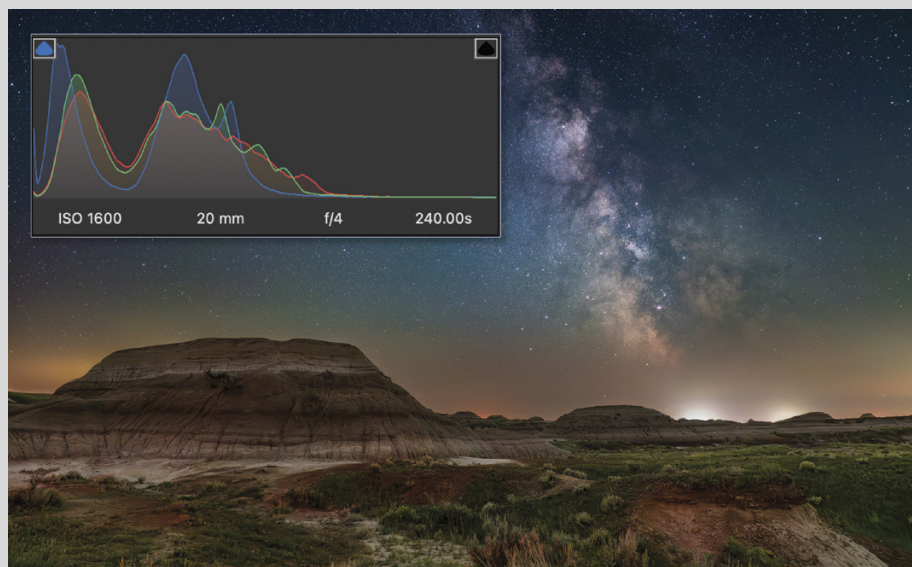
Here are some pointers to keep in mind for your next imaging session.

Don't Slam the Histogram

What ETTR means is to always expose so that the image’s histogram is shifted over to the right. *Histograms* are graphs of how many pixels the image contains at every brightness level, typically labeled from 0 (pure black) at the left end to 255 (pure white) at the right; see *S&T*: Feb. 2025, p. 73.

However, today’s 14-bit camera sensors can differentiate more than 16,000 tonal levels in RAW files (always shoot RAW!), in each of the three color channels — red, green, and blue. This sounds great, but most of those thousands of brightness steps sample the mid-tones and highlights. The dark regions, called the “shadows,” are where most of the content of our nightscapes lies and are sampled by very few tonal values.

When reviewing images in the field, your camera’s histogram display provides an objective indicator of the exposure. If you allow the histogram to appear like a steep cliff to the left, then the image is badly underexposed.



▲ **SHIFT THE HISTOGRAM** Milky Way nightscapes can benefit from the Expose to the Right (ETTR) technique — that is, exposing long enough so that the histogram plot of brightness levels is shifted to the right when shooting in the field. This blend of tracked sky and untracked ground images was taken at Alberta’s Dinosaur Provincial Park with a full-frame Nikon Z6III camera and 20-mm lens.

Attempting to stretch or raise the shadows in processing often results in a litany of ugly artifacts, such as posterization, weak contrast, banding patterns, perhaps a green color cast, and most certainly noise!

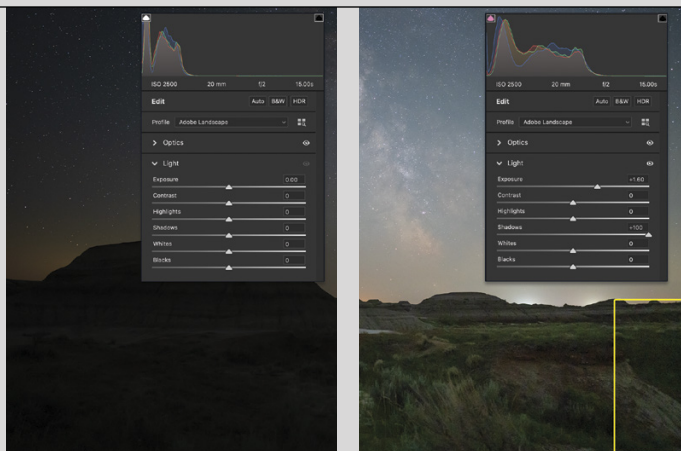
By exposing to the right, you lift the image content out of the inky shadows into the mid-tones for more precise sampling, with the higher signal also overpowering noise and sensor artifacts. On the other hand, don’t increase your exposure so much that the histogram slams to the right. That blows out highlights beyond recovery. A good night-scape histogram should be a mountain of pixels rising from a valley at the left and descending into another wider valley at right, achieved “in-camera” and thus requiring minimal exposure correction later in post-processing.

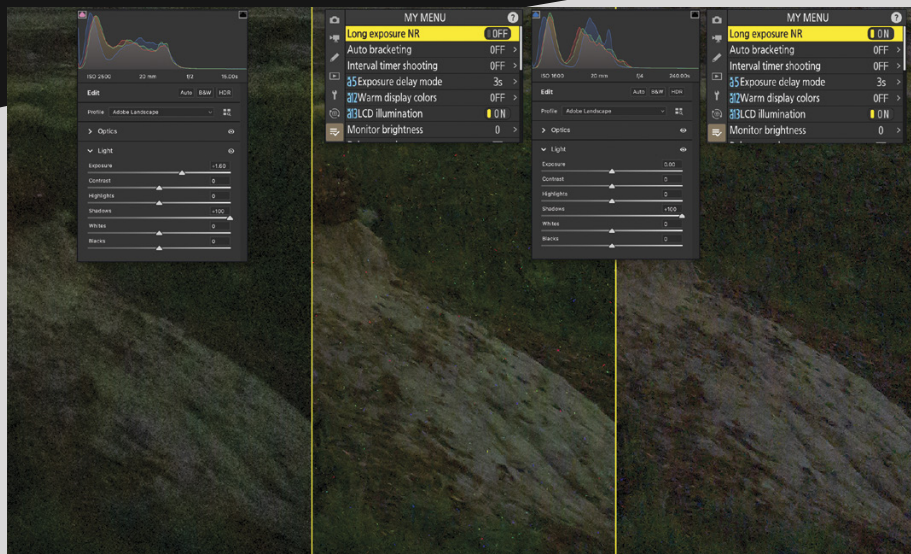
ETTR is considered best practice with any form of astrophotography. Where ETTR becomes essential is for the most demanding of nightscapes — wide-field images of the Milky Way over a landscape illuminated only by starlight. In such scenes it’s not the sky above that’s the challenge; it and the Milky Way can be quite bright. The dark landscape below is what’s tough to capture. That’s where you’ll see the most noise and color casts, especially in the corners of the frame, which are made even darker by the inherent light falloff, or *vignetting*, of fast, wide-angle lenses.

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► UNDEREXPOSED VS. PROCESSED

Left: This dark, “out-of-camera” image is a 15-second shot following the 300 Rule for the 20-mm lens used to minimize star trailing. **Right:** Raising the Exposure level by 1.6 stops and the Shadows to 100% reveals noise shown in the corner close-up on the next page.





▲ **GOING LONG FOR LOWER NOISE** *Left:* Compare this blowup of the corner of the previous 15-second exposure at ISO 2500 and f/2 with the same corner of an ETTR image at right, taken at ISO 1600 and a smaller aperture of f/4 (for more depth of field), but for 4 minutes, requiring no boost in processing. *Middle:* This shot with the camera's Long Exposure Noise Reduction (LENR) feature off shows hot pixels. *Right:* Activating the LENR produces the lowest noise and best color and detail.

Revisiting the Exposure Triangle

But how can you increase exposure? Every Photography 101 tutorial presents the concept of the exposure triangle, explaining how the three camera adjustments of shutter speed, aperture, and ISO work together to establish the brightness of an image. Increase one factor and you can decrease one or both of the other two.

All that's true, but ISO is often erroneously explained as the "sensitivity" of the sensor. Not so. Raising the ISO doesn't make the sensor more sensitive to light nor allow it to record more signal. It just amplifies the weak signal coming from the few photons the sensor does record, making the scene look brighter, but now with the noise also made more visible.

Only two factors in the exposure triangle actually increase the incoming signal: lengthening the exposure time (that is, using a slower shutter speed) and widening the lens aperture (opening up to a lower, faster f/ratio). Only those two adjustments let in more photons and improve the signal-to-noise ratio.

Breaking Exposure Rules

For Milky Way nightscapes, we typically shoot at wide apertures of f/2 to f/2.8, contending with optical aberrations that

distort stars at the corners of the frame when lenses are used "wide open."

With shutter speeds there's also a limitation. While cameras can take as long an exposure as we'd like, we're shooting a moving subject — the sky. Various rules dictate how long a shutter speed we can use before we see noticeable trailing of the stars. The venerable "500 Rule" stated that the maximum exposure time was 500 divided by the lens focal length. With today's sharp lenses and high-resolution camera sensors, a 200 or 300 Rule is more accurate (see S&T: Apr. 2025, p. 55).

In our quest for the sharpest stars, we dutifully obey the rules and use short shutter speeds. But this often results in severe underexposure — a slammed histogram. Brightening the RAW image after the fact by raising the Exposure slider in your image-editing software does make the scene brighter, but it reveals all those ugly artifacts lurking in the shadows, just like cranking up the ISO does.

To increase the actual signal, don't be afraid to exceed the shutter-speed limits imposed by strict "no star trail" rules. Any trailing you get might not be that noticeable, especially when viewed on Facebook or Instagram. But you can gain a full stop, or more, of starlight.

Separate the Ground and Sky

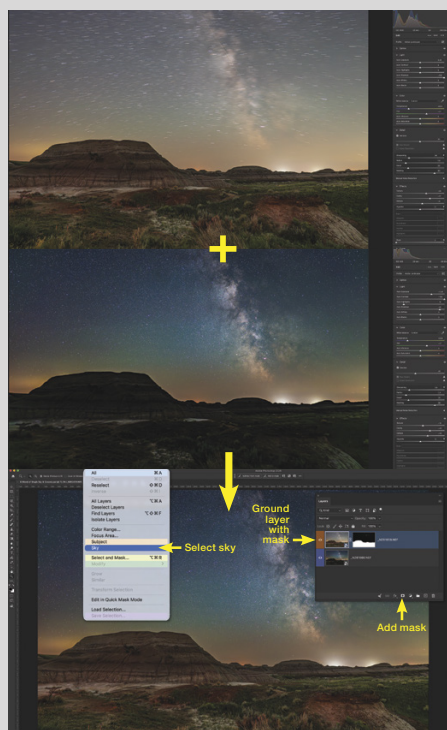
By far the best technique in the field, however, is to shoot separate exposures for the foreground and sky, using the shutter speed, aperture, and ISO that work best for each. Shoot the sky with 10- to 30-second exposures at high ISO and as wide an aperture as your lens will allow without showing objectionable aberrations. Then shoot the foreground at a lower ISO for less noise and at a smaller, slower aperture for enough depth of field to make foreground features appear in better focus. Decreasing both the ISO and aperture can lengthen your exposure time on dark, moonless nights to several minutes.

The drawback is the introduction of another form of noise — random, colored "hot pixels" from thermal noise buildup in the sensor. It's worse on hot summer nights with high-megapixel cameras. This noise can be eliminated by *dark frames*, which are exposures of the same length as the "light frame" but with no light hitting the sensor.

While darks can be taken at the end of the session and subtracted later, I've found the best way to eliminate hot pixels is to turn on Long Exposure Noise Reduction (LENR), an option available on all cameras. The camera takes a dark frame right after the light and subtracts it in-camera. Because the sensor is then as close to the same temperature for both shots as it can be, an LENR dark frame is the most accurate. Yes, LENR locks up the camera for another few minutes, but the result is a cleaner image, needing less work in post-processing.

Stacking vs. Tracking

A single, long-ETTR exposure of the foreground can be blended with a short, untracked exposure of the sky. (See the workflow on page 55 at upper left.) Alternatively, many nightscapers opt to beat noise by taking a lot of untracked images and then stacking them. Clever software such as *Starry Landscape Stacker* for macOS (tinyurl.com/starry-landscape-stacker) and *Sequator* for Windows (sites.google.com/view/sequator) can stack short, untracked exposures and align the moving stars



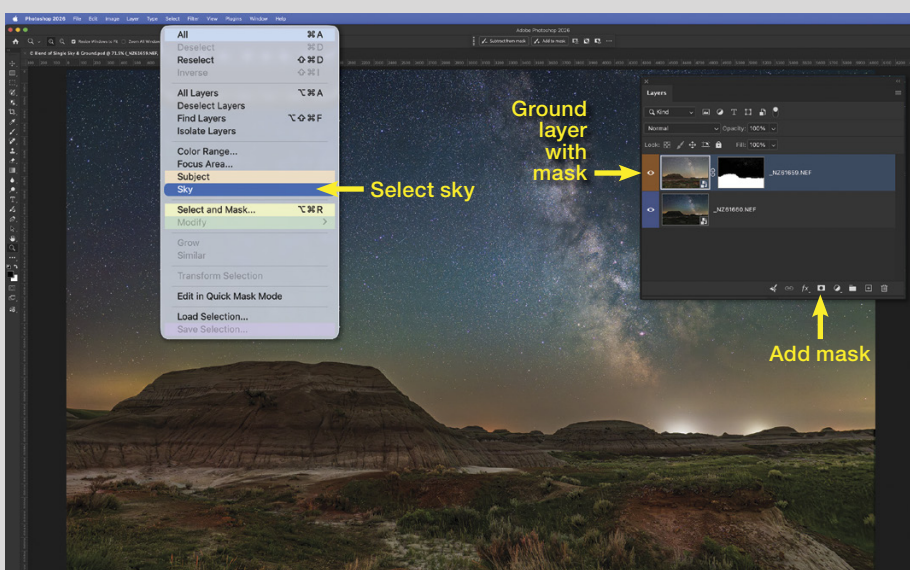
separately from the static ground.

While stacking short exposures does smooth noise, I find the result doesn't produce the depth, detail, and contrast of a single, long-ETTR foreground exposure taken at a lower ISO. And with *Starry Landscape Stacker*, I find the app's imperfect masking of the sky and ground can introduce horizon "ghosts."

The method I prefer for most Milky Way nightscapes is to use a star tracker for the sky. This allows exposures to extend to a minute or more for a good ETTR sky, revealing rich detail in the Milky Way with no star trails. I shoot the even-longer ETTR foreground image with the tracker motor off, usually before the tracked sky shot.

The drawbacks of a tracker are the more complex setup in the field and the extra work in processing, since the camera motion will misalign the sky with the foreground. Even so, I feel the better results are worth the effort. However, applying the ETTR edict can improve your photos, no matter what gear you use to take images of the night sky.

■ Contributing Editor ALAN DYER is coauthor with Terence Dickinson of *The Backyard Astronomer's Guide*. He can be reached at amazingsky.com.



▲ **BLENDING THE GROUND AND SKY** In the final composite, the foreground is a 4-minute *untracked* ETTR exposure taken at f/4 (top), while the sky is a 1-minute *tracked* exposure at f/2 (middle). Bringing each developed RAW file into *Adobe Photoshop* as layers and using **Select > Select Sky** makes it easy to **Add Layer Mask** in the Layers panel to the ground layer (bottom). Select the mask and **Invert** the selection to mask out its trailed sky and reveal the tracked sky below.

Spotting Triton

Track down Neptune's unusual companion.

Observing Neptune when it's at opposition is easy. Indeed, if you know its position relative to nearby stars, you can even spot the eighth planet through 7×50 binoculars. But seeing Triton, Neptune's largest moon, is more of a test. Common wisdom states that you need at least an 8-inch telescope to spot it. Of course, when I read that I immediately thought, "I've got to try to see it through my 6-inch." I plan to do so around the time Neptune reaches opposition (the evening of September 25th in the U.S.) and report on my observation in a future column.

Neptune was discovered on September 23, 1846. Less than three weeks later, on October 10th, British astronomer William Lassell discovered Triton with his homemade 24-inch reflector. And even though the mirror was made of speculum (a copper and tin alloy that, when polished, reflected approximately 70% of the light striking it), it offered plenty of aperture to reveal the satellite.

Of the more than 400 moons known to orbit the planets in our

solar system, only Jupiter's four Galilean satellites, Saturn's Titan, and our Moon are larger than Triton. Its nearly circular orbit (an eccentricity of only 0.000016) keeps it approximately 354,000 km (220,000 miles) from Neptune, which is comparable to the Earth-Moon distance. Triton takes 5 days, 21 hours, 2 minutes, and 40 seconds to revolve around Neptune.

Interestingly, the moon moves in a *retrograde* orbit, which is unlike any other large satellite in our solar system. This means that, instead of orbiting in the same direction that Neptune rotates, it moves in the opposite direction. This strongly suggests that the moon was captured by Neptune instead of forming in the planet's orbit.

At opposition, Neptune and Triton lie some 4.3 billion km (2.7 billion miles) from Earth. For observing purposes — and taking into account the tilt of Triton's orbit from our point of view — the separation between Triton and its parent planet at that distance translates to between 8" and 17", depending

on where Triton is in its orbit. Obviously, you'd want to try for it when the moon is at or near its maximum apparent distance from Neptune.

If you're a double-star observer, these angular distances don't sound all that daunting. I'm sure many of you have split binaries with less than 8" separation through telescopes as small as 2.4 inches. But the stars in those systems probably were fairly close in brightness.

Neptune currently shines at magnitude 7.8. Triton, however, is much fainter, registering only magnitude 13.5. That difference — nearly six magnitudes — translates to the planet being about 190 times brighter than its moon.

To spot the ice giant's faint companion, start by picking a night when Neptune and Triton are near their maximum separation. A great way to find out when this occurs is to head to the Jet Propulsion Laboratory's Horizons System page at tinyurl.com/hrzapp. On the page, there are five lines to set up. The first (Ephemeris Type) is defaulted to Observer Table and doesn't need to be changed. Click the **Edit** button in the Target Body line and then type Triton in the Specify the Target Body window and click search. The Observer Location (line 3) should stay at its default setting "Geocentric." Line 4 is for Time Specification. Here, click **Edit** and enter a date range. Line 5 is Table Settings. Press the **Edit** button, then deselect everything in the Observer Table Settings window that opens and choose only **12. Satellite angular separ./vis.** Scroll to the bottom of the page and click the **Use Specified Settings** button.

Doing that will send you back to the main page. Now click the green **Generate Ephemeris** button and scroll down to the line that reads "Date__ (UT)__HR:MN ang-sep/v." Beneath that are the columns for the date — at 0^h UT, which is 8 p.m. EDT — and how far Triton is from Neptune in arcseconds. (You can ignore everything after the decimal point.) So, if you plan to observe at 8 p.m. on October 11th, the evening after new Moon, Triton will lie a worthy 15.8" from the greyish blue planet. Pretty slick.



Neptune and its largest moon, Triton, shown to scale.

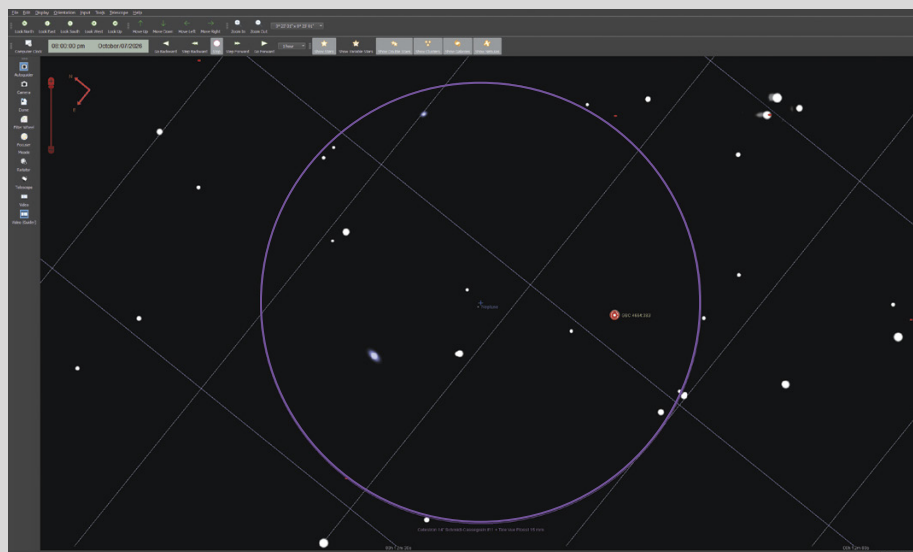
Even slicker is S&T's own *Triton Tracker* app at skyandtelescope.org/triton. Enter the above date and time, click the **Calculate using entered date & time** button, and pick from the three telescope views offered (direct, inverted, or mirror-reversed).

On every occasion when I've observed Triton, with one exception it's been through telescopes of at least 16 inches aperture. Through such light buckets, you can pretty much center Neptune and — boom! — there's Triton. And while that's true, you'd probably want to make an initial observation during evening hours and then head back to the scope six or so hours later to see if the dot you had identified as Triton has moved a bit.

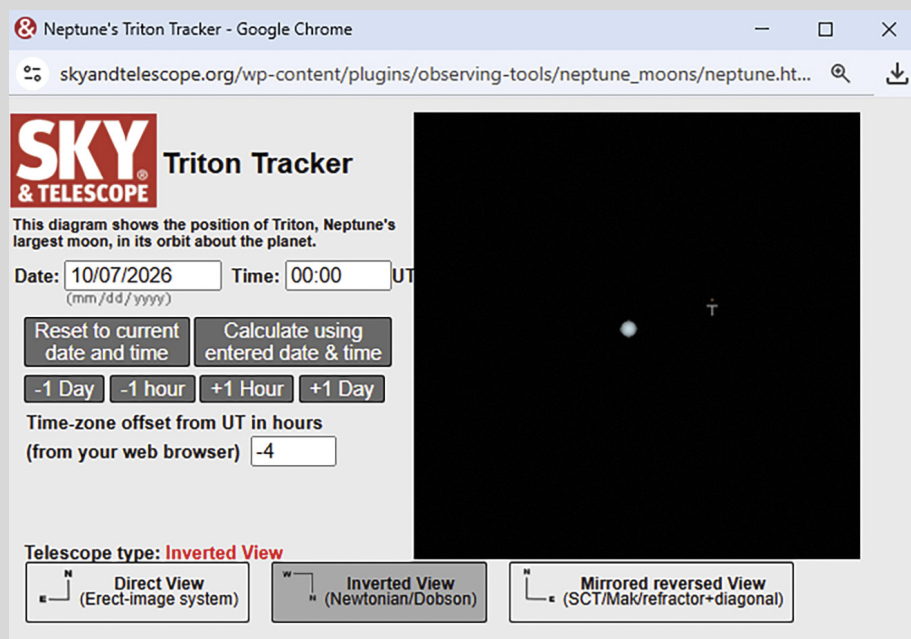
Prepare a sketch that includes a few background stars to help confirm the moon's movement and identity. Use a digital planetarium like Software Bisque's *TheSky*, set its field of view equal to that of the eyepiece you're using, and set the magnitude limit to 14. Although the program won't show the position of the moon, it will provide enough background stars for you to compare your (hopefully) two positions of Triton.

Observing this distant satellite is a wonderful challenge through 8- to 11-inch scopes. To succeed, you need several things. First, near-perfect seeing. If the atmosphere is unstable, try for Triton on another night. Second, your scope needs to be perfectly collimated. The planet must be a tight, bluish sphere, not elongated in any way. Third, you need an eyepiece magnification of at least 250×. Indeed, if your image looks good at that power, you'll have verified the quality of both the atmosphere and your collimation. Finally, Neptune has to be high enough above the horizon to have climbed above the thickest part of our image-distorting atmosphere. I usually think of this window starting two hours before Neptune reaches its highest point (on the meridian, due south) and ending two hours after.

Choose a night in which Triton lies 16" from Neptune's 2½"-wide blue disk. The moon would be six Neptune diameters away (as measured from the planet's center). Then use the *Triton Tracker* to



▲ Making a finder chart using a powerful planetarium program such as Software Bisque's *TheSky* can simulate your particular telescope and eyepiece field of view. This helps you to chart background stars at the time of your planned observation.



▲ Use S&T's *Triton Tracker* app to show the position of the distant moon relative to the planet as it should appear in your own telescope.

determine in which direction the satellite lies from the planet and search that area carefully for a faint point of light.

Think you've found Triton? Congratulations. But to be sure, mark its position on that sketch of the field you made before your observation. Then come back in a few hours and find it again. If it's moved just a little bit relative to Neptune, you did it. If sky conditions have deteriorated, you can

check again the following night. Just remember that Neptune moves roughly 22" per day relative to the stars.

Now head out, find the eighth planet, spot its largest moon, and cross this observation off your astronomical bucket list. Good luck!

■ **MICHAEL E. BAKICH** is an amateur astronomer and author who lives in Tucson, Arizona.



LINKING UP This image (with north to the right) shows the delightful Burbridge Chain stretching off the northeastern side of the glorious spiral NGC 247. From left to right the galaxies are: PGC 2796, PGC 2794, PGC 2798, PGC 2791, and PGC 842319.

Let's Line Up

Test your observing mettle on this selection of galaxy chains.

There's something appealing about seeing many galaxies in the same field of view. Perhaps my mind grapples in awe with the sheer scale of the structure I'm witnessing all at once. I don't think I'm alone here, because the eight galaxies around M86 seen together in a 1° eyepiece field are always a hit at a star party. The scene becomes even more special when galaxies are arranged in an orderly chain, and yes, I invariably pan that field to mop up the best-known of them, Markarian's Chain (*S&T*: Apr. 2022, p. 22). Surely there must be many such wondrous arrangements! Scouring books, articles, and catalogs, I've found several more — although most command a large telescope and a determined observer. Let's start bright and go deeper!

Learning the Links

Of the autumn galaxy chains, Arp 331, the **Pisces Chain**, is my favorite. It's a physical group centered on the lenticular galaxy NGC 383. Find the 12th-magnitude galaxy 2.5° north-northwest of 4.5-magnitude Tau (τ) Piscium toward Beta (β) Andromedae. The five bright-

est galaxies are NGC 383, NGC 380, NGC 379, NGC 385, and NGC 384, ranging in magnitudes between 12.4 and 13.1. All should be within the reach of smaller telescopes, but I had an incredible view of them through my 18-inch on a dark December night from the Inyo Mountains in California. With averted vision, I could see all five together at 147×, glistening like a string of gems behind a field of dim stars. Increasing the power to 207× yielded an even better sight, revealing eight galaxies within the 20' field of my eyepiece. I readily detected the five brightest as well as NGC 382 with direct vision, and NGC 386 was barely visible. I needed averted vision for 15.5-magnitude NGC 387 to become apparent. Through my 28-inch at 291×, the chain of eight galaxies barely fit into a 15' field of view, and I saw all of them and 14.7-magnitude NGC 375 with direct vision. It took work to pick out PGC 197570, a physical member well-aligned with the rest of the chain.

Anchored around IC 1459 (also designated IC 5265) and spanning about 1.5° in length, low in my California sky lies the **Grus Chain**. It helped that I was

viewing from the Sierra Nevada mountains at an elevation of 2,400 meters (8,000 feet), giving me great transparency toward the south. I've only observed this chain with my 28-inch, but that isn't representative of its overall brightness — Contributing Editor Steve Gottlieb has detected many of its members with 8- and 13-inch telescopes. Unlike the Pisces Chain, this one is so spread out that I could sometimes fit only three galaxies at a time in my widest field of view (43'). It was nevertheless fun to “hand-off” from one galaxy to the next. I started with bright IC 5270 (magnitude 12.3), which you can find 1.6° southwest of 5.1-magnitude Pi (π) Piscis Austrini and 20' south-southwest of 6th-magnitude HD 217096. Thereafter I slewed south to IC 5269 (magnitude 12.2), then on to low-surface-brightness IC 5269B (magnitude 12.4), the brightest of the bunch 10.0-magnitude IC 1459, and modestly bright IC 5264 (magnitude 12.6). Farther south lies the challenging 13.2-magnitude NGC 7418A, along with NGC 7418, which glows modestly at magnitude 10.9, and taking up the tail is 12th-magnitude NGC 7421.

Sinking Deep

While panning around planetarium software, I found that 13.2-magnitude **NGC 1044**, NGC 1046, PGC 3080165, and PGC 10176 form a fairly isolated

line-up, about 1.7° southwest of 4.3-magnitude Mu (μ) Ceti and a mere 13' north-northwest of 7.3-magnitude HD 16762. I couldn't have anticipated what a beautiful sight it would be in my 28-inch: At 291 $\times$, all four galaxies were simultaneously visible! The faintest of the quartet, PGC 10176, appeared virtually stellar.

About 2.7° southwest of 4.5-magnitude Nu (ν) Aquarii lies a dim chain of six 14th- to 15th-magnitude IC galaxies peppered with a handful of PGC objects. Pointing my 28-inch at 139 $\times$, I quickly picked out three, IC 1347 appearing visually the brightest at 14.4, even though **IC 1348** is cataloged as marginally brighter at 14.3, and IC 1349 (magnitude 14.6). Tacking on 291 $\times$, three dimmer galaxies — IC 1353, IC 1351, and IC 1355 — revealed themselves as faint, condensed glows. PGC 942712 and IC 1352 both appeared bright and had superposed stars. PGC 938239 was the faintest galaxy I detected, while I couldn't see PGC 942315.

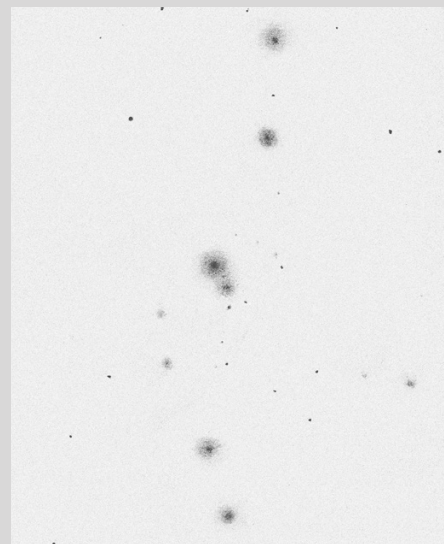
Observing from California's Central Coast, I found **Arp 332** challenging due to its southerly location — it's about 1.5° east-northeast of 4.1-magnitude Tau³ Eridani. I caught it just past its culmination when it cleared a tree that obstructed my view of the meridian. With Arp 332, pick your poison — the "easy" chain comprising NGC 1228, NGC 1229, NGC 1230, and IC 1892 (ranging in magnitude between 13.2 and 14.4) — or the very challenging, small chain consisting of three dim PGC galaxies stretching some 3' north of IC 1892. With my 28-inch at 139 $\times$, I could simultaneously view all four galaxies of the easy chain. I spent a lot of time trying to eke out any fainter members. I recollimated the scope, tried different eyepieces, and at 291 $\times$ I finally managed to make definitive observations of PGC 11748 and PGC 806184, as well as a possible detection of PGC 805977.

Chain-Gawking

A few years ago I pondered how many galaxy chains could just be hiding out there, unbeknownst to us deep-sky observers. I thus wrote a computer



▲ **IN PISCES** You'll find this graceful grouping of galaxies in northernmost Pisces, about 2.5° north-northwest of 4.5-magnitude Tau (τ) Piscium. If you feel inspired, you could sketch it, like Contributing Editor Howard Banich did (*right*).

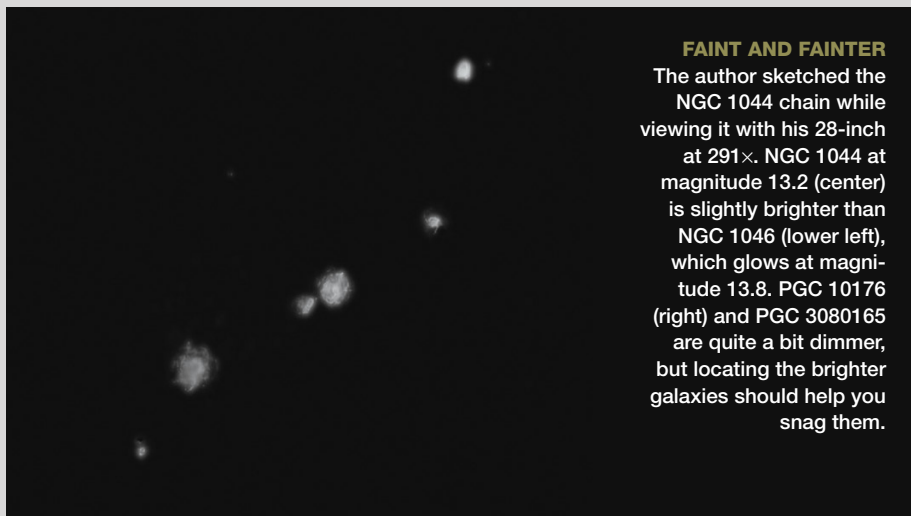


program to scan the *Principal Galaxies Catalogue* for more-or-less linear arrangements of galaxies. Not having magnitude information, the program spat out numerous uninteresting or very dim chains. Drat, I didn't strike any hidden treasure. However, the program did identify a handful that I thought might look good through my 28-inch. So, I tried my luck with them.

One of those finds, lying 1.3° west-northwest of 5.3-magnitude Rho (ρ) Piscium, has **PGC 1595534** for its brightest denizen at magnitude 15.2. The chain of six galaxies was challenging through my 28-inch at 291 $\times$, exacerbated by having to hand-

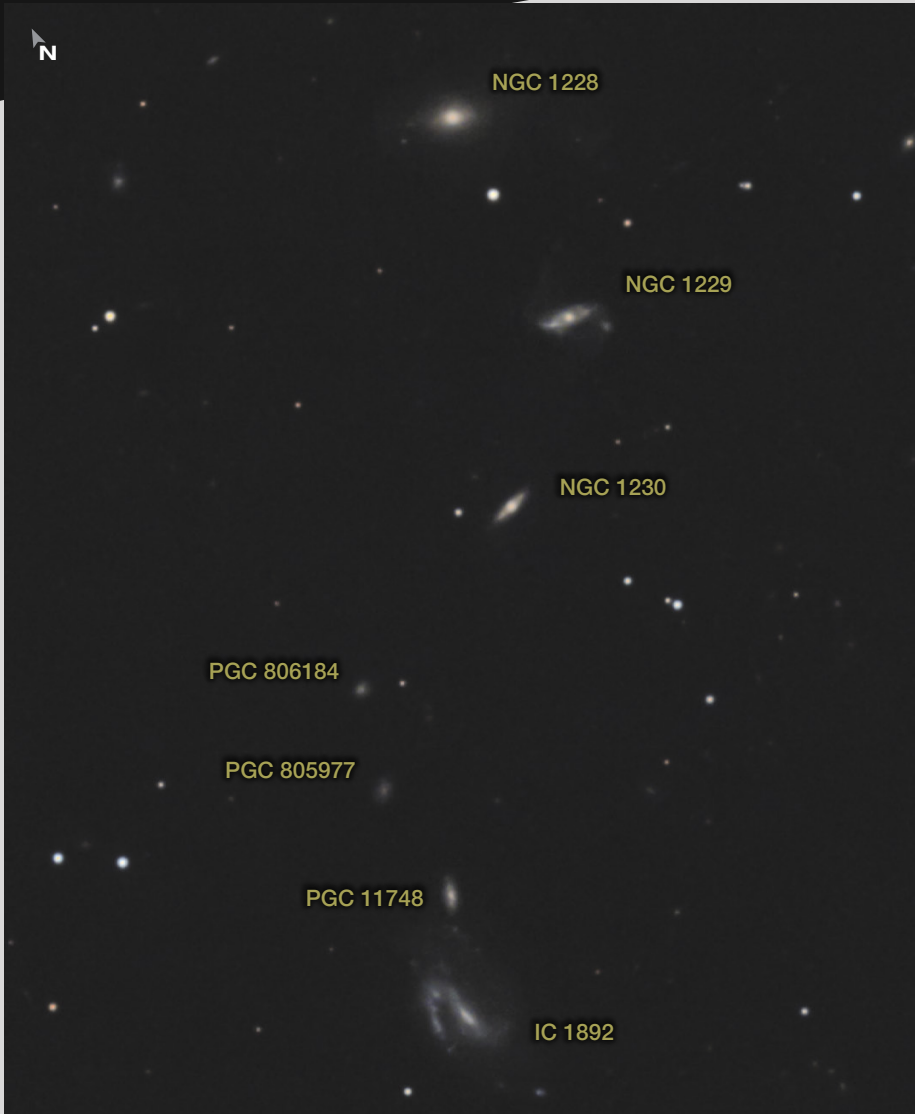
track the telescope. Nevertheless, I glimpsed five of them. PGC 1595431 and PGC 1595534 were continuously visible with averted vision, whereas I only saw PGC 1595531 intermittently. PGC 1595614 and PGC 1595409 were very difficult and offered only infrequent glimpses. You might have better luck.

A mere 20' north-northeast of the core of the beautiful 9.1-magnitude galaxy NGC 247 in Cetus lies a chain of five faint galaxies. Named the **Burbidge Chain** (after a 1963 article by Margaret Burbidge, Geoffrey Burbidge, and Fred Hoyle), it was however discovered earlier on a Lick Observatory plate. Famous as it is, this is a formi-



FAINT AND FAINTER

The author sketched the NGC 1044 chain while viewing it with his 28-inch at 291 $\times$. NGC 1044 at magnitude 13.2 (center) is slightly brighter than NGC 1046 (lower left), which glows at magnitude 13.8. PGC 10176 (right) and PGC 3080165 are quite a bit dimmer, but locating the brighter galaxies should help you snag them.



Chain Links

Chain	Brightest Galaxy	Mag	Size	RA	Dec.
Pisces	NGC 383	12.4	1.4' × 1.4'	01 ^h 07.4 ^m	+32° 25'
Grus	IC 1459	10.0	5.2' × 3.8'	22 ^h 57.2 ^m	−36° 28'
—	NGC 1044	13.2	0.6' × 0.6'	02 ^h 41.1 ^m	+08° 44'
—	IC 1348	14.3	0.8' × 0.6'	21 ^h 01.7 ^m	−13° 21'
Arp 332	IC 1892	13.2	1.9' × 1.0'	03 ^h 08.5 ^m	−23° 03'
—	PGC 1595534	15.2	0.7' × 0.3'	01 ^h 20.8 ^m	+19° 31'
Burbidge	PGC 2791	13.6	1.0' × 0.4'	00 ^h 47.6 ^m	−20° 26'
Arp 325	PGC 68034	15.7	0.2' × 0.1'	22 ^h 06.3 ^m	−21° 04'
Shakhbazian 38	Shk 38-1	16.5	0.1' × 0.1'	01 ^h 10.9 ^m	+08° 19'

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 and are of the brightest galaxy in the chain.

◀ **ECLECTIC COLLECTION** Arp 332 in Eridanus comprises a fun selection of different types of galaxies. You should be able to spot the NGC and IC galaxies with relative ease (provided you have large aperture), but it might take a bit of coaxing to reveal the PGC galaxies.

dable visual target. Using my 18-inch under dark skies in central Texas, I picked out 13.6-magnitude PGC 2791 and PGC 2796 without much difficulty, while PGC 2794 took lots of effort. It was only with my 28-inch at 291× that I was able to pull out PGC 2798, though I failed in my quest for PGC 842319.

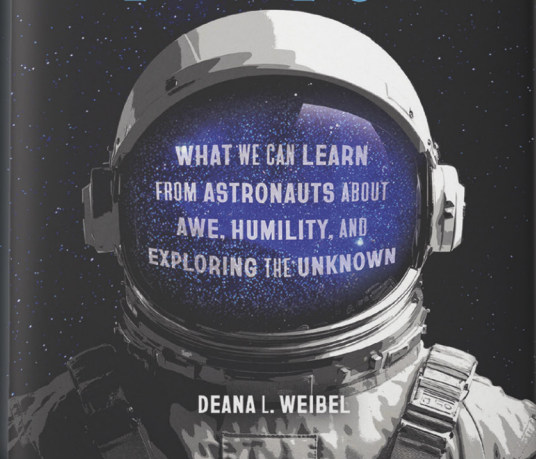
Arp 325 is a faint and dense chain of five objects in southwestern Aquarius, about 55' east-southeast of the 11th-magnitude galaxy NGC 7184. In my 18-inch at 345× under a very dark sky in the Warner Mountains of northeastern California, the whole chain looked like an elongated, extremely faint edge-on galaxy. Two cores would flash in occasionally giving it a mottled appearance. Employing my 28-inch at 291×, the chain appeared as a fuzzy filament with averted vision, with occasional sensations of mottling. Tacking on 486× I was able to isolate the two brightest galaxies, PGC 68034 and PGC 68036, forming a nearly isosceles triangle with a star. Not satisfied, I invoked the phone-a-friend lifeline. Jimi Lowrey’s 48-inch made easy work of the entire chain at 610×, resolving all five galaxies and also revealing a sixth off-chain galaxy (PGC 832857).

If you made it this far, congratulations! You’re ready for **Shakhbazian 38** and its grouping of five galaxies. Find the chain 1° northwest of 5.2-magnitude Zeta (ζ) Piscium. I expect it to be accessible in my 28-inch, but I’ve only observed it with Lowrey’s leviathan at 610×. I resolved four components in moments of good seeing, but otherwise the collection appeared as one clumpy elongated mush! Do let us know if you manage to snag this chain.

■ **AKARSH SIMHA** is eternally grateful to Randy Pufahl and Mark Wagner for enabling him to realize his dream telescope. The aperture upgrade has once again left him running to dark skies at the slightest opportunity like his teenage self.

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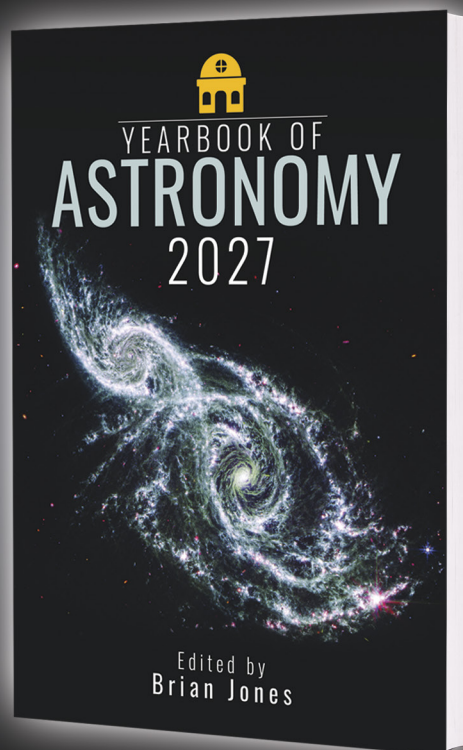
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The annual appearance of the *Yearbook of Astronomy* has been eagerly anticipated by astronomers ever since this invaluable book first appeared in 1962. Maintaining its appealing style and presentation, the *Yearbook of Astronomy 2027* contains comprehensive jargon-free monthly sky notes and charts to enable astronomers everywhere to plan their viewing of the year's eclipses, comets, meteor showers and minor planets as well as detailing the phases and so on of the Moon and visibility and locations of the major planets throughout the year. To supplement all this are 25 entertaining and informative articles on a wide range of topics, including Lithium; Gravitational Lensing; The Mythical Vulcan; The Vera Rubin Observatory; The Astronomers' Stars: Across the Spectrum; Mars Attacks! How the Red Planet Affects Earth's Climate; What's the Matter? It's Dark Down Boulby Mine; A History of Observatory Designs: The Modern Era; The Unluckiest Astronomer Who Ever Lived; and The Flight Log of Exoplanet Explorer 9: The First Landing on an Exoplanet.

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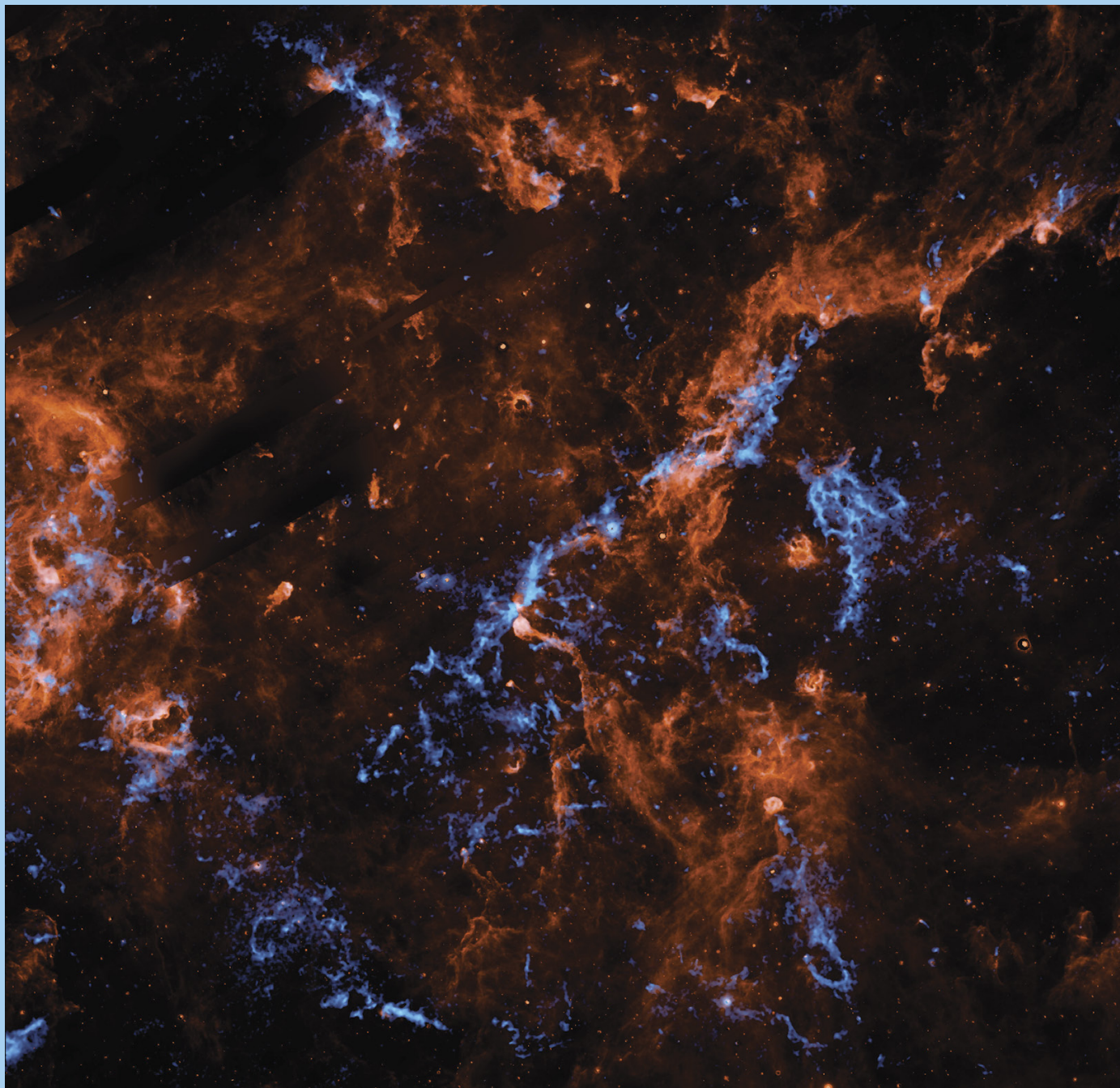
Interstellar ices host chemical reactions that make molecules necessary for life.
Is the secret of life embedded in ice?

You can glide on it wearing skates, plunk cubes of it in your drink, or slip and fall on it if you're not careful. But the substance we know on Earth as ice is only one form ice can take.

Out there, in the frigid spaces between the stars, ice looks far different. Scientists have found more than 20 distinct structures for frozen water so far. (The crystal structure found in your ice cubes is called Ice Ih.) In the coldest conditions, around 10° above absolute zero, water's molecules

▲► **INTERSTELLAR ICE** The infrared image above shows material in the star-forming region Cygnus X, at wavelengths that highlight the region's dust lanes. The image on the facing page shows the same patch of sky but at different infrared wavelengths that reveal water ice (blue) and hydrocarbon molecules (orange). The densest regions of ice coincide with the densest regions of dust. The dust shields the ice from intense ultraviolet radiation emitted by newborn stars. Both images come from NASA's Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer (SPHEREX) and are part of its work mapping interstellar ices in giant molecular clouds.

NASA / JPL/CALTECH / IPAC / HORA ET AL. (2);
FROZEN TEXTURE: ALANVEC / SHUTTERSTOCK.COM



don't form that stable lattice, because the extremely low temperature and pressure can't push water into any type of consistently recognizable crystalline form. Scientists call it *amorphous solid water* instead.

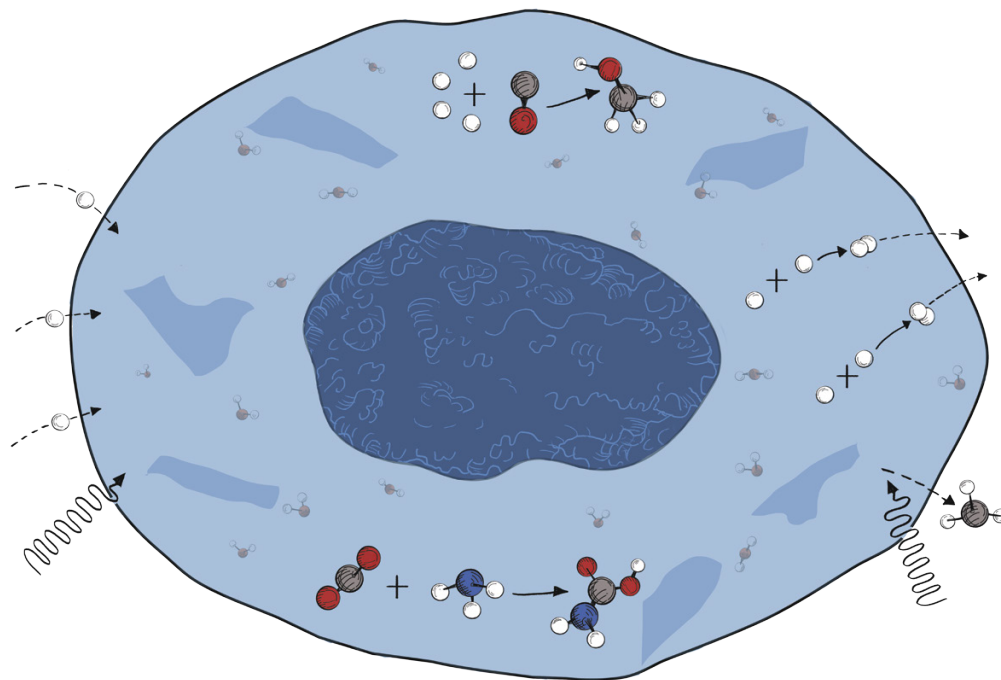
And although water is the predominant molecule that makes up interstellar ice, it isn't the only ice in the *interstellar medium* (ISM). Interstellar ices are made of varying proportions of molecules like water, carbon monoxide, carbon dioxide, and ammonia. These molecules, all with fewer than six atoms, are known as the simple ices. You wouldn't want to put those in your beverage glass.

But, as it turns out, you might want to produce some chemistry with them.

Stars and planets inherit their material from the cold, dense clouds of gas that collapse to make them. But scientists don't know how "chemically advanced" this material is. Is it just small molecules, like water and carbon dioxide? Or could the clouds foster the development of larger *organic* (that is, carbon- and hydrogen-bearing) molecules, long before planets exist to host them?

At first glance, the answer should be no. Chemistry on Earth needs energy, especially for the kinds of reactions that

► **ICY FACTORY** All sorts of reactions can occur in the icy mantle around an interstellar dust grain. Molecular ingredients arrive, react in various ways, and then either stay or leave and return to the interstellar medium. Incoming radiation sometimes provides energy for transformations and reactions.



form organic molecules like the ones essential to life. And these clouds are *cold*. “How do you form complex organic molecules at 10 kelvin?” asks Karin Öberg (Center for Astrophysics, Harvard & Smithsonian). “That seems like it should be impossible. If we try to do organic chemistry here on Earth [at] 10 kelvin, nothing happens.”

Interstellar ices appear to be one solution. Surrounding tiny grains of silicon-rich dust in cold, dark clouds of gas, ices form thin mantles that typically contain 100 or so layers of single atoms, where the universe’s tiniest building blocks can land. There, these simple atoms and molecules “meet, greet, and accrete,” as astrochemists like to say, reacting to become larger chemical species.

The reactive properties of the raw materials in these interstellar clouds enable this cold chemistry. Some of the particles, such as charged ions and radicals formed by ultraviolet radiation, are so unstable that they need little or no energy to form new molecules with neighbors nestled near them on the ice. Astrochemists are discovering that those icy meet-cutes yield molecules that might survive all the way through cloud collapse to star and planet formation. The encounters might even enable the creation of larger organic molecules like the ones we see in amino acids and the products of the cellular respiration cycle universal to all life forms on Earth.

This is the story of interstellar ice: the unassuming frozen substance that might be more critical for the development of stars, planetary systems, and perhaps even life than we’ve ever imagined.

Ice Detectives

Astrochemists use a combination of techniques to determine the various mixtures of ice in the ISM. That “ice inventory” provides clues about the molecules that could be synthesized on (and perhaps even within) the ice. The pro-

cess includes three areas of research: observations, theory, and laboratory experiments.

“We use telescopes to make observations, and then we try to explain those observations using models,” explains Ilsa Cooke (University of British Columbia, Canada). “The models allow for different chemical and physical processes under conditions that might be present in space: really low temperatures and low pressures. In the lab, we can determine whether that process can happen and measure how fast that process might happen at low temperatures.”

An imposing, silvery contraption chock-full of metal tubes jutting out at all angles sits on a table in Cooke’s Vancouver lab, lurking behind astrochemists analyzing data on their laptops. This ultra-high vacuum chamber can mimic extreme conditions found in the ISM. Inside it lies a small surface cold enough that scientists can create analogs of interstellar ices, mixing various molecules such as water, carbon monoxide, methane, and other chemical species at temperatures as low as 10K.

Spectrometers that capture photons from many parts of the electromagnetic spectrum measure the wavelengths of light absorbed by each ice mixture. Researchers use experimental absorption spectra like these to help identify ices observed in interstellar space. Additional instruments measure chemical species that are actively leaving the solid ice’s surface by moving into the gas phase, a process called *desorption*. In cold interstellar clouds, desorption happens when a source of energy, like an ultraviolet photon, hits a dust grain, providing the energy for an ice molecule on the grain to escape as a gas.

Finding ices and complex molecules inside clouds is one part of the equation, but understanding how the molecules form on ice in the first place is another. Gas molecules like hydrogen can float around in the ISM and bump into other

atoms to create some simple reactions. But the sheer number of complex molecules being found on interstellar ice means that something more than gas chemistry must be at work.

Cooke's team, along with collaborators from Hokkaido University in Japan, is one of various groups of astrochemists around the world using vacuum chambers like this one to examine things like how certain types of highly reactive chemical species diffuse through the icy mantle of a dust grain to find other particles to react with.

"We know that the abundance of certain molecules [in the ISM] cannot be explained from gas phase reactions alone," says Carina Hobbs, a graduate student in Cooke's lab. "The reason we study ices is because they're these major happening places in these regions."

What's Life Got to Do with It?

The search for interstellar sources of "biorelevant" molecules — things that are essential for life on Earth — gained traction in 2009 with the identification of glycine, the simplest amino acid, in samples from the comet Wild 2. Scientists have since found glycine in other solar system sources, including the carbonaceous asteroids 101955 Bennu and 162173 Ryugu and Comet 67P/Churyumov-Gerasimenko.

The discovery of glycine in material from primitive solar system bodies brings up tantalizing questions. When did it form? Could it predate the solar system? Did it form on an icy

Cheers

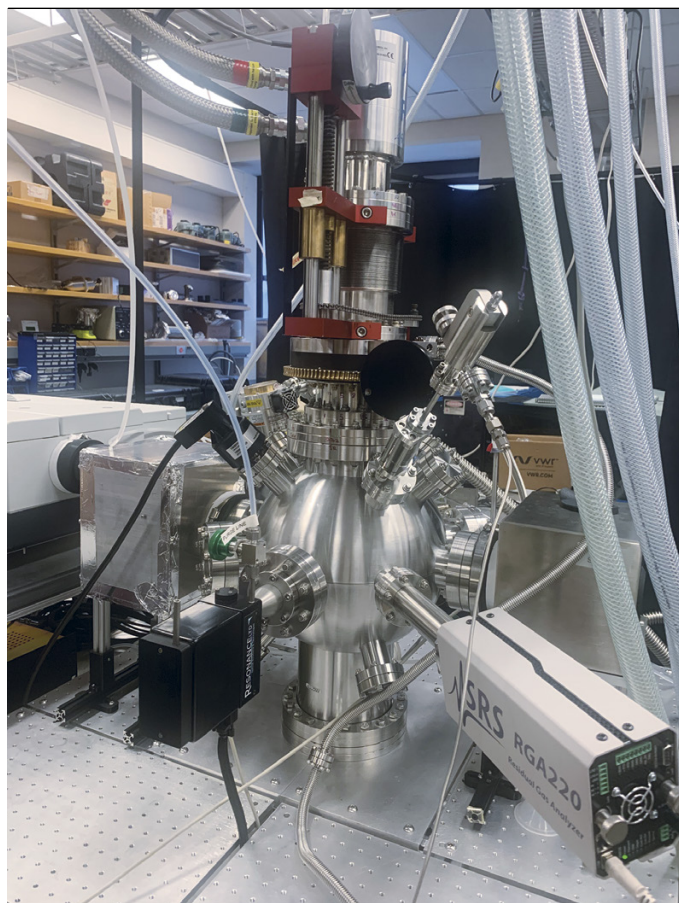
The crystal structure found in your ice cubes is called Ice Ih. The "h" stands for "hexagonal" — one of the lattice forms that frozen ice can take. Scientists have identified more than 20 different forms for ice, including a cubic one they think floats in Earth's atmosphere and another called Ice VII embedded in diamonds formed deep inside Earth's mantle.



mantle in the cloud that spawned the Sun? Studies published in 2023 suggest some answers.

Among them, an investigation by Joshua Marks (University of Hawai'i, Mānoa) and others demonstrated that an amino acid precursor known as carbamic acid (H_2NCOOH) could plausibly form within interstellar ice at temperatures down to 62K, in the very earliest stages of a gas cloud beginning to coalesce into a protostellar system. Carbamic acid is a *complex organic molecule*, or COM, an organic molecule with at least one carbon atom and at least six total atoms. The acid is the simplest molecule that contains all of the necessary elements to form all amino acids: an amino group (H_2N) and a carboxylic acid group (COOH).

The scientists also observed the acid in laboratory experi-



◀▶ **INTO THE VOID** *Left:* About the size of a person's head, the ultra-high vacuum chamber (sphere at center) in the University of British Columbia's lab is where scientists create interstellar-like conditions to study various ices. *Right:* Graduate student Carina Hobbs looks into a different vacuum chamber at Hokkaido University in Japan. The image of her eye is reflecting off the metal surface that researchers cool to interstellar temperatures and on which ice of different kinds will form.



▲ **COMET SAMPLES** The Stardust mission's principal investigator, Donald Brownlee, holds up Vs for victory to celebrate the successful arrival of material from Comet Wild 2.

ments up to a temperature of 290K, similar to that of a protoplanetary disk, which suggests that it could survive the star- and planet-formation process, too.

A separate research team led by scientists in Spain found evidence of a glycine *isomer* (a molecule with all of the atoms that make up glycine, but in a different structure) floating as gas in the molecular cloud G+0.693–0.027, located near the center of the Milky Way. The isomer's existence suggests that glycine could also plausibly be synthesized in ISM conditions. Scientists have already figured out a potential chemical pathway in laboratory experiments. Whether it happens in space — either in the gas or solid phase or both — is still a mystery.

A more recent lab study found chemical pathways in interstellar ice analogs that could create *nitriles*, molecules with a carbon atom attached to nitrogen that can form nucleobases, the building blocks of DNA.

In addition to amino acids and nitriles, astrochemists are looking at another set of critical biorelevant molecules: those involved in the citric acid cycle (also called the Krebs cycle). The citric acid cycle is an eight-step process that transforms partially digested glucose (simple sugar) molecules into important energy-producing molecules including adenosine triphosphate (ATP), a key source of cellular energy. Researchers have found citric-acid-cycle intermediates on Ryugu, as well as in the Murchison meteorite. Bennu and Ryugu samples also contain all five of the nucleobases that form DNA and RNA.

A 2025 study demonstrated that the chemical reactions necessary to form all of the intermediate molecules of the citric acid cycle could plausibly occur in interstellar ice exposed to ionizing radiation. Whether those molecules could survive in that form all the way to comet, asteroid, and planet formation is a question that will require far more sensitive instruments than we currently have available to us.

A New Ice Age

Nevertheless, current ice studies using the exquisite sensitivity provided by JWST are helping us understand more about carbon chemistry at all stages of a star's life cycle, including whether ices themselves protect carbonaceous compounds on their journey from the clouds of the ISM to mature star and planet systems.

The JWST Ice Age project, proposed in 2017 and commenced after JWST's delayed launch in 2021, has already produced more than a dozen academic papers, reporting on a range of experiments involving interstellar ice. Scientists are building full "inventories" of ices in molecular clouds, detecting COMs by studying the wavelengths of light absorbed by them, and studying how interstellar ices encase key carbon-containing molecules that could form amino-acid building blocks in a later stage of stellar evolution.

"The central question we wanted to investigate was how the icy building blocks of planets evolve as they fall in [toward] their central stars and move into the planet-forming region of the [protoplanetary] disk," says Melissa McClure (Leiden University, The Netherlands), Ice Age's principal investigator.

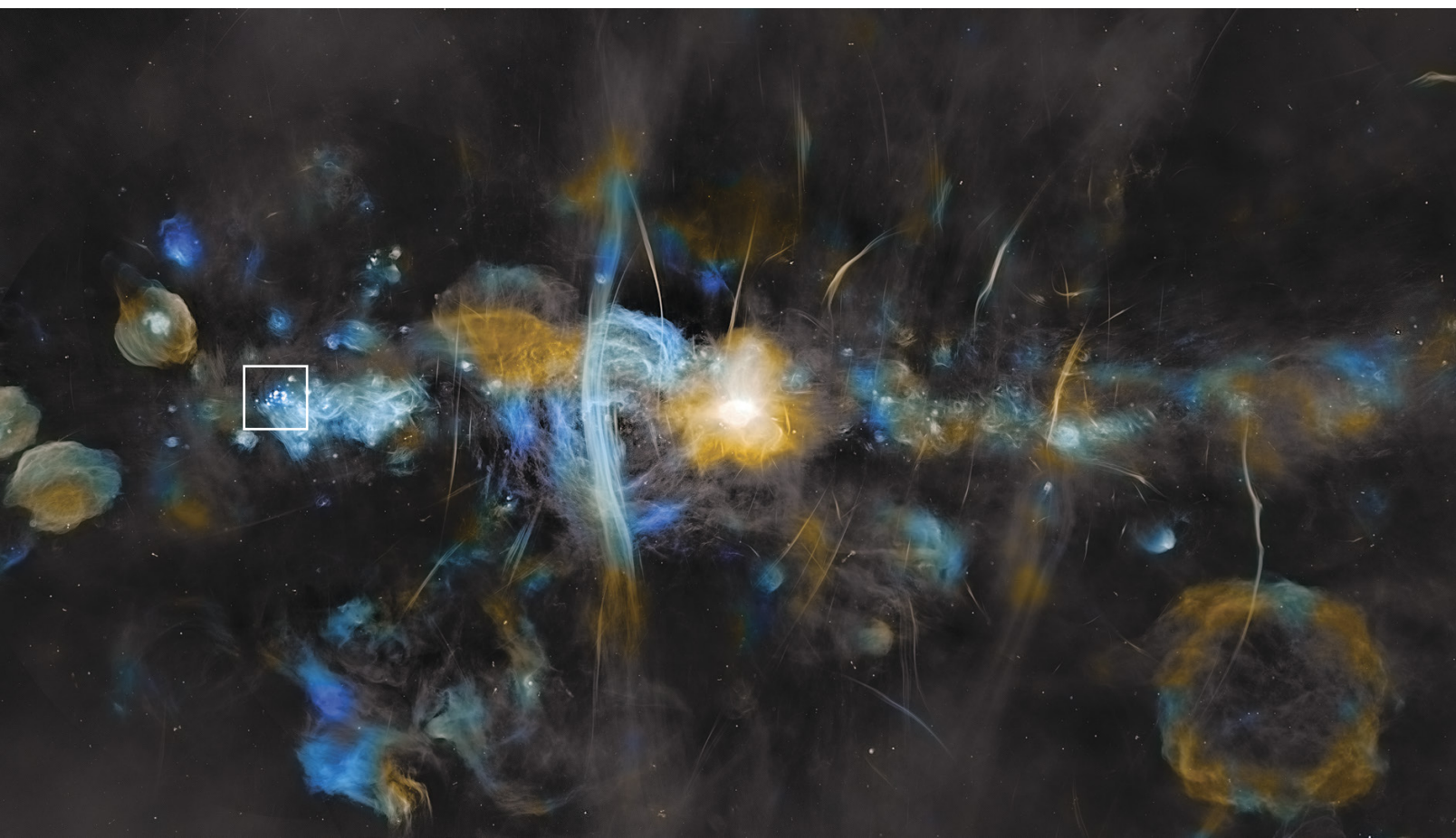
The implications could be enormous for our understanding of how primitive but biologically relevant chemical species emerge in cold, dark corners of space. On one hand, understanding where the bulk chemical building blocks are found in the earliest stages of star formation — such as in the dense, starless cloud of Chamaeleon I, one of Ice Age's targets — could help astrochemists determine how much of these early, simple species are present before such a cloud begins to collapse into a protostellar system. Molecules like water, carbon monoxide, and carbon dioxide carry elements including hydrogen, carbon, and oxygen — all of them critical for the formation of life.

But could COMs that originate in these clouds survive the process of infall? As a cloud of gas and dust collapses into a warmer, spinning disk that births a star and planets, could these COMs tag along for the ride — and maybe seed life on new worlds?

"We know that we see COMs in meteorites and expelled by comets," McClure explains. "But if the building blocks of those molecules grew to something like glycine in a molecular cloud, or even a comet, you could seed planets with some of the pre-cooked ingredients for life, and it would make it a lot easier to start life on another planet."

Ice Age data published in 2023 described the first observational measurements of the coldest and densest ices in a molecular cloud, illustrating the initial evolutionary state of ices before infall by looking in a portion of the cloud that the team expected to form biologically relevant molecules. The 2023 project also detected chemical signatures known as *functional groups* for COMs in these ices, such as the one for alcohols (OH) found in ethanol ($\text{CH}_3\text{CH}_2\text{OH}$). These findings had earlier been predicted by the team's chemical models.

"That suggested that COMs do form early in these clouds," McClure said.



▲ **GALACTIC CENTER** Astronomers have found a chemical look-alike of the amino acid glycine in the molecular cloud G+0.693–0.027 (boxed), which lies in the central parts of the Milky Way, shown here in radio. The discovery suggests that molecules relevant for life as we know it may receive a head start when forming thanks to icy coatings on interstellar dust grains.

From there, the team performed an analysis of major ice species found in the edge-on protoplanetary disk HH 48 NE. They found carbon monoxide ice trapped inside carbon dioxide and water ices. That carbon compounds can burrow into other ices — where they’re shielded from destruction by less volatile substances — suggests icy grains can carry substantial amounts of carbon deep into planet-forming disks. This transport could lead to more carbon-rich planets, which theoretically could be more hospitable to forming life (*S&T*: Dec. 2020, p. 34).

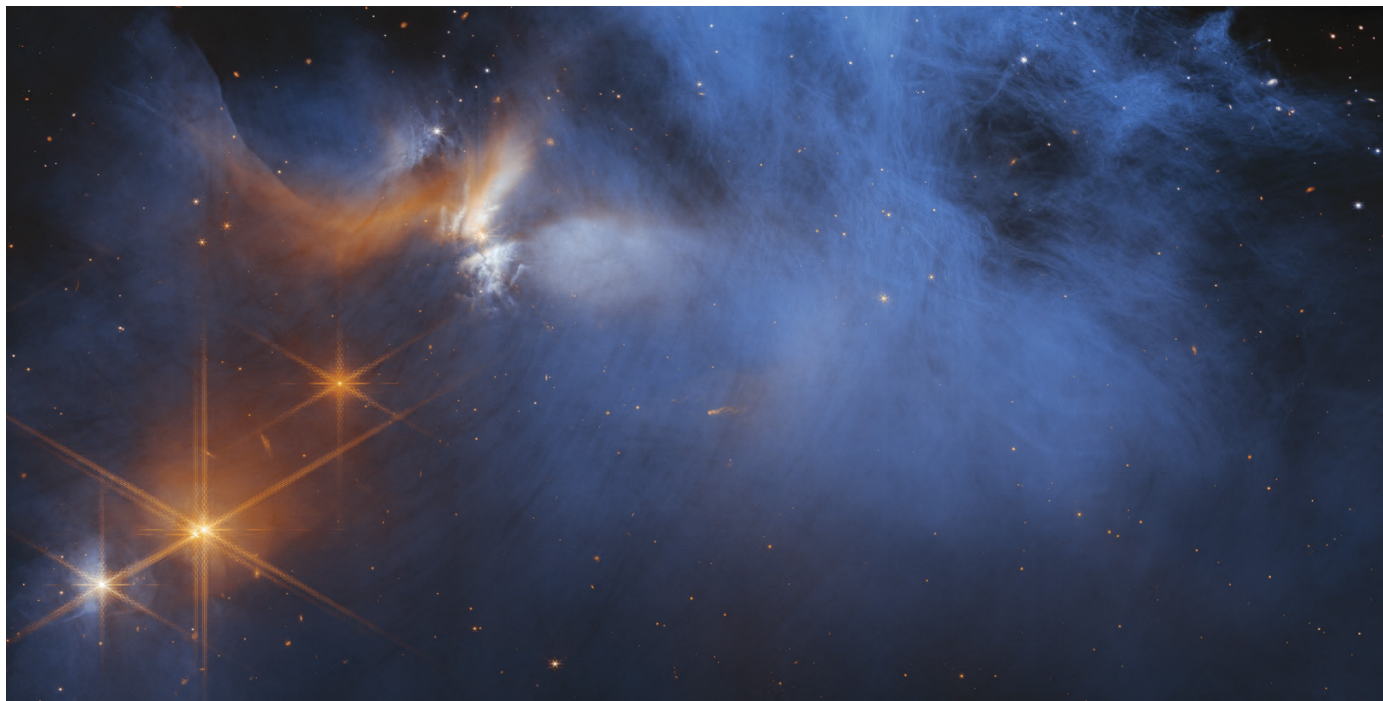
Ice Age studies in 2024 provided more chemical evidence for how icy mantles might encourage the survival of COMs during infall. One study showed that icy dust grains in the center of a molecular cloud were four times larger than dust grains found in the ISM. The built-up ice layers could provide a housing for COMs nestled within, protecting them from sublimation as the dust grains fall in and heat up during the formation of protoplanetary disks.

A second study that year found a feature called “dangling OH,” a portion of a water-ice molecule not connected to another water molecule. That finding confirms that clouds’ water ices either bind to other ices, as astrochemists have

observed in protoplanetary disks, or that the ice itself is porous, McClure explains. Pores could allow molecules to embed themselves in the ice, protecting them from heating up and sublimating during infall. “Both of those possibilities increase the likelihood that rare COM-rich ices like ethanol or glycine could survive infall onto the protoplanetary disk, where comets form,” McClure says.

An Ice Age follow-up project known as CHEERIO (for “Ice Astrochemistry at the Edge of a Star-Forming Cloud”) and so named in honor of the British researchers leading the project, will collect more detailed spectra from fainter regions at the edges of the molecular cloud Chamaeleon I than Ice Age scientists previously took. The new data will allow astrochemists to “really see how the ice is built up [in molecular clouds], all the way from bare grains to very thick ice mantles close to the center of these clouds, where stars will eventually form,” McClure says. That could lead to clues about when carbon-containing compounds ingratiate themselves into the ice structure.

Another JWST program headed by McClure, called Mapping Inclined Disk Astrochemical Signatures (MIDAS), is currently following up on the discovery of carbon monoxide



▲ **CHAMAELEON I** This near-infrared image from the James Webb Space Telescope shows the central region of the Chamaeleon I molecular cloud (blue) illuminated by an outflowing protostar (orange, upper left). Researchers target the cloud to study how icy grains facilitate molecules' buildup.

ice trapped in water and carbon dioxide ices. The project has already found something similar in another star-forming region, suggesting the movement of solid carbon by means of ices into protoplanetary disks could be universal.

An Icy Interstellar Visitor

JWST has also enabled astrochemists to examine ice from another planetary system, with the 2025 discovery of the interstellar comet 3I/ATLAS.

"To begin with, our solar system was packed full of all these small icy bodies that built up from interstellar ice particles," explains Martin Cordiner (NASA). "When we see an interstellar comet, it's really exciting to be able to ask which ices are in those objects, and what they can tell us about the ices in the environments that they came from."

Cordiner and his team used JWST data to examine infrared spectra coming from 3I/ATLAS's coma (S&T: Sept. 2026, p. 8). And what they found was truly surprising: The amount of carbon dioxide emanating from the comet's ice was, in Cordiner's words, "off the charts."

"[3I/ATLAS] is anything but normal" compared to known comets in our solar system, Cordiner says. "It's showing some really unusual properties. We don't know exactly how these objects get modified during this potentially billion-year passage, but it's reasonable to think that the interior composition is representative of where they came from. And so when we see that these objects are different to our own comets, that's super exciting as a cometary scientist."

Carbon monoxide and hydroxyl groups need radiation in order to react and form detectable amounts of carbon dioxide

on icy mantles. The abundance of carbon dioxide in 3I/ATLAS when compared to comets from our own solar system suggests that the comet's ices could have been exposed to higher levels of radiation than existed in our system's natal cloud. Or, the comet could have formed near its protoplanetary disk's carbon dioxide snow line, the location where the temperature was low enough for the molecule to freeze instead of existing as a gas.

"Interstellar visitors give us an idea [of] how similar or different that chemistry is in other solar systems," Öberg says. "Given the large amount of exoplanets, it is an interesting question. Are we chemically special or chemically normal?"

The Search Continues

When it comes to interstellar ice and life-supporting molecules, there is so much more to discover. Perhaps ice and dust grains interact in additional ways that we haven't yet imagined. Maybe amino acids really can be synthesized in supercold environments, before a protoplanetary disk forms. And perhaps other interstellar visitors will yield evidence of biorelevant molecules embedded in their icy cores.

"Who'd have thought that so much chemistry would happen inside ice at 10K?" Cordiner says. "Everything's frozen so solid, yet all these amazing molecules are being produced in there."

Far from a frigid curiosity, interstellar ice might just be what we can't live without.

■ **NICOLE BOECK** (née Nazzaro) is a biochemist and science writer based in the Seattle area.

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An Unfamiliar Moon

Our Moon is second only to the Sun as the most familiar object in the sky. So familiar that seeing it from a new perspective is a very special treat.

It wasn't until earlier this year during the Artemis II flyby that humans cast their unaided gaze at the Moon's entire western hemisphere. That's for several reasons: While it's true that Apollo astronauts orbited our satellite more than 300 times, their altitude on closest approach averaged some 111 kilometers (69 miles) to conserve fuel and facilitate landing. This is a perspective similar to the view visitors to the International Space Station have of Earth below — high and wide, but not high enough to see the entire world below. Additionally, NASA timed the Apollo missions so that the Sun was low in the Moon's *eastern* sky to highlight local lunar topography — Mare Orientale along the western limb was never seen in sunlight.

As Artemis flew by in early April, it passed at a distant 6,545 km from the lunar surface, which presented exceptional views of the western hemisphere that are only seen from Earth as a foreshortened sliver along the librated limb once in a while. This presented the first time in history that humans could see this hemisphere of the Moon as a *whole*, rather than a mosaic stitched from many low-orbit photos taken by robotic spacecraft.

The images snapped with telephoto lenses and DSLR cameras by the astronauts as they were directed by ground control have the look of pictures taken by most any backyard observer with a good camera and large telescope. They reveal chains of craters clearly tracing back to the Orientale impact basin as well as immense, displaced slabs of the lunar crust in the southwestern area that were shattered in that impact and appear frozen in time. The subtle colors revealed in the astronauts' snapshots of this side of the Moon are typical of images captured with backyard equipment. Even more alien to my eyes are the craters standing in stark relief at the sunrise terminator — completely new from an earthbound observer's point of view — making these pictures feel both wondrously strange yet familiar at the same time.

—SEAN WALKER





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NASA / Additional processing by Sean Walker

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What We Like

Sharp, color-free views
The big refractor experience
Excellent stars across
full-frame detector
(with optional field flattener)

What We Don't Like

Heavy OTA requires a big mount
No finderscope included

**Prices subject to change*

STELLARVUE HAS MADE premium refractors for the amateur market for nearly 30 years. Over that time the company has earned a reputation for producing high-quality, hand-figured instruments in their optical shop in Auburn, California, each of which includes detailed optical test reports that often become the fodder for bragging rights in online astronomy forums. Its latest and largest apochromatic refractor is the SVX180T-2. The scope comes at a premium price, but is it worth it? They loaned us one along with a field flattener so we could find out.

The SVX180T-2 (180T hereafter for brevity) is a *big* telescope. Its flat white finish is accented with black anodized trim on the dew shield and focuser. Fully collapsed, the scope is 44.25 inches (112.4 centimeters) long and 54 inches with the dew shield extended. A pair of hinged tube rings and a Losmandy-style dovetail mount-

ing bar are included, as well as an additional top plate (which serves as a carrying handle) that's tapped and slotted to accept various accessories such as guide scopes or a minicomputer. While the scope doesn't come with a finder, it does include a saddle that accepts standard quick-release finderscope brackets. The company's website advertises that the 180T comes with a threaded lens cap, but mine was a push-fit that snugly held it in place. The scope arrives in a heavy-duty case with wheels for easy transport. Also in the case was a Bahtinov focusing mask and a Stellarvue baseball cap.

The entire ensemble weighs in at 20.2 kg (44.5 pounds), so you'll need a sturdy, heavy-duty mount for it. Its tube is oversized by nearly a full inch with internal, knife-edge baffles to both aid with thermal stability and control off-axis reflections. I paired it with Software Bisque's Paramount MX+ and

Sky-Watcher's EQ8-Rh Pro German equatorial mounts.

Stellarmvue offers three focuser options with this scope: A Stellarmvue-made 3-inch focuser (included with purchase), a Feather Touch 3.5-inch focuser (\$1,020), or a MoonLite 3.5-inch NightCrawler focuser/rotator combo (\$2,300). My review unit came with the 3.5-inch Feather Touch, which I motorized with an Optec QuickSync FTX40 motor. Also provided was the optional SFFX-3 Field Flatteners (\$545), designed to correct up to a full-frame (24 × 36 mm) sensor.

The 7-inch objective is a hand-figured triplet made with two super-low dispersion elements and one of lanthanum glass. Its 1,260-mm focal length produces an f/7 focal ratio. Stellarmvue tests its objectives with a Zygo laser interferometer and provides the test results with each scope. And if that weren't enough, they also include a USB drive containing three videos showing the actual Ronchigrams for red, green, and blue wavelengths.

I'm often asked, "Did they cherry-pick the scope they sent you?" I can confidently say that yes, this scope was cherry-picked for me. In fact, they're *all* cherry-picked. According to Stellarmvue's founder, Vic Maris, every one of the objectives is hand-figured over a period of a year or more. The task takes so long because they can only be worked on for a few minutes a day, as the figuring process heats the glass. This also changes its shape and requires a cooling period before the last corrections are evaluated and the process can continue. This ultra-patient approach ensures that no optics leave the Stellarmvue shop until they've been figured as perfectly as possible.

Beneath the Firmament

My first task with any telescope I review is a star test with an eyepiece on a night of good seeing here in Florida.

► The SVX180T-2 ships in a heavy-duty hard case with wheels for easy transport. The scope comes with a Zygo optical test report as well as a Bahtinov focusing mask and a Stellarmvue baseball cap. Also shown is the optional SFFX-3 Field Flatteners (bottom right).



▲ The 7-inch triplet air-spaced objective consists of two super-low dispersion elements and lanthanum glass to produce color-free views both inside and outside of focus.

► The optional 3.5-inch rack-and-pinion Feather Touch focuser has 114.3 mm (4.5 inches) of travel and includes a 10:1 dual-speed knob and a quick-release finder bracket. Also shown is the visual back and 2-to-1¼-inch eyepiece adapter.



The atmosphere can sometimes be extremely steady in my area, so I've witnessed a few star tests with textbook-perfect Airy disks. There they were: an unusually fine set of closely spaced concentric rings, with more finely spaced rings than I'm used to seeing. I had to sanity-check my view with other experienced observers as I'd never seen this before. The intra- and extra-focal patterns were identical as well. This was a promising start.

For my deep-sky imaging tests with the provided SFFX-3 Field Flatteners, I used a Player One Zeus 455C Pro, which has a full-frame Sony IMX455 color sensor. Stars looked tight and round across the field. Zooming in to 400× on the screen showed some slight distortion in three of the corners, a sign my camera wasn't quite perfectly aligned with the optical path. A better test without futzing with the camera's tilt-correction screws is to use a DSLR or mirrorless





After a slight adjustment, stars were perfectly sharp and round from corner to corner when pairing the scope with the optional SFFX-3 Field Flatteners. This image of M13 taken through the scope consists of almost 200 minutes of exposure using a Player One Astronomy Zeus 455C Pro camera with a full-frame sensor.

camera, as the sensors in these tend to be more parallel to the camera body. Indeed this was the case, as the situation was reversed with only one corner showing some minor elongation. This is an excellent result without doing any additional fine-tuning of my imaging train — I only had to make sure that all my camera adapters were seated properly to correct the last bit out. After that, stars were tack-sharp across the entire field.

The 3.5-inch Feather Touch focuser provided with the test scope is a rack-and-pinion-driven system with four coarse and fine-focus knobs that were buttery smooth. A ring with three spokes permits loosening and rotating the focuser, then locking it into position. This was often helpful when framing images, as well as turning the focuser to a convenient position when slewing around the sky with the scope on an equatorial mount.



▲ A plate connecting the top of the machined tube rings is slotted to facilitate connecting additional accessories, including tube rings for a guide scope or other ride-along devices like a minicomputer.

I used this scope extensively for imaging the Moon and Jupiter with high-speed planetary video cameras as well as for deep-sky astrophotography. I was quite surprised by the difference in performance between this and my 6-inch f/7 apochromat, particularly when observing the Moon and planets. In fact, on most nights the 180T would show just as much planetary detail as a 14-inch SCT I had acquired for lunar imaging. While I'm not a frequent planetary imager, the pictures of Jupiter I took with the 180T were the best I've ever recorded myself, even with larger optics.

Where this scope really shines is with an eyepiece in the focuser. I brought the 180T to the annual Winter Star Party, where the *seeing* (atmospheric stability) is typically quite good, using the scope visually for at least half of the nights during the week-long event. The views of Jupiter were some of the best I've ever



▲ This image of the first-quarter Moon demonstrates the full 98" by 65" field of view of the scope at prime focus with a full-frame Canon EOS Ra mirrorless camera.

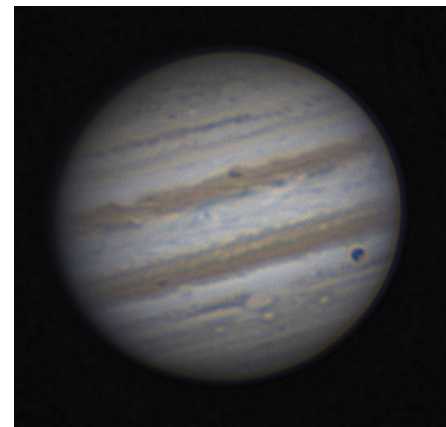
seen. Along with several other observers, I kept comparing the view through the 180T and a nearby high-quality 18-inch Dobsonian also trained on Jupiter at similar magnification. The images were more comparable than you might expect (remember, seeing was also quite good). There were small details in Jupiter's clouds (white storms and churning in the wake of the Great Red Spot) I'd see first in the big Dob and then identify in the refractor after I knew what I was looking for. The 18-inch offered more resolution and a brighter image as you'd expect, but the 7-inch wasn't much behind. On a night of a bit more turbulence, the views were pretty much identical. Seeing of course is the ultimate bottleneck for large-scope performance.

Moving away from solar system targets, I easily saw all six stars of the Trapezium in M42 and spotted nebulosity within the Pleiades star cluster, M45. (It was slight, and to be sure, I asked others if they saw it as well, each describing where in the field they saw it without coaching.) Omega Centauri, a Winter Star Party favorite for the early morning crowd in February, was powdery and fine like diamond dust. Brighter stars and other clusters snapped into focus with no color fringing. Position-

ing Sirius just out of the eyepiece field of view didn't impart any unwelcome glare or odd internal reflections.

On a really great night while observing the Moon, I had a 3.7-mm TeleVue Ethos in the 180T, producing 340×. It was spectacular and solid. As the seeing was extremely steady, I then added a 2× Powermate to the mix, yielding 681× and giving me the best views of the Moon I can recall through any telescope. The stability came and went of course, but for long moments it was like I was flying low over the lunar surface.

At this year's Grand Canyon Star Party in June, a friend brought his SVX180T-1. While not the review scope specifically (it's the previous generation), it is, however, representative of the family line. The seeing was not nearly as steady at the Grand Canyon as I often enjoy in Florida, but the performance of the sister scope was just as good under less than ideal seeing as the 180T-2. This brings up an important aspect of evaluating bigger scopes. Large apertures are more often defeated by seeing conditions, as smaller scopes can often perform better when the seeing is fair. Seven inches is a good compromise, in which you get the resolution boost from a fairly large aperture, but it isn't



▲ The scope's 180-mm aperture provides plenty of resolution to resolve small features on the planets. This image was captured at the Winter Star Party in the Florida Keys, with the 180T paired with a Player One Astronomy Neptune-C color video camera. Not only are several white ovals clearly resolved, but some albedo features are visible on the moon Ganymede as it transited the planet at right.

so large that you suffer as much when seeing isn't great.

Final Considerations

The SVX180T-2 is my favorite scope I've reviewed for multiple reasons. Out of the box, the scope yielded some of the best views of the Moon and planets, especially Jupiter, I've ever had when the sky conditions supported it. And I didn't need to spend multiple nights fiddling with camera-angle adjusters to take great deep-sky images with it. I've always had to do some tweaks to the corners of an image since the advent of small-pixel cameras, but the field here is well corrected to my satisfaction across a full-frame sensor.

Seven inches makes a large refractor, and this scope delivers views befitting of that title. You do have to be mindful that this is a fairly heavy telescope, which requires a mount rated for a load of 23 kg at least. Yes, the scope's premium performance comes at a premium price. But after spending time under a great sky with one, I feel those views are definitely worth it.

■ Contributing Editor RICHARD S. WRIGHT, JR. enjoys both visual astronomy as well as astrophotography.

Soup Up Your Commercial Scope

Here's a few hacks to enhance a mass-market Dobsonian.

FACTORY-MADE TELESCOPES are fine, really. I had a better time observing with a used, mass-produced 8-inch Dobsonian than my very first scope — a wonderful but wobbly 6-inch Newtonian I made from scratch. The 8-inch is a mass of decayed particleboard and steel that I bought for \$150. Though I maintain that the racing stripe I added really helped its look, there are more useful modifications than just paint. Oregon ATM and frequent contributor Lauren Wingert has handily outdone me with her own slew of mods — she's tweaked and tuned her Orion XT10i Intelliscope nearly beyond recognition.

A Newtonian is just a very special way to hold its two optics a prescribed

distance apart. It requires provisions for blocking stray light, for focusing, and for aiming. In this sense, a commercial Dobsonian is “finished.” Lauren argues, however, that such a scope — fresh from the factory — is unfinished in the operational sense. Knobs or aiming might be bad, or maybe it isn't properly protected against the elements. So her angle is, “How can I make this thing work better?”

Lauren's first fixes focus on finding. One of the main sources of wasted observing opportunity is the time spent hunting down a target. The XT10i features digital encoders — that is, it has an accurate sense of where it's pointing. But Lauren found the Intelliscope system a bit clunky to use in practice: It has too many menus, an awkward user interface, and so on. One of her rather involved tweaks was building a Bluetooth unit that connects the Intelliscope to a tablet, sidestepping the old hand controller with its green backlight. Now, she uses her tablet as the push-to interface via the popular planetarium app *SkySafari*. This makes finding objects “feel like a video game,” Lauren notes. Steer the scope while watching the app until the icon lands on an object, and that object will be waiting in the eyepiece.

Most commercial Dobs come with-out any push-to capability; my predecessor, Jerry Olton, and I have both

◀ The telescope's front end shows a slew of upgrades, including (from left) a Pinty rifle green laser, a 9×50 finder, and an 80-mm refractor/finder. Also shown is a tablet running *SkySafari* and a kitchen timer (white) to remind Lauren to press the scope's Orion Computerized Object Locator every so often to keep it awake. An angle gauge (red) helps to locate a target based on its altitude angle given in a planetarium app.

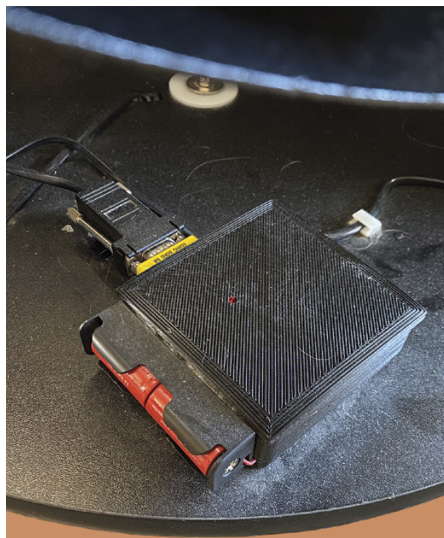


▲ Lauren Wingert's heavily modified Orion XT10i Intelliscope reflector. About a third of her modifications are visible here, including the two oversized finderscopes and the red welding magnetic holders as extra counterweights.

written about ways to add this feature to any telescope using the *SkySolve* program or the PiFinder electronic finderscope (*S&T*: May 2023, p. 70, and Aug. 2026, p. 76, respectively). But manually finding targets has its place, and Lauren's battery of upgrades is no slouch here. We both favor dual-finder setups — that is, a 1× finder in tandem with an optical finderscope. In my case, I prefer a Telrad-style reflex finder with a reticle pattern that shows different angular diameters. Lauren prefers pairing her finderscope with a green laser pointer, which she dimmed by sticking in a lower-voltage battery. (Beware that many lasers bought online come at unsafe, and often outright illegal, power outputs.)

On her XT10i, Lauren uses a 9×50 right-angle, correct-image finder, since its upright image matches the star charts. And under dark skies, this small refractor often shows a dim target clearly, facilitating fast finding. Lauren





▲ For Lauren, her most impactful change overall is the Bluetooth module that she built with a BT board, an Orion RS232 cable, a null modem, and other components bundled in a slick, 3D-printed housing. This lets her control the Dob's push-to using *SkySafari* on a tablet.



▲ Lauren's modified eyepiece rack features a flip-down lid to shield the eyepieces from dew. Also seen is a rubber mat to protect the scope's particleboard base from the damp ground and a small bag to safely stow knobs and fittings so they don't get lost in the dark.



▲ A section of a fishing vest is attached to the adjacent side of the Dobsonian's rocker box with Velcro. It serves as a handy collection of pockets for onboard storage of assorted observing gear such as eyepieces, headlamp, spare batteries, red flashlight filters, etc.

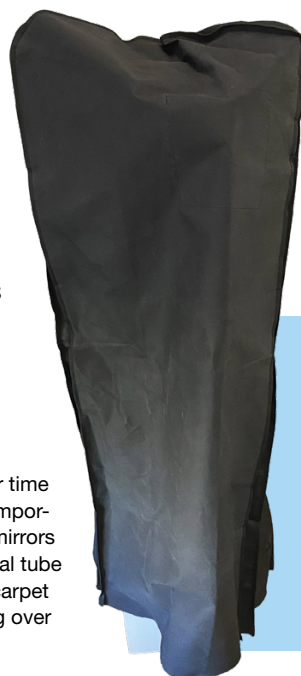
goes a step further: Adjacent to her 9×50 is a much larger 80-mm homemade refractor, operating not only as a large finder but also as a tandem observing instrument. It's nice to view objects at multiple scales (the Veil Nebula, the Andromeda Galaxy, and the Pleiades come to mind), and this setup allows it without even leaving one's seat. The refractor's weight does, however, require extra ballast near the telescope tube's mirror end.

Dew is a particular bugbear of mine — I often observe in Texas ranchlands, which are prone to heavy dewing. I fight it with electric heaters. One of the main drivers of dew is radiative cooling. The more your scope's objective, finder, eyepiece, etc. are exposed to the sky, the cooler your optics get, often dunking them just below the dew point. Typically, a long dew shield would suffice, and Lauren has made one for each finder and the main scope. Similarly, she added a flip-down lid to her eyepiece rack to keep them shielded from the sky. Lastly, when she's out observing, the scope sits on a rubbery gym mat she carved up to keep its particleboard base from soaking up dew straight from the grass.

There are dozens of other modifications. And I've already written about Lauren's experiments in *flocking* (applying light-stopping materials like black velvet to interior tube surfaces) in the December 2025 issue, page 74. This fix brought the biggest improvement in telescope views for her. She has a bag for knobs and other small parts so she no longer loses them in the grass. There's also an angle gauge for faster push-to, an aftermarket fan to speed up the cooling, welding magnetic holders repurposed as counterweights, and even a section of a fishing vest that serves as a collection of gear pockets for keeping things safe and organized.

Lauren's lesson is that stargazing snafus

► Dust is a problem on longer time scales than dew, but it's still important to manage. To keep her mirrors clean, Lauren stores the optical tube up on a wood block to keep carpet dust away, and a garment bag over the tube does the rest.



are fixable, whether it's one problem or 40. But not all fixes are equal (Lauren notes that the Bluetooth hack, flocking, and adding a comfy chair brought the biggest gains by a wide margin), and you really don't have to incorporate any of these fixes to enjoy your commercial Dobsonian. But each little fix buys you quality time at the eyepiece, or even an entire evening that would have been lost to dew or a dropped doodad.

■ Contributing Editor JONATHAN KISSNER is back at the drawing board, and he plans to incorporate many of Lauren's modifications to his next telescope project.

SHARE YOUR INNOVATION

Have a modified scope or another project, big or small, that seriously improved your stargazing? Send your ideas to workbench.kissner@gmail.com.



SPIRAL ENHANCEMENT

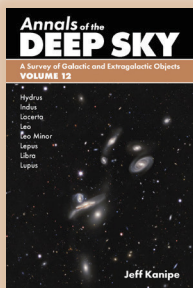
Julien Lecomte

Messier 33 in Triangulum is a face-on spiral galaxy residing approximately 2.7 million light-years away. This picture emphasizes the many pinkish star-forming regions in its spiral arms including the largest currently known, NGC 604, seen left of the galaxy's nucleus.

DETAILS: *Takahashi FSQ85 astrograph with ZWO ASI533MM Pro camera. Total exposure: 38 hours through color and narrowband filters.*

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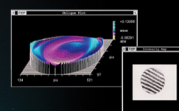


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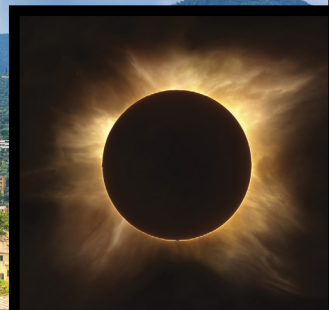
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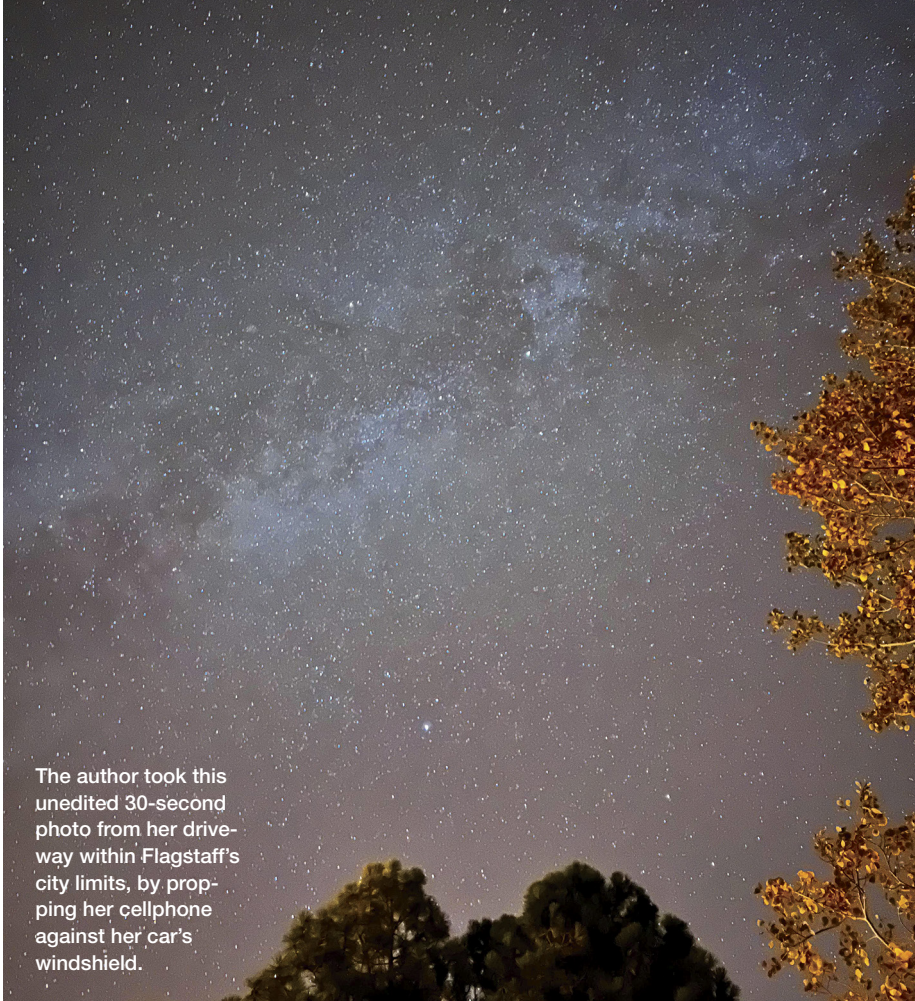
I REMEMBER THE SCENE VIVIDLY —

the two brilliant stars that mark the bottom of the Big Dipper's bowl lay just above the horizon and parallel to it, a sure sign that Halloween was near. On October evenings, I watched from my childhood home in rural New Jersey as the Big Dipper rotated downwards night after night until its bowl came to rest perfectly on my northern horizon.

This was how the Big Dipper accompanied me on our annual hayride and when I went trick-or-treating. This view of the Big Dipper was my Halloween companion, but unlike the Great Pumpkin that Linus waited for, it showed up on my New Jersey horizon every year without fail.

In observing the Big Dipper as Halloween approached each year, I had created a meaningful, personal connection to the night sky. Today, my view of this scene is just as star-filled, even though I now live in a city of more than 77,000 people. That's because my home is Flagstaff, Arizona, the city that in 1958 created the world's first ordinance to protect the night from artificial light.

As the anniversary celebrations for the United States and Route 66 wrap up this year, another big celebration is happening in Flagstaff. On June 14, 2001, the Flagstaff Dark Skies Coalition proposed the creation of the International Dark Sky City program — and on October 24, 2001, Flagstaff was officially recognized as the first such city in the world.



The author took this unedited 30-second photo from her driveway within Flagstaff's city limits, by propping her cellphone against her car's windshield.

Twenty-five years later, Flagstaff still leads the world in developing best practices for preserving our view of the night sky. By the time you read this, the city will have finished retrofitting nearly 4,000 streetlights, switching from low-pressure sodium bulbs to narrowband amber LEDs, the highest standard for minimizing artificial sky-glow from LEDs. Likewise, the Arizona Department of Transportation has just completed its own retrofit to amber LEDs for nearly 400 streetlights in the Flagstaff area, including those on interstate roadways — another first.

The results are stunning: I can still see the Milky Way with my own eyes from the city's downtown core. Buffalo Park, which lies near the city center and hosts the annual Flagstaff Star Party (this year it will take place October 1st through 3rd), has a median Sky Quality Meter reading of 20.6 — enough to reveal some 2,800 stars and a well-defined Milky Way on a moonless night.

Flagstaff today stands as a model for other cities, demonstrating through

empirical data that a city can safely illuminate the ground and grow economically without sacrificing an inspiring view of the cosmos. Even in a city as large as Phoenix (population 5 million), the application of Flagstaff's solution to light pollution would restore a thousand stars to its sky — and the Milky Way — all while improving health and quality of life. As more and more cities lose their stars in the transition to white LEDs, it's time for us to reverse the clock on light pollution. Flagstaff's real-world example proves that we can bring star-filled skies back to our cities.

After Flagstaff's 25th anniversary celebration has concluded on October 24th, I will keep watching the sky as the Big Dipper settles into its Halloween position once again. Thank you for this inspiring view, Flagstaff — and happy anniversary!

■ **DANIELLE ADAMS** is a cultural astronomer and the executive director of the Flagstaff Dark Skies Coalition.

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