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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

SEPTEMBER 2024

The Secret Lives of Comets

Page 12

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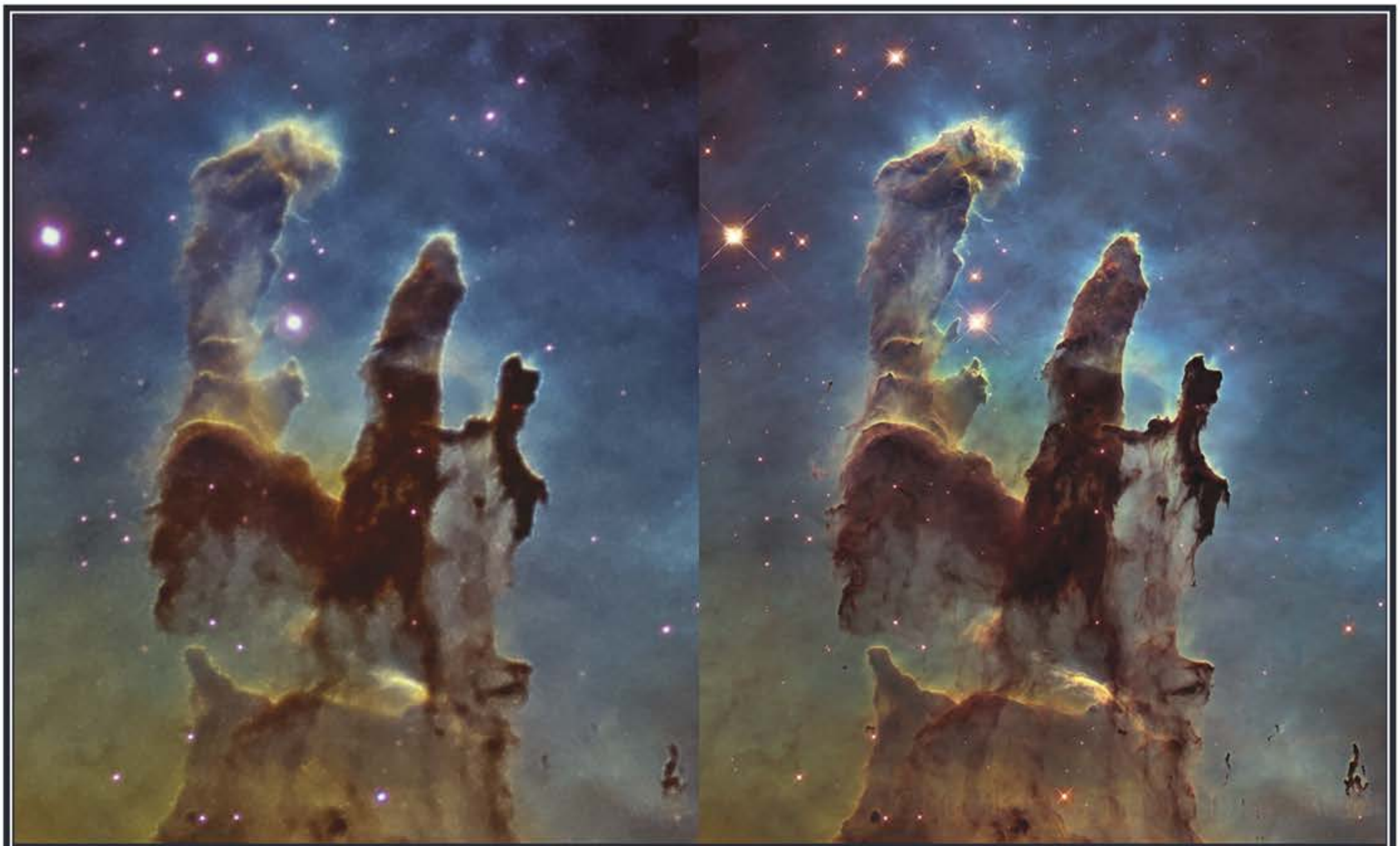

The image on the right is the famous Pillars of Creation (M16) taken with the Wide Field Planetary Camera of the Hubble Space Telescope. The image on the left is taken with a QHY600M-PH Camera through a 7-inch refractor from the author's backyard in Buenos Aires. Courtesy Ignacio Diaz Bobillo. To see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

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ON THE COVER

Comet Leonard changes during its 2021–22 apparition.
PHOTO: GERALD RHEMANN

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Lasting Impressions

COMETS REALLY MAKE you ponder the concept of longevity. Take Comet Tsuchinshan-ATLAS, the focus of our cover story this month. Also known as C/2023 A3, this comet formed, along with the Sun and planets, around 4.6 billion years ago. It has lingered ever since in the distant Oort Cloud, which encapsulates our solar system. Even by astronomical standards, it's been around for quite a while.

Yet, considered from our human perspective, Comet Tsuchinshan-ATLAS's life might be rather brief. We only discovered it in January of last year, and it's possible that it could disintegrate during this month's perihelion, when it makes its first and perhaps only approach to the Sun.

As Arwen Rimmer writes in her article on page 12, "Once a comet starts its journey toward the inner solar system, its days are numbered." In all of those 4.6 billion years, C/2023 A3 has never passed near our star, and we have no idea how it will respond. As other comets before it, it might go *poof* at perihelion, disappointing observers. If that happens, then for us this new comet will effectively have "lived" for less than two years.

▲ Comets Leonard (C/2021 A1, on the cover) and NEOWISE (C/2020 F3, above) dazzled us in recent years. Will C/2023 A3 do the same in 2024?

On the other hand, after it passes the Sun late this month, Comet Tsuchinshan-ATLAS might last into a truly venerable old age. If it survives perihelion, it will either remain within the solar system, journeying for more than 80,000 years before nearing the Sun again, or it will be flung into interstellar space. If that happens, it might "live" essentially forever — that is, until it slams into another object or comes near enough to another star that it crumbles into dust.

This paradoxical quality of comets — should we consider them short- or long-lived? — adds to their allure. Hopefully, Comet Tsuchinshan-ATLAS will be long-lived from our viewpoint. If it survives grazing the Sun on September 27th, it will make its nearest passage to Earth 15 days later, on October 12th. If all goes well, it could put on quite a show.

Alas, all tenures, whether of comets or editors, must come to an end at some point, and I plan to retire this fall. My 10th anniversary as editor in chief of *S&T* falls on the 29th of this month — the very day, as Bob King notes on page 48, Comet Tsuchinshan-ATLAS will be at its highest in the morning sky for observers at mid-northern latitudes. It feels like an auspicious time to pass the reins to the next editor in chief. (See the posting for my position at **skyandtelescope.org/about/job-opportunities**.)

As it's been for C/2023 A3, it's been one helluva ride for me. I'll share more thoughts on that in a coming issue.

Peter

Editor in Chief

SEAN WALKER

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The Essential Guide to Astronomy

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

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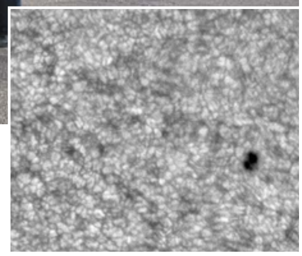
Capturing Solar Granules

In "Observing Solar Granulation" (*S&T:* May 2024, p. 52), Thomas A. Dobbins reminds us of the pioneering photographic work of Jules Janssen. It's often overlooked, however, that the first photograph of solar granulation was recorded by Lewis M. Rutherfurd using a 13-inch refractor on August 11, 1871, as he later reported in the *Monthly Notices of the Royal Astronomical Society* (**https://is.gd/Rutherfurd1871**).

To confirm Rutherfurd's claim, solar physicist John W. Harvey suggested that we reenact Rutherfurd's observation by mounting his original 13-inch refractor in a beam of sunlight at Kitt Peak's McMath-Pierce telescope. The reenactment was entirely successful, and from our examination of Rutherfurd's original plate that has survived with the refractor, as well as of scans of two copy plates that Rutherfurd sent to the Royal Astronomical Society in 1878, it's clear that Rutherfurd was indeed successful in 1871. We reported our results, with coauthor Sian Prosser of the Royal Astronomical Society, at the 2017 meeting of the Solar Physics Division of the American Astronomical Society.

John W. Briggs • Magdalena, New Mexico



▲▶ John W. Harvey and John W. Briggs used Lewis Rutherfurd's refractor to create a replica of the first photograph of solar granulation.

JOHN W. BRIGGS

Every Which Way

In the May From Our Readers, Monica Young replied to Walter Prendergast's question in "Outta Sight" (*S&T:* May 2024, p. 6) about "Dark Energy: A Brief History" by Elizabeth Fernandez (*S&T:* Feb. 2024, p. 26). Her response confuses me. If "we can look in any direction and see the galaxies speeding away from us," doesn't that place us at the point of origin for their motion? It seems to me that our galaxy is probably moving in the same direction as some galaxies and in an opposite or other direction than other galaxies. Those galaxies moving in the same direction as us would appear to move more slowly away from us than those galaxies travelling in some other direction. This being said, if we study all this galactic motion can we not extrapolate where all this movement began?

Bill Edwards
Toms River, New Jersey

Monica Young replies: *Think of it this way: Imagine you have a balloon, and you draw points on it with a marker. Now, you blow the balloon up. From any one point, all the other points will appear to be moving away from it. In fact, none of the points are moving at all, it's just that the space between them is expanding. This is what is happening in our universe.*

You're right that there are some nearby galaxies moving toward us — the Andromeda Galaxy will collide with the Milky Way in a few billion years, for example. But that's due to the actual motions of the galaxies. If we look farther afield, we see that indeed every galaxy appears to be moving away from us due to the expansion of space, rather than from any motion of their own.

You might also find this article relevant: **https://is.gd/CenterofUniverse**

Local Black Holes

I thoroughly enjoyed Fabio Pacucci's "Distant Lights in the Darkness" (*S&T:* May 2024, p. 20). It read like a playful storybook but was packed with news about what the James Webb Space Telescope is finding and how it jibes with current cosmological theories. I'm hoping we'll see more of Pacucci's work in future issues. One question I came up with is, what about nearby black holes? Has JWST discovered any small black holes in the Milky Way Galaxy?

Tom Kellogg
Aptos, California

Fabio Pacucci replies: *Tom Kellogg's question is an important one: There are probably about 100 million stellar-mass black holes in the Milky Way, and possibly a few intermediate-mass black holes. We know for sure there is at least one supermassive black hole (Sgr A*). So how come JWST is discovering so many supermassive black holes (SMBHs) in the distant universe, but we never hear about it discovering smaller, local black holes?*

It's because JWST is an infrared telescope and thus particularly suited for discovering very distant, very massive black holes. Stellar-mass black holes emit radiation only when they are close to a companion star and can accrete gas. These objects are named X-ray binaries, because they are particularly bright in X-rays, but not so much in the infrared. They may emit some infrared light, but they appear similar to many other stars in the lower energy range of the electromagnetic spectrum.

JWST detects SMBHs in the faraway universe by observing enormous quantities of gas swirling around the black hole, at velocities of a few thousand kilometers per second. The gas around smaller, stellar-mass black holes in the Milky Way does not move at such vast speeds.

Other instruments can find black holes in the Milky Way, however. For example, astronomers recently discovered Gaia BH3, a 33-solar-mass black hole roughly 2,000 light-years from Earth. They did this by studying the velocity of nearby stars in the Milky Way with Gaia: **cdn.eso.org**. *My colleagues and I are planning to observe this stellar-mass black hole with the Chandra X-ray Observatory.*

Stellar Prose

I've been a subscriber since January 1975 and always enjoy each issue of your wonderful magazine.

I was completely charmed by Tony Flanders' "Seeking Star Pairs" (*S&T:* June 2024, p. 20). His prose is so enjoyable it reminds me of *Starlight Nights: The Adventures of a Star-Gazer* by Leslie Peltier, and that's high praise!

I now realize he has a wealth of articles and blogs that I need to read and enjoy. Perhaps I should be embarrassed that I haven't shown sincere appreciation in the past, but I will definitely be watching for his writings in the future.

Tony Flanders has a new follower in me, and I hope his writings can be collected into a book at some point.

John McVey
Boise, Idaho

Persephone

In "Gateway to the Underworld" (*S&T:* May 2024, p. 45), Stephen James O'Meara writes that Persephone's name "is commonly derived from [the Greek] *pherein phonon*, meaning 'to bring (or cause) death.'" Well, when I read that, as a linguist, I knew it was a folk etymology, a guess by some scholar carried forth in publications. The true etymology of her name is obscure and likely lost.

While there are many variant Greek forms of her name, the Mycenaean Greek Preswa, the Homeric Persephoneia, Persephassa, the 5th-century BCE Persōphata and Pherrophatta, and Plato's Pherépapha, the first element's S cannot be derived from pherein. If the Indo-European root *perso-* for 'sheaf of corn' is offered, the second element could be 'beat' for 'she who beats the ears of corn' but that's only another forced attempt. Modern astronomy depends on nomenclature from many ancient sources, but the original meaning of Persephone's name was garbled and lost over time.

Carl Masthay
St. Louis, Missouri

FOR THE RECORD

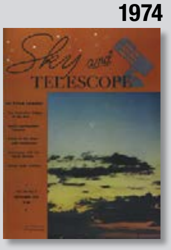
- In "Firm Evidence for a Neutron Star in Supernova 1987A" (*S&T:* June 2024, p. 10), the image in the bottom-right panel shows quintuply ionized argon atoms, not triply ionized. The original image is available at **https://is.gd/SN1987A_argon**.

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

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

1949

1974



1999

September 1949

Scorching Orbit "On the evening of June 26, 1949, Dr. Walter Baade had taken a 60-minute exposure near Antares with the new 48-inch Schmidt telescope on Palomar Mountain. Upon examining the plate next day he came across an asteroid trail so long that it . . . indicated an object very close to the earth . . .

"Although it now appears that the mean distance [from the Sun] slightly exceeds one astronomical unit, [when at] perihelion the asteroid passes inside the orbit of Mercury . . ."

Baade chose the mythologically apt name Icarus, for the boy who escaped capture on wings of wax but flew too close to the Sun. Today we know of some 30 asteroids with orbits lying wholly inside Earth's.

September 1974

Spectral Veil "On June 11th, Eugene Epstein [opened the Astronomical Society of the Pacific symposium] with a review of current knowledge about the still mysterious millimeter continuum, where neither optical nor radio telescopes work well in their present forms . . . In millimeter astronomy, a major problem still is accurate calibration of the equipment, which is necessary before flux measurements can be compared with those made in adjacent parts of the spectrum. . . . The problem is further confused if the equipment is housed in a protective radome, which is subject to dewing. . . .

"Less than a dozen installations in the world are presently equipped to work in the millimeter range . . . R. B. Leighton [of Caltech] showed slides of a prototype 10-meter paraboloidal dish currently being machined in the old optical shop where the Hale 200-inch mirror was ground."

Since 2018, the 50-meter Large Millimeter Telescope, a joint Mexico-U.S. project, has been fully operational atop 15,000-foot Volcán Sierra Negra.

September 1999

Dead Moon? "By the dawn of the Space Age [a] host of [amateurs] and a handful of professionals [were collecting] controversial reports of luminous spots, colored glows, mists, and obscurations, all suggesting that the Moon is still volcanically active. . . . Following the Apollo program, an overwhelming consensus emerged that lunar volcanic activity ceased hundreds of millions of years ago. . . .

"[Even so, a] dedicated handful of amateur observers continue to stand watch, hopefully turning their filter wheels, awaiting the next outbreak of violet glows at Aristarchus or the latest outgassing in Alphonsus. Their ongoing vigil bears tribute to the powerful allure of ideas about the Moon that are as much of a flawed anachronism as the canals of Mars."

In their article, William Sheehan and Thomas Dobbins critically discuss some of the enduring reports of transient lunar phenomena.

This image showcases the Sif Mons area with the active volcanic region highlighted in red.

SOLAR SYSTEM

Venus Volcanoes Are Active

KILOMETER-SCALE LAVA flows appeared in two volcanic regions on our sister planet between 1990 and 1992, Davide Sulcanese (Gabriele d'Annunzio University, Italy) and team reported May 27th in *Nature Astronomy*.

Venus is the proverbial hellscape: Its surface is smothered in ancient lava flows, and the temperature is that of a self-cleaning oven. Planet-wide outpourings of lava appear to have happened in the last few hundred million years or so. Scientists have also found indirect signs that volcanism continues today on a smaller scale.

A breakthrough came last year, when researchers scanning through archival data from NASA's Magellan spacecraft discovered that a vent on the slopes of the volcano Maat Mons had become shallower and changed its shape over the course of eight months, possibly due to eruption-spurred collapse (*S&T:* July 2023, p. 8). The changes came with hints of accompanying lava flows, but these were inconclusive.

Now, Sulcanese and his colleagues have found unambiguous evidence for additional sets of flows. Magellan used radar to map almost all of Venus's surface during its four-year mission in the 1990s, imaging some areas more than once. A small subset of these areas was re-imaged from either "left-looking" or "right-looking" angles. The Italian team focused on the 16% of the surface covered by radar images taken with similar left-looking perspectives.

The researchers found two sets of sinuous and fan-shaped features that appeared between different mappings. One lies on the western flank of the shield volcano Sif Mons, the other a quarter of the way around the planet in western Niobe Planitia, a fairly flat region with numerous volcanoes.

The features flow around obstacles and down the gently sloping ground. (The ground's tilt is revealed by other Magellan observations.) The flows extend from several kilometers to tens of kilometers, comparable to basaltic flows in Hawai'i.

"I think we'd be hard pressed to find many scientists who didn't think Venus had ongoing volcanism before," says planetary scientist Paul Byrne (Washington University in St. Louis). "But it's one thing to expect something and quite another to actually have evidence for it. Now, with this new discovery, I think we can confidently say that Venus is actively volcanic in the present."

The flows are radar-bright, indicating they're rougher than their surroundings. This might be because they're young and haven't been around long enough to be eroded, or perhaps they're a rougher type of lava lying on top of an older, smoother type, Sulcanese says.

Based on the potential flow volume and a rough estimate of how many eruptions might occur — extrapolated from Earth and scaled to Venus's mass and surface area — the team suggests that volcanism might be as active on Venus today as it is on Earth.

■ **CAMILLE M. CARLISLE**

SOLAR SYSTEM

Close-up on Asteroid Dinkinesh and Its Double-lobed Moon

WHEN NASA'S LUCY mission passed by asteroid 152830 Dinkinesh (*S&T:* Mar. 2023, p. 11), principal investigator Hal Levison (Southwest Research Institute) expected it to be "just a rock in space." But when the team saw the rock had a double-lobed moon, what started out as routine became "anything but boring."

Lucy launched in 2021 on a mission to visit multiple Trojan asteroids sharing Jupiter's orbit (*S&T:* Feb. 2022, p. 12). Later, the team added tiny Dinkinesh to the list of targets — not for science but because it offered a good place to test the spacecraft's autonomous range-finding and tracking system.

On November 1, 2023, Lucy came within 430 km of Dinkinesh, speeding past at 4.5 km/s (10,000 mph). Its photos revealed the double-lobed moon, named Selam ("peace" in the Ethiopian language Amharic).

Unlike other known contact binaries, Selam's lobes are roughly equal in size: 210 and 230 meters (690 and 750 feet) across, respectively. Their apparent linear alignment with Dinkinesh indicates that the bodies are tidally locked, Selam rotating synchronously in its 52.7-hour orbit around Dinkinesh.

The moon's double-lobed form is unexpected, because while 15% of small asteroids are contact binaries, and dozens of near-Earth asteroids have moons, Selam is the first contact binary observed orbiting another object. "None

DAVIDE SULCANESE / IRSPS - UNIVERSITÀ D'ANNUNZIO

STARS

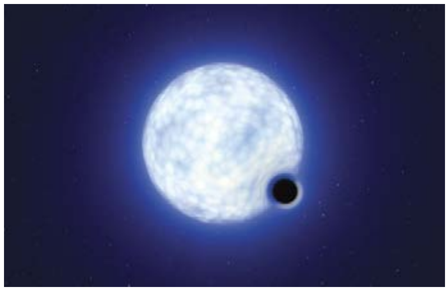
A Black Hole Without a Supernova?

SOME MASSIVE STARS may collapse completely into black holes — without the fanfare of a supernova.

When a massive star reaches the end of its life, it usually erupts in cataclysmic fireworks. In these supernovae, a dying star typically kicks off its outer layers asymmetrically, shunting the collapsed core to one side. If there's a binary companion, such a kick changes or disrupts their mutual orbit.

But massive stars might not always detonate in such dramatic fashion, according to Alejandro Vigna-Gómez (Max Planck Institute for Astrophysics, Germany) and colleagues. Their work, published May 9th in *Physical Review Letters*, centers on a binary system in the Large Magellanic Cloud known as VFTS 243. In this system, an O-class star some 25 times more massive than the Sun orbits a black hole that tips the scales at 10 solar masses. Surprisingly, the massive star in VFTS 243 maintains an almost perfectly circular orbit around the system's black hole.

Vigna-Gómez's team used the star's orbit to model the black hole's formation, concluding that its progenitor probably lost a third of the Sun's mass when its dense core collapsed — not enough for a full-blown supernova. What's more, the emission of neutrinos during core-collapse must have been nearly symmetric in all directions. In the end, the dying star's collapse likely proffered a kick of only 4 km/s (9,000 mph) to the newly formed black hole.



▲ This is an artist's impression of VFTS 243, in the Large Magellanic Cloud. Sizes are not to scale: In reality, the blue-white star is about 200,000 times larger than the black hole.

"The case . . . seems pretty convincing," says Christopher Kochanek (Ohio State University), who wasn't involved in the research. But Kochanek points out a possible (albeit fine-tuned) alternative: A supernova might still have happened if the two stars were in an elliptical orbit before one of them died. The asymmetrical mass loss might then have pushed them into a circular orbit.

If stars can collapse completely into black holes, the scenario could help solve an enduring mystery. Previous efforts, such as the Vanishing and Appearing Sources during a Century of Observations project, have identified thousands of stars that disappeared from sky surveys conducted over the last 70 years. Complete collapse might explain the vanishing act for some fraction of these stars.

■ COLIN STUART

IN BRIEF

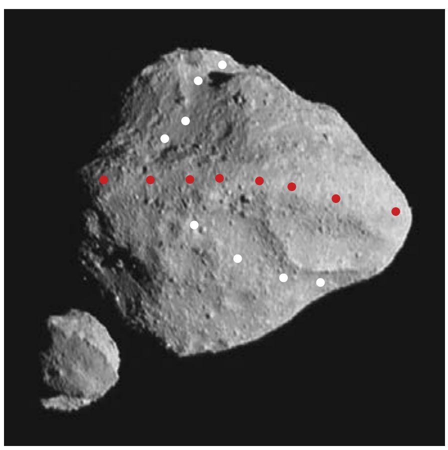
China's Chang'e 6 Lands on Moon

On May 3rd, a Long March 5 rocket lit up the dawn sky over Wenchang Space Launch Site in China, carrying the Chang'e 6 sample-return mission. On June 1st, Chang'e 6 landed successfully on the Moon, in the Apollo Crater near the south pole on the lunar farside. The mission then sampled lunar regolith, grabbing samples from the surface as well as drilling for them. By June 3rd, those samples had been transferred to an ascent vehicle, which then lifted off to rendezvous with a waiting orbiter. Unlike previous Chang'e missions, this one featured international cooperation, with science instruments contributed from teams based in France, Sweden, and Italy, as well as a Pakistani CubeSat that accompanied the larger spacecraft. The spacecraft also carried a small rover that took a "selfie" of the lander. The sixth mission of the successful Chang'e series followed the Chang'e 1 and 2 orbiters, as well as the nation's first lander and rovers, carried by Chang'e 3 and 4. In 2020, China completed its first automated lunar sample return with the whirlwind Chang'e 5 mission, which touched down on the Mons Rümker volcanic formation on the lunar nearside and brought back samples after only 24 days. Once the Chang'e 6 samples are returned, scientists hope to better understand the history and formation of the Moon.

■ DAVID DICKINSON

of the models have predicted anything like that," Levison says.

Levison's team suggests Selam formed when Dinkinesh lost material due to the YORP (Yarkovsky–O'Keefe–Radzievskii–Paddack) effect: Sunlight striking its surface and the ensuing emission of heat combined into a force that spun up the asteroid and ejected material from its surface.



▶ The moon Selam is seen in projection relative to Dinkinesh. Dots mark an equatorial ridge (red) and a trough (white) that could represent where a fragment separated from the surface.

The asteroid's surface may hold keys to its history. While Dinkinesh has the diamond shape of near-Earth asteroids, which tend to be loosely bound "rubble piles," its surface sports a ridge and trough that hint at internal strength.

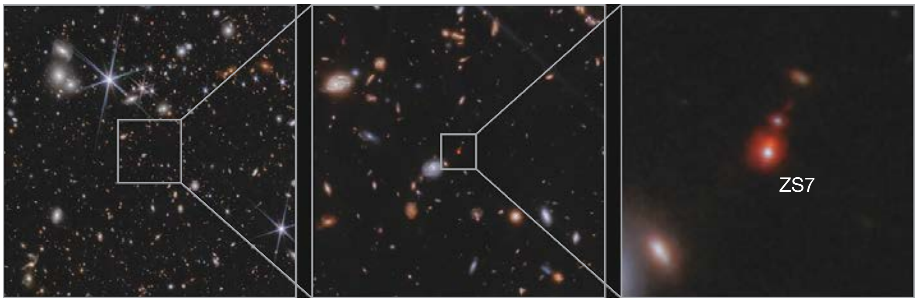
"The thing is fractured," Levison says, "and seems to have a piece broken away." Closer material may have fallen back onto the asteroid to form its equatorial ridge, while more distant material eventually recombined to become the double-lobed satellite.

■ JEFF HECHT

BINARY SYSTEM: ESO / L. CALÇADA; ASTEROID AND MOON: NASA / GODDARD / SWRI / JOHNS HOPKINS APL / NOIRLAB

GALAXIES

Webb Sees Most Distant Galaxy Merger



▲ The galaxy ZS7 appears to be undergoing a merger in which two black holes emit both doubly ionized oxygen (OIII, dark red) and ionized hydrogen (Hβ, orange). The source to the upper right of the central orange blob marks the offset black hole.

THE JAMES WEBB SPACE TELESCOPE (JWST) has spotted two galaxies colliding 750 million years after the Big Bang. In a study appearing in the June *Monthly Notices of the Royal Astronomical Society*, Hannah Übler (University of Cambridge, UK) and colleagues report the detection of the galaxies' two supermassive black holes.

Using JWST's Near-Infrared Spectrograph, the team observed a previously discovered galaxy, dubbed ZS7, known to host a supermassive black hole. The spectra show *narrow emission lines* associated with this obscured black hole at the galaxy's center.

The real surprise came with the discovery of a *broad* emission line. This light is emitted by gas clouds whipping around an unobscured black hole with the mass of 50 million Suns — and that black hole is offset from the galaxy's center by about 2,000 light-years.

"That [offset], along with additional imaging data, indicates a merger of two systems with massive black holes at a very early time," Übler says.

Übler thinks that, because the black holes are so close to each other and their relative velocities are so small, the two "will most likely merge within the next few hundred million years."

However, Fabio Pacucci (Center for Astrophysics, Harvard & Smithsonian), who was not involved with this study, says it's difficult to tell whether distant galaxies are actually merging.

"This is an exciting discovery that tells us that black hole pairs may be common in the high-redshift universe," he says. But he also considers another scenario offered by the team to be equally likely: Perhaps the two galaxies' black holes already merged, their coalescence kicking the merged black hole away from the galaxy's center.

Regardless of whether the merger is just beginning or already over, the discovery joins a growing body of research suggestin that in the early universe black holes are merging and becoming more massive faster than predicted (*S&T:* May 2024, p. 20).

■ ARWEN RIMMER

EXOPLANETS

Earth-size Planet Discovered 40 Light-Years Away

Artist's illustration of Gliese 12b

THE DISCOVERY OF Gliese 12b — the closest transiting, temperate, Earth-size planet found to date — promises to help us understand terrestrial planets outside the solar system.

Gliese 12b orbits a cool red dwarf star 40 light-years away. With an orbital period of 12.8 days, its surface might be temperate enough for life (although uncomfortable for humans), with an equilibrium temperature of 107°F (42°C). We don't yet know the status of its atmosphere, but the planet is close enough to be a future target for the James Webb Space Telescope (JWST).

Gliese 12b was initially detected using NASA's Transiting Exoplanet Survey Satellite; follow-up observations confirmed those transits were real and helped characterize the planet. Two groups of astronomers, led by Shishir Dholakia (University of Southern Queensland, Australia) and Masayuki Kuzuhara (Astrobiology Center and National Astronomical Observatory of Japan, Japan), reported observations simultaneously, in the June *Monthly Notices of the Royal Astronomical Society* and in the June 1st *Astrophysical Journal Letters*, respectively.

So far, astronomers have studied atmospheres in only one other system of terrestrial planets: TRAPPIST-1. It hosts no less than seven planets, three of them "potentially temperate Earth-size planets that are suitable for atmospheric transmission spectroscopy," Kuzuhara says. However, the system's two innermost planets studied so far appear to be stripped of any significant atmosphere (*S&T:* Aug. 2023, p.8 and Nov. 2023, p. 9).

But unlike TRAPPIST-1, Gliese 12 is a quiet star. While some red dwarf stars flare regularly, stripping their planets of their atmospheres, X-ray observations have found Gliese 12 to be an inactive host, and that bodes well for any planetary atmosphere.

Kuzuhara and colleagues plan to ask for observations of Gliese 12b with JWST. Meanwhile, Dholakia hopes to obtain radial velocity measurements. The gravitational tug of Gliese 12b pulls on its host star, so observations of the star's wobble enable measurement of the planet's mass, which can in turn narrow down its interior structure.

■ ARIELLE FROMMER

SOLAR SYSTEM

Voyager 1 (and Some of Its Instruments) Back Online

NASA ENGINEERS HAVE announced that the Voyager 1 spacecraft is back online and transmitting useful data from two of four science instruments, after a problem with a corrupted chip complicated communication with the spacecraft for several months.

Problems began last November, when Voyager 1 suddenly began sending a repeated gibberish signal instead of science and engineering data. Troubleshooting the 46-year-old spacecraft revealed the culprit: a memory chip in one of the spacecraft's three onboard computers was corrupted, perhaps due to a strike from a speedy charged particle known as a galactic cosmic ray.

Without the ability to replace the chip, the team instead focused on a software-based workaround, moving the affected code elsewhere. No spot was large enough to hold the entire affected code, though, so the team first broke it into pieces for distribution. As the engineers relocated pieces to different positions in the computer, they had to ensure the code could function as a whole. They also needed to update any references to the affected code.

The first test of this approach was on the code that returns the spacecraft's engineering data. That modification was done on April 18th. Voyager 1 is currently 163 astronomical units away, and a signal takes 45 hours round-trip from Earth to the spacecraft. The team thus had to wait two days, until April 20th, to see if the fix had taken hold. With the successful return of data, the team once again had access to the spacecraft's general status.

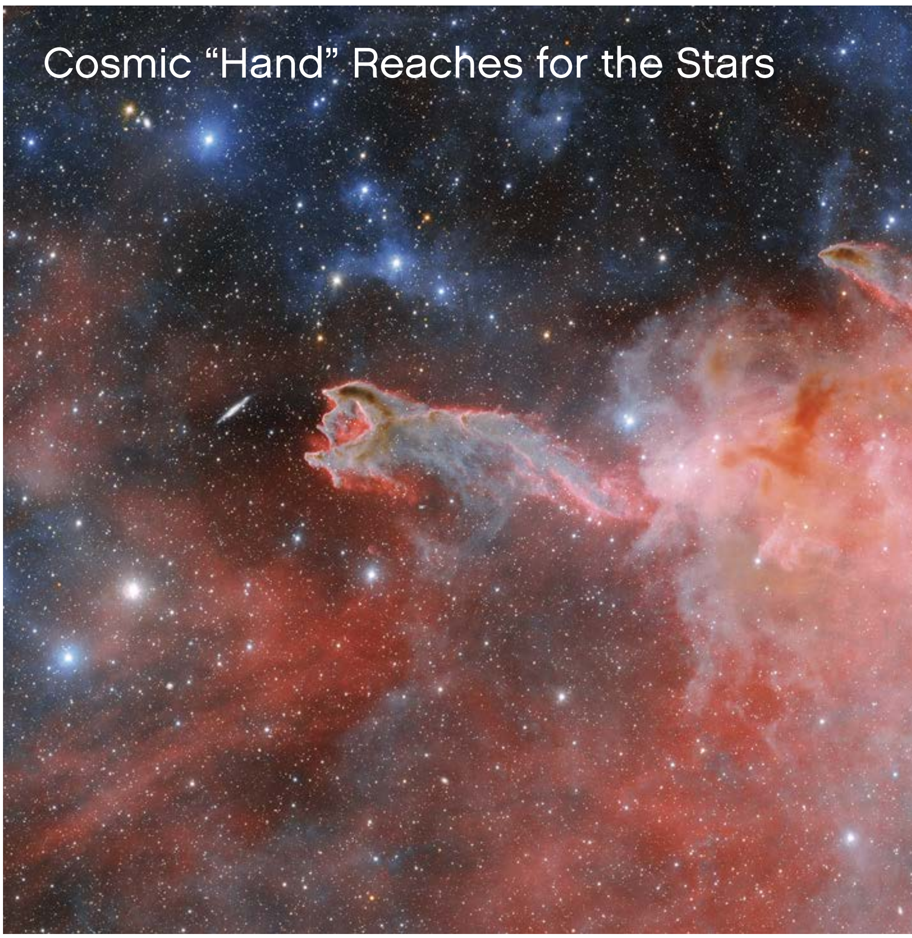
Additional updates allowed the spacecraft to resume sending back science data on May 17th. Two of Voyager 1's instruments — the magnetometer and plasma wave subsystem — are operational as of press time. These instruments measure distant magnetic fields and particles, respectively, and are thus crucial to understanding the boundary between our solar system and interstellar space.

▲ This picture of Voyager 1 showcases the Golden Record time capsule affixed to its side.

Engineers are still working to bring two other systems back online: the low-energy charged particle instrument and the cosmic ray subsystem. (Six other instruments are either no longer operational or were switched off after the spacecraft's Saturn encounter in 1980.)

■ DAVID DICKINSON

Cosmic "Hand" Reaches for the Stars



Stars are born not brilliant but obscured, cocooned in dusty gas. Astronomers have worked for decades to understand how infant stars emerge from these cocoons, and this image, from the Dark Energy Camera (DECam) on the Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory in Chile, helps shed light on the process. In this image, DECam captures Cometary Globule 4, which appears as a giant, outstretched hand about to snatch an unrelated background galaxy. ("Cometary" refers to the tail-like appearance of the dusty gas stretching to the right.) This star-forming region is 1,300 light-years away in the southern constellation Puppis. The sensitivity of DECam combined with its hydrogen-alpha filter reveals a faint reddish glow in the core and around the rim of the object, which comes from hydrogen ionized by the intense radiation from massive stars nearby. The globule still has plenty of dusty gas to form additional new stars, which will emerge in due time.

■ MONICA YOUNG

VOYAGER 1: NASA / JPL; COSMIC "HAND": CTIO / NOIRLAB / DOE / NSF / AURA; IMAGE PROCESSING: T. A. RECTOR / D. DE MARTIN / M. ZAMANI

The *Secret* Lives **of Comets**

As we await the apparition of Comet Tsuchinshan-ATLAS this fall, let's trace its path through time and space.

ALAN DYER

OLD COMET, NEW VIEW Comet NEOWISE, a long-period comet hailing from the outer edge of the solar system, appeared in the summer skies of 2020 to provide some much-needed delight to observers worldwide. This ancient object won't return for its next visit to the Sun for thousands of years.

Comets are ancient history. These cosmic fossils formed in the early days of the solar system, alongside the Sun and planets. The scientists who study them are like astronomical archaeologists: Their trowels are telescopes, their dig sites the night sky, and their artifacts a fascinating class of objects that contain untapped secrets about how our little corner of the cosmos came to be.

A dozen space missions have been launched since the 1970s to study comets — including the European Space Agency (ESA) probe named Rosetta, which actually landed on one (*S&T:* May 2017, p. 14). Where comets hail from, the angle of their orbits, their composition, their brightness, their tails, their atmospheres, and even what they look like when heat and tidal forces tear them apart, are all vital clues that point inexorably backward in time to the conditions of the solar nebula, the dusty gas from which our entire solar system formed.

Several pristine comets enter the solar system every year: These are objects that have never made a close pass by the Sun before and have spent their existences lurking in the icy expanse far, far beyond Neptune. One object in particular, Comet Tsuchinshan-ATLAS (C/2023 A3), will reach perihelion this September and make a close approach to Earth in October. Let's take a hypothetical jaunt through the lifetime of this cosmic dinosaur — from its formation and exile to its return and ultimate demise — and see what it can teach us about planetary formation.

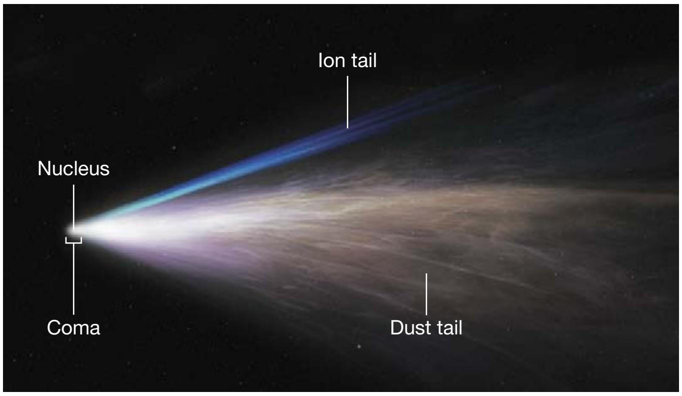
A Long Time Ago . . .

Any scientific model that attempts to discern our solar system's beginnings must account for the composition, placement, and size of the current population of *planetesimals*: small, solid bodies that coalesced early on. Countless of these planetesimals collided and stuck together to form planets, and the remainder still circulate around our system.

So here's where the current theories stand: Some 4.6 billion years ago, our environs were a *protoplanetary disk* — an elemental swirl of rock, gas, and dust, with an emerging star at the center. And — oh look! There's Comet Tsuchinshan-ATLAS. It has just recently formed and is already knocking about the nebula with countless other planetesimals. Recent scholarship suggests that this youthful stage in a planetary system's development lasts around 10 million years — a brief but exciting time for our baby comet.

After the Sun finally achieved nuclear fusion and the planets formed, there was still an uncountable population of small bodies (such as C/2023 A3) left over. Some objects were snagged by planets as moons, others pelted the planets with violent impacts. A tiny fraction settled permanently into the asteroid belt. Gravitational interactions cast the rest out into interstellar space, never to return.

Earth itself was a target of these early impacts. Key evidence lies in the composition of our atmosphere. "Earth has xenon in its core and in its atmosphere, but they are not the same," says Kathrin Altwegg (University of Bern, Switzer-



▲ **THE PARTS OF A COMET** A comet begins as a mixture of rock and ices. As it flies closer to the Sun, those ices begin to sublimate, surrounding the nucleus in a gaseous coma. Tails may also form, as the Sun's solar wind and radiation pressure drive away gas ions and dust, respectively. The slower dust grains make a broad, curved tail, while the faster-moving ions shoot out in a tail that's straight and narrow.

land), one of Rosetta's project leaders. "They have different isotopic ratios. This means they have two different origins. For 50 years scientists asked why, and we now have an explanation: impacting comets."

Rosetta scientists found that two of xenon's heaviest isotopes were scarcer in the gas surrounding Comet 67P/Churyumov-Gerasimenko. This same deficit exists in Earth's air (*S&T:* Mar. 2023, p. 34), providing a definitive link between the impact-delivery of *volatiles* and Earth's current atmosphere. Volatiles are substances that can be easily vaporized, such as hydrogen, methane, ammonia, water, nitrogen, carbon dioxide, sulfur dioxide, and, yes, xenon.

Comets delivering xenon to early Earth could also have contributed prebiotic material such as phosphorus and the amino acid glycine, which Rosetta also detected on Comet 67P. This means that comet impacts could have supplied the building blocks for life on Earth.

Comet Tsuchinshan-ATLAS didn't get the chance to make such an important contribution, though — it was stuck in the outskirts of the solar system.

Comet Origins

After the planets formed, most of the remaining planetesimals settled into two reservoirs: a donut-shape region beyond Neptune and a more distant, spherical collection of icy bodies called the Oort Cloud that encloses the entire solar system. While we've observed several thousand trans-Neptunian objects, especially in the region called the Kuiper Belt, we have not directly seen the Oort Cloud. In fact, it's so vast and far away, and the objects there so small, dark, and sparse, we wouldn't even know it was there at all if it weren't for all the pesky comets it sends our way. Such as Comet Tsuchinshan-ATLAS, for example.

For the last 4 billion years, C/2023 A3 has been in a kind of suspended animation. It has been frozen solid in a void so desolate, it might never have encountered another object in the whole lifetime of the Sun if not for a chance encounter with gravity. It is impossible to know the exact circumstances that altered the course of our comet, but *galactic tides* are the leading explanation. The Sun's gravitational influence is weak in the Oort Cloud, so bodies out there are subjected to a tug of war between our host star and the Milky Way itself. The competition can change the small objects' trajectories over time. Other theories for the perturbation of Oort Cloud bodies include interactions with dwarf planets and passing stars.

Whatever the reason, Comet Tsuchinshan-ATLAS has been nudged into a nosedive that's taking it through the inner solar system, close enough to the Sun that it will pass just outside the orbit of Mercury.

PARTS OF A COMET: CASEY REED / S&T; ORBIT: BEATRIZ INGLESSIS / S&T

FAST FACTS

Origin: Oort Cloud

Size: about 10 km wide

Speed: 67 km/s (150,000 mph) at perihelion

Orbit: near-hyperbolic, retrograde, and inclined 139° from the ecliptic plane

Perihelion: Sept. 27, 2024

Closest approach: Oct. 12, 2024, 0.47 a.u. from Earth

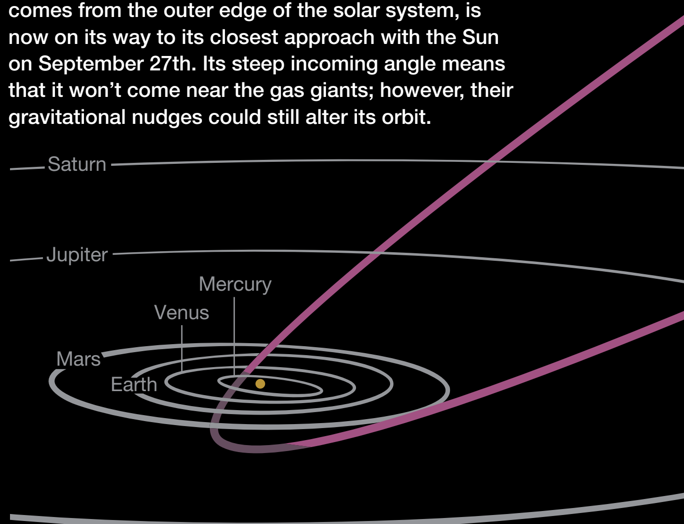
Potentially visible to unaided eye: late September

Magnitudes over time:

- January 2023: 13.5
- Early May: 10
- October (predicted): magnitude 0?

Fate: Long-period comet, with a perihelion every 80,000 years, or an interstellar object

RARE VISIT Comet Tsuchinshan-ATLAS, which comes from the outer edge of the solar system, is now on its way to its closest approach with the Sun on September 27th. Its steep incoming angle means that it won't come near the gas giants; however, their gravitational nudges could still alter its orbit.



Comet Orbits

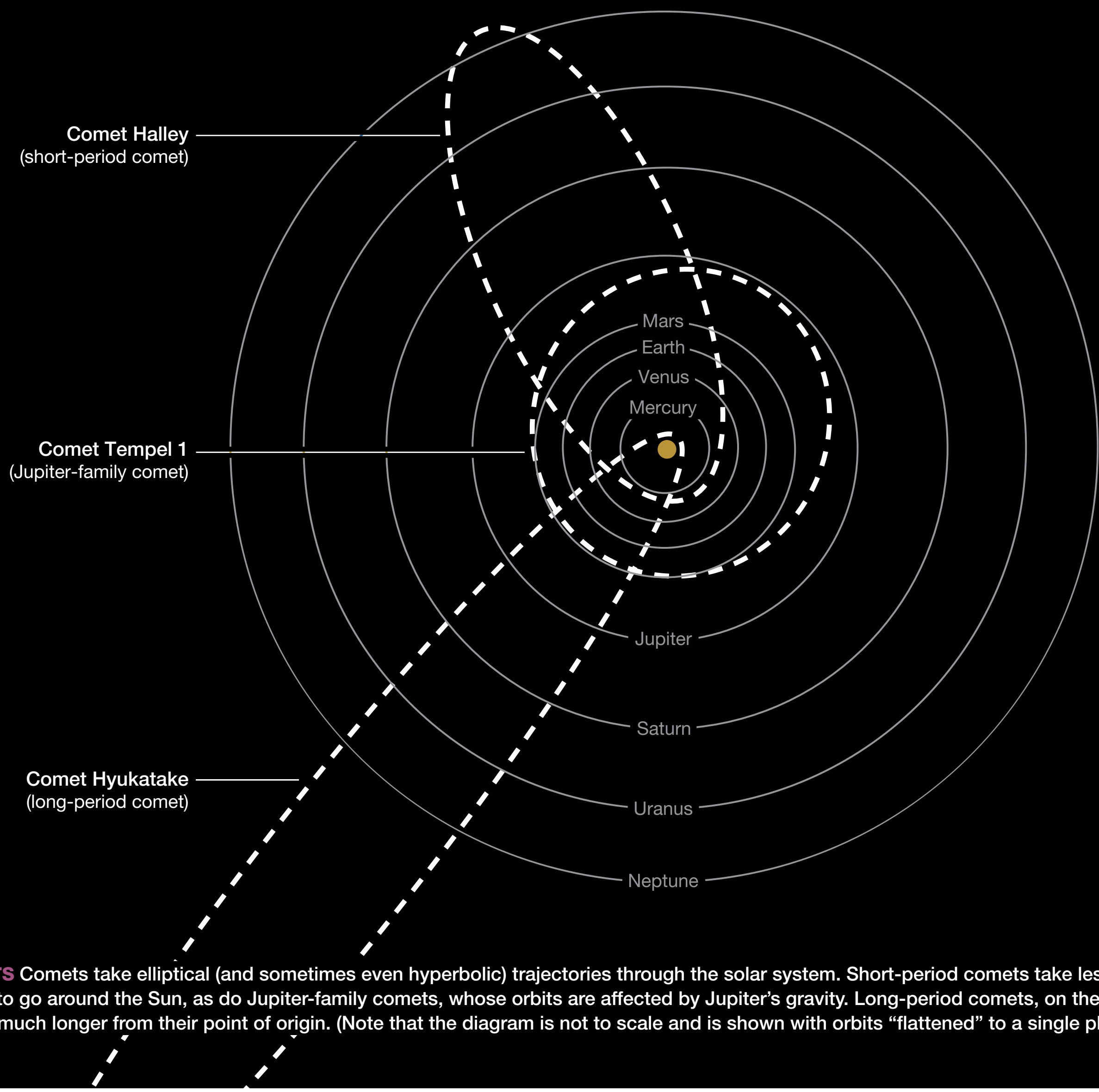
There are different kinds of comets, and they are classified primarily according to their orbital period. *Short-period comets* go around the Sun in 200 years or less; most of these come from the region just beyond Neptune. *Long-period comets*, as well as those on an ejection trajectory, usually come from the Oort Cloud. There are also short-period comets that started out in the Oort Cloud but were caught in the gravitational fields of the gas giants at some point in the past and shifted into smaller orbits, like Comet Halley. Objects that started in the trans-Neptunian region and moved to Jupiter's neighborhood are known as *Jupiter-family comets*.

The orbit of Comet Tsuchinshan-ATLAS is nearly hyperbolic, meaning it will either have a very long period (80,000-plus years) or, once it passes the Sun, it might be ejected from the solar system altogether. We know it's coming from the Oort Cloud because the inclination of its orbit from the ecliptic plane is 139.1°, bearing down on us from a steep angle. The Kuiper Belt hugs the plane of the planets' orbits, so objects from there won't reach such large inclinations, whereas comets from the spherical Oort Cloud can head in from any direction.

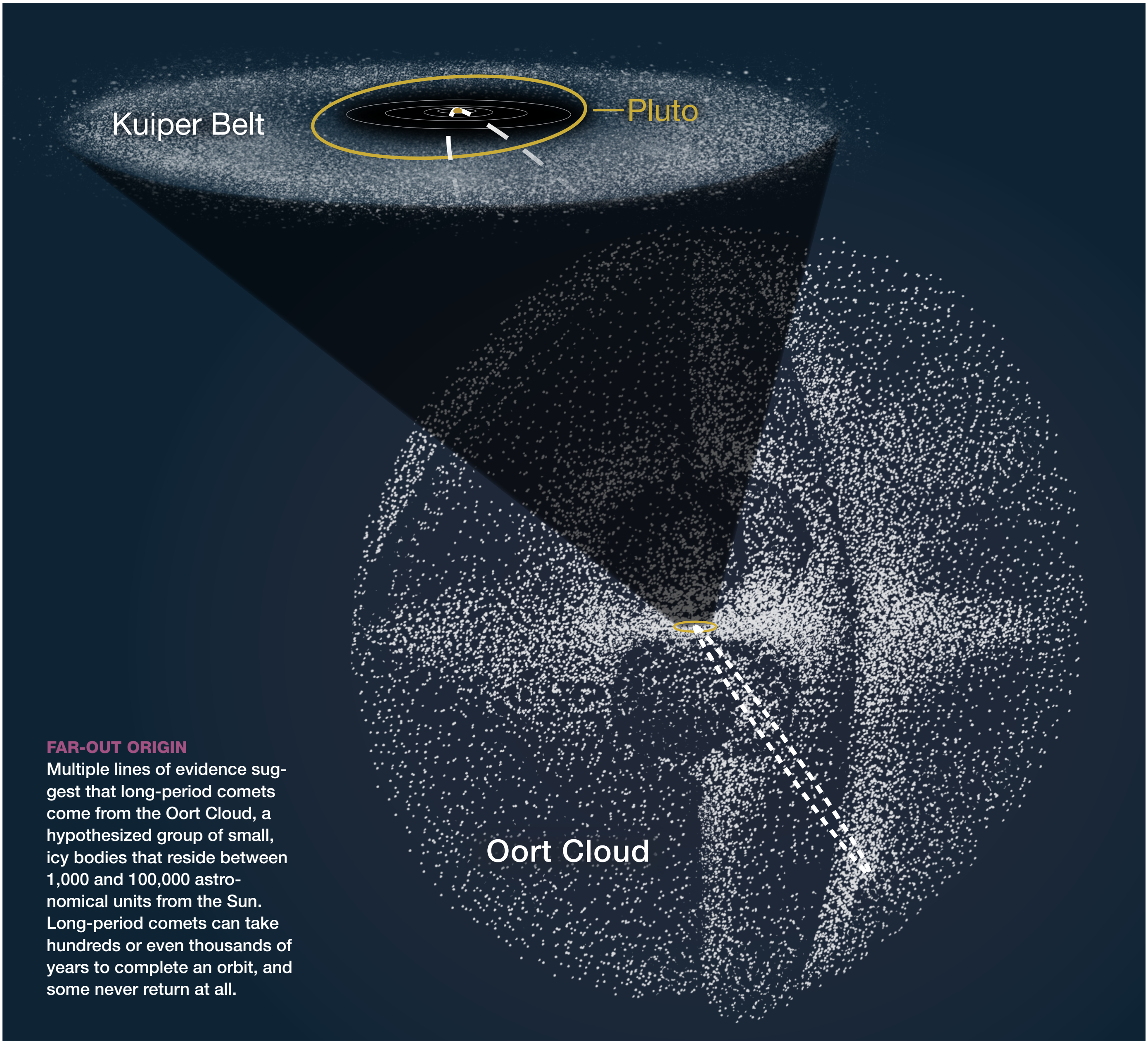
Discovery

Astronomers at the Purple Mountain Observatory in China first discovered Comet Tsuchinshan-ATLAS on January 9, 2023, but no follow-up observations were reported in the following weeks. Astronomers recorded the comet as officially "lost." This is a common occurrence, because if an object can't be located quickly after an initial sighting to confirm its

BEATRIZ INGLESSIS / S&T



ORBITS Comets take elliptical (and sometimes even hyperbolic) trajectories through the solar system. Short-period comets take less than 200 years to go around the Sun, as do Jupiter-family comets, whose orbits are affected by Jupiter's gravity. Long-period comets, on the other hand, travel much longer from their point of origin. (Note that the diagram is not to scale and is shown with orbits "flattened" to a single plane.)



FAR-OUT ORIGIN
Multiple lines of evidence suggest that long-period comets come from the Oort Cloud, a hypothesized group of small, icy bodies that reside between 1,000 and 100,000 astronomical units from the Sun. Long-period comets can take hundreds or even thousands of years to complete an orbit, and some never return at all.

BEATRIZ INGLESSIS / *S&T*

trajectory, predictions of future positions become too uncertain to find it again.

Luckily, the South African component of the Asteroid Terrestrial-impact Last Alert System (ATLAS) independently found C/2023 A3 on February 22, 2023. After these reports were posted online, astronomers with the Zwicky Transient Facility (ZTF) in California, which does continuous surveys of that region of the sky, combed through their archival data. By tracing backwards from the two sightings, they found that they had captured an image of the comet even earlier, on December 12, 2022.

"We call this a pre-discovery," says Quanzhi Ye (University of Maryland), an astronomer with the ZTF Solar System Working Group. "The image of the comet captured by our survey technically predates the first sighting, but we didn't find it in the archives until it was reported by the other two groups. That's why it is named after them."

Comets' orbits are easily influenced by forces that act from both within and without, so it's impossible to predict their paths with complete surety. Sublimation-induced torques could crop up at any moment and set the comet spinning or change the direction of its trajectory. And while C/2023 A3 is not expected to closely approach the giant planets, gravitational perturbations could still influence its future path in unpredictable ways. We won't know until it passes perihelion whether the comet is destined for a long loop around the solar system or whether it will be banished forever into interstellar space.

And it might all be a moot point, anyway. Many comets break up long before they graze the Sun. Since

Comet Tsuchinshan-ATLAS has never approached the Sun before, its durability has never been tested.

The Nucleus

The physical body of a comet — its *nucleus* — is usually between 1 and 10 km (between 0.6 and 6 miles) across and no more than half ice; the rest is rock and dust. The ice is mostly water (90%), but astronomers have also observed ices of carbon dioxide, carbon monoxide, methane, and ammonia. Since comets are relics of the solar nebula, their composition provides direct evidence that volatiles made up most of the protoplanetary disk.

The first detailed observations of a comet's nucleus were made by NASA's Deep Impact spacecraft in 2005. This daring mission flew to Comet 9P/Tempel 1 and shot it with an impactor. In studying the subsequent debris, scientists found materials such as clays, carbonates, and crystalline silicates. They observed more dust and less ice than expected, and the dust itself seemed more like a fine powder than dirt. In fact, the impactor ejected so much material, and the crater was so much bigger than expected, that scientists concluded that the nucleus must be mostly empty space — less like solid ground and more like a snowbank.

Rosetta found the same during its years-long journey with Comet 67P/Churyumov-Gerasimenko. Joining up with the nucleus in 2014, Rosetta was the first orbiter to follow a comet for several years, including through perihelion. Its lander, Philae, is the only craft so far to collect data directly from a comet's surface.

"There was an instrument on Rosetta called CONSERT, which was a little bit like an ultrasound but with electromagnetic waves," Altwegg says. "It was made to study the interior, the nucleus. And they got some very good results."

Astronomers long characterized comet nuclei as "dirty snowballs," until observations of Comet Halley in the 1980s showed its composition was rockier than expected. Likewise, Rosetta's CONSERT instrument (short for Comet Nucleus Sounding Experiment by Radiowave Transmission) established that a significant portion of 67P's interior is carbonaceous rock and dust.

But how are comet interiors structured, exactly? Do they have solid-rock cores surrounded by ice? Or perhaps multiple alternating layers? Or are they more like gravel all the way through? If so, how does the ice mix with the other material — does it smoothly saturate on the level of individual grains, like a slushy? Or does the ice surround bigger pebbles and rocks, like a soda with ice cubes?

"The best thing to learn about how the dust and ice are mixed would be to dig down — about 10 meters, at least," says Altwegg. Her dream mission would be a drilling campaign, extracting an ice core to bring back to Earth for study. "That would be wonderful. Because for me, the biggest mystery about comets is still the interior."

Touchdown missions like Deep Impact and Rosetta are complex and rare endeavors; a robotic mining operation, like the one Altwegg is hoping for, is currently beyond our capabilities. For the near future, at least, remote observations of the atmospheres and tails of comets like C/2023 A3 will continue to be our primary source of information about their nature and composition.

▲ **THE NUCLEUS** ESA's Rosetta mission captured this close-up of Comet 67P/Churyumov-Gerasimenko from 29 km (18 mi) away. Its surface is in parts smooth or slumped with scattered boulders and in other parts rough and jagged.

ESA / ROSETTA / NAVCAM

The Coma

In the near–absolute zero temperatures of the Oort Cloud, comets are dark and inactive. It's only when they enter the warmer region of the planets that their ices start to *sublimate*, transitioning directly from a solid into gas. The emerging gases also eject dust from the surface. Theatrics ensue as all of this material forms an atmosphere around the comet's nucleus called a *coma*.

The gaseous envelope will begin to glow as it approaches the Sun. Usually the coma appears whitish or yellow; however, it can sometimes take on a greenish hue, perhaps due to sunlight irradiating diatomic carbon and cyanogen in the nucleus. Sky-watchers were even able to observe this interesting effect with the naked eye, when Comet C/2022 E3, a long-period comet with an orbit of 50,000 years, came within 0.28 astronomical unit (a.u.) of Earth in 2023.

NASA acquired the first close-up of a coma in 2004 using its space probe Stardust. Stardust's primary mission was to capture dust grains from the short-period comet 81P/Wild 2. Among the material the probe captured, scientists found glycine, the protein building block that Rosetta also found on 67P later on. Stardust's find marked the first time scientists saw glycine in cometary material.

The comae of pristine comets, such as C/2023 A3, differ from those of short-period comets like Tempel 1, Churyumov-Gerasimenko, and Wild 2. The latter are all Jupiter-family comets and have visited the Sun before, whereas pristine

PUFFS IN THE WIND Solar wind activity can disrupt a comet's ion tail, creating puffs and disconnections, as it did to Comet 12P/Pons-Brooks.

DAN BARTLETT

comets have been largely untouched by solar radiation. Pristine comets also become visible farther out in the solar system, often between 4 and 10 a.u. and sometimes beyond 20 a.u. away — past the orbit of Uranus. Ye says this is because they contain ices that sublimate at a lower temperature than water ice does, which starts to sublimate at around 3 a.u.

C/2023 A3 was first seen at a far-off distance of 7.3 a.u., which is typical for a first-time or rare visitor. "We can assume that it has carbon monoxide," Ye says, "because that is the typical cometary material that can suddenly outgas at such a distance."

While intense outgassing from solar illumination erodes the nuclei of short-period comets over the eons, altering their original composition and erasing evidence of conditions in the solar nebula, the pristine nature of comets like C/2023 A3 makes them unique time capsules. That is why ESA astronomers and engineers are designing the upcoming Comet Interceptor mission to study a pristine comet.

Comet Interceptor, which is set to launch in 2029, is unusual because it has no specific target — at least not yet. After launch, it will first go to a "parking" location at the L_2 Lagrangian point, which lies around 1.5 million km from Earth's nightside along the Earth-Sun line. It will wait there for a few years until astronomers detect suitable target candidates, that is, "new" objects that have never visited the inner solar system before, says Marina Galand (Imperial College London), who leads one of the mission's instrument teams.

Once the team identifies a good target, the spacecraft will be able to transfer from L_2 to encounter the comet. Three components — a mothership and two probes — will separate and perform simultaneous observations from multiple points in order to create a 3D picture of the nucleus, its coma, and its interaction with the space environment.

We won't get this up close and personal with Comet Tsuchinshan-ATLAS, but it might still give Earth-based observers a nice show later this year — hopefully displaying not just a fuzzy coma but tails as well.

The Tails

Comets usually have two tails: dust and ion. The *dust tail* is created by sunlight, which exerts radiation pressure that can be quite significant on tiny grains. As the comet sails along in its orbit, solar photons constantly pummel the coma, blowing away grains caught up with the gas. The dust forms a broad, slightly curved, and often yellowish tail. The yellow color (which comes from reflected sunlight) is easier to see with the naked eye than the bluish tone of the second tail, called the *ion tail*.

Ion tails are made of ionized gas molecules that are carried away from the coma by the charged particles and magnetic field of the solar wind. The fast-moving ions line up in a thin, straight, and bluish tail. The color comes from carbon monoxide, which absorbs sunlight and fluoresces at a wavelength of 420 nanometers.

Observations of ion tails were the first evidence of the solar wind, and scientists still use tail behavior as a kind of windsock to learn about changes in that wind. Conversely, instruments that were designed to study the solar wind can also be used to study ion tails.

Samuel Grant (University College London) has used computer simulations to predict when and where an ion tail will occur — information that's especially useful for determining when a tail will fall in the sensor range of a space-based instrument like ESA's Solar Orbiter.

"We can do ground-based spectroscopy of a coma, but that just gives us an approximate idea of its composition," Grant says. "But if you can fly a spacecraft through the ion tail, you can collect material that was once sealed inside the comet."

While Solar Orbiter won't pass through the ion tail of C/2023 A3, Grant says that there's a chance — depending on the solar weather conditions at the time — that Earth itself may do so. If that happens, cometary ions could join other solar wind particles in making aurorae.

We don't know much about C/2023 A3's coma and tails yet. Hopefully the tails will lengthen substantially as the comet approaches the Sun, as the rising temperatures cause more outgassing. Comet tails sometimes reach incredible lengths, extending up to 10 million km. As the tails grow, they continue to point away from the Sun, because both sunlight and the solar wind flow outwards from the Sun. This occurs no matter where the comet is in its orbit, meaning the tails will appear in front of the nucleus (relative to its trajectory) after it passes perihelion and makes its way past Earth.

Most of the time, tails seem pretty simple. Like flags flying in the wind, they react to the local space environment in predictable ways. But odd things have happened. If the solar wind grows suddenly in strength, magnetic fields carried by the wind can pinch the ion tail, causing strange, bendy distortions in its shape. Even more violent solar events, called *coronal mass ejections*, can rip off the tail completely. Astronomers have also observed brightenings, flashes, and bands of light in dust tails, which are thought to be caused by sudden, large ejections of material from the comet itself. Such events can sometimes precipitate a total break-up of the object.

The End

A comet can lose between 0.1% and 1% of its mass every time it passes through the inner solar system. Obviously, this whittling down cannot go on indefinitely. Eventually, even if it takes billions of years, heat from the Sun will erode the nucleus so much that it will disintegrate, and all the gas will blow away.

A comet might meet its end before that. Whether it crashes into Jupiter or comes too close to the Sun and breaks up prematurely, the end result is the same: a loss of structural integrity. Once a comet starts its journey toward the inner solar system, its days are numbered.

The only way a comet can pull through in one piece is if it's like C/2023 A3, which could be slingshotted out into interstellar space after a singular trip past the Sun. Assuming it survives its journey through the inner solar system, it will be sent back out through the Oort Cloud and, eventually, into interstellar space.

In 2017, the first confirmed object from another star, 1I/'Oumuamua, passed through the solar system. It was going so fast that it will never return — it will just keep going and going until it reaches another star system, and another, until it eventually crashes into a larger body or breaks up. It's possible that something like this could happen to C/2023 A3. After that, who knows?

ARWEN RIMMER is a writer and musician based in Cambridge, England.

ESO / SEBASTIAN DEIRIES

FANFARE Comet McNaught's tail fanned out in a spectacular display for Southern Hemisphere observers in 2007. This view over the Pacific Ocean was captured from Paranal Observatory in Chile.

Who First Described th

EDGEWORTH-KUIPER KING Accompanied by five satellites, Pluto is the largest known world orbiting the Sun beyond Neptune. In 1943 and again in 1949, Irish scientist Kenneth Edgeworth predicted a vast number of small objects in this part of the solar system. This painting shows the distant Sun hanging above Pluto's frigid surface.

MICHAEL CARROLL

e Comet Belt Just Beyond Neptune?

It's time the so-called Kuiper Belt was finally rebranded.

Billions of kilometers away, past the orbit of distant Neptune, small objects scamper around the Sun, most with mean distances that are 38 to 48 times greater than that of Earth.

The most famous and best-loved of these frigid bodies is the largest, Pluto. And yes, despite past statements to the contrary, Pluto remains what it was following its discovery in 1930: the largest known member of the solar system beyond the orbit of Neptune.

But Pluto has plenty of company. In 1992 David Jewitt (now University of California at Los Angeles) and Jane Luu (now University of Oslo, Norway) found another world orbiting the Sun beyond Neptune. This world is much smaller than Pluto and received its name only recently. Why did naming it take so long? "Because I just don't give much of a damn about the names of things I've discovered," says Jewitt. "The IAU [International Astronomical Union] has a whole committee of lost souls who do and eventually they pressured me into it." He chose Albion — the ancient name for Britain — because he's fond of William Blake, who used the name in his poetry. Whereas Pluto requires 248 years to orbit the Sun, Albion takes even longer, around 295 years.

The Trans-Neptunian Belt

Since Albion's discovery, astronomers have found thousands of additional trans-Neptunian objects in the solar system. Nearly all belong to what is often called the *Kuiper Belt*. Most short-period comets — those that orbit the Sun in less than 200 years — originate here, launched sunward by gravitational tugs from the giant planets. Because the Kuiper Belt aligns with the plane of the solar system, short-period comets usually travel fairly close to this plane. In contrast, comets with much longer orbital periods come from all directions, because they arise from the much more distant Oort Cloud, which is spherical.

GERARD KUIPER Although he made many discoveries in the outer solar system, Gerard Kuiper thought that the region just beyond Neptune's orbit was empty of everything but Pluto — yet today this zone of trans-Neptunian objects is often called the Kuiper Belt.

The term "Kuiper belt" first appeared in 1988, in an article by Martin Duncan (then at Lick Observatory) and colleagues in the *Astrophysical Journal Letters*, four years before Albion's discovery. The name honors Dutch-born American astronomer Gerard Kuiper, who made several major discoveries in the outer solar system. In 1944 he found that a mere moon — Titan, Saturn's largest — has an atmosphere. In 1948 he spotted Uranus's fifth satellite, Miranda, and in 1949 Neptune's second moon, Nereid, which has an extremely elliptical orbit.

The following year, in 1950, Kuiper used the 200-inch Hale telescope atop Palomar Mountain in California to measure Pluto's diameter. If you grew up during the 1950s, 1960s, or 1970s, this was the number you learned. It meant Pluto was larger than Mercury but smaller than Mars. Despite Kuiper's claim of precision, his estimate for Pluto turned out to be a drastic overestimate (see the sidebar on the facing page).

A MOON WITH ATMOSPHERE Gerard Kuiper's discovery of methane gas around Saturn's large satellite Titan astonished astronomers, for it meant that a mere moon could have an atmosphere. The Voyager spacecraft later found that this atmosphere is thicker than Earth's and consists mostly of nitrogen. This image was recorded in 2005 by the Cassini orbiter spacecraft.

A year later, in 1951, Kuiper published a 68-page article in a book entitled *Astrophysics*. He wrote about the origin of the solar system. In a section called "Comets and Unknown Planets," he speculated about a lost belt of small bodies just beyond Neptune's orbit. He was intrigued by Clyde Tombaugh's failure to find such objects in the search that had yielded Pluto.

"You know, Clyde, although your discovery of Pluto was a very important event, knowing how thoroughly you went through it, I am more impressed with what you did *not* find out there," Kuiper once told Tombaugh, as David H. Levy recounts in his 1991 biography, *Clyde Tombaugh: Discoverer of Planet Pluto*.

Kuiper went on to explain the apparent *absence* of small bodies beyond Neptune. The objects themselves would have had too little gravity to fling their peers out of the belt. "We must therefore assume that the planet Pluto is responsible for the dispersal of the comets," Kuiper wrote. Neptune is about 30 astronomical units from the Sun while Pluto is, on average, 39.4 a.u. distant. But Pluto's elliptical orbit carries it from 29.6 to 49.3 a.u., which means it sweeps through most of the zone that Kuiper believed was empty.

At the time, Pluto was thought to be a substantial fraction of Earth's mass. If Pluto was at least a third as massive as our world, Kuiper noted, the distant world's gravity would alter the orbits of the small objects. They would then pass closer to Neptune and the other giant planets, whose greater gravity would catapult the small bodies away. Many of them would end up in the remote reservoir of cometary objects that Dutch astronomer Jan Oort had proposed in a scientific paper published in 1950. According to Kuiper, this explained why no trans-Neptunian belt exists today. However, at distances greater than 50 times Earth's, remnants of the "comet ring" probably still survive because here Pluto's gravity is too weak to clear out the cometary bodies.

Today we know that the trans-Neptunian belt does indeed exist. Moreover, most of its known members have mean distances between 38 and 48 a.u., a region Kuiper thought was empty of everything but Pluto. Thus, calling this zone full of trans-Neptunian objects the Kuiper Belt is like naming a church after an atheist. Furthermore, even though Pluto turns out to be the largest of this belt's many residents, it's much too puny to hurl objects toward Neptune, contrary to what Kuiper conjectured.

How Pluto Got Its Groove Back

▲ **PLUTO AND CHARON** Pluto has five moons, one of which, Charon, measures about 1,200 km (750 miles) in diameter — half Pluto's size. Charon orbits Pluto every 6.4 days.

NASA / JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY / SOUTHWEST RESEARCH INSTITUTE

The plethora of objects in the Edgeworth-Kuiper Belt as well as early overestimates of their sizes have fooled many people into thinking that Pluto is no longer special — in particular, that it is no longer the largest known member of the solar system beyond Neptune.

Although Gerard Kuiper had said that Pluto was halfway in size between Mercury and Mars, observations during the 1970s showed otherwise. In 1976 astronomers spotted methane ice on Pluto. Methane ice is bright and reflective, so to look as dim as it does, Pluto must be smaller than Mercury, perhaps smaller than the Moon.

Then, in 1978, James Christy (U.S. Naval Observatory) discovered Pluto's first moon, which he named Charon. Charon's slow orbital motion indicated that Pluto is only 0.2% as massive as Earth. During the 1980s, eclipses between Pluto and Charon yielded Pluto's approximate diameter, proving that Pluto is indeed smaller than the Moon. Unlike any other object in the Edgeworth-Kuiper Belt, however, Pluto has an atmosphere. This complicated the interpretation of the eclipse observations and left Pluto's exact size somewhat uncertain.

The first years of the 21st century were especially dark times for Pluto. Astronomers were finding new worlds that threatened to dethrone Pluto as king of the trans-Neptunian domain. The greatest danger came in 2005 with the discovery of Eris, which is currently about three times farther than Pluto. Shortly after the discovery, Michael Brown (Caltech) said: "If it's not larger than Pluto, then I'll eat my telescope" (*S&T:* Dec. 2005, p. 24).

So you might want to skip dinner at the Brown residence unless you relish telescope stew. In November 2010 Eris passed in front of a star in the constellation Cetus and failed to live up to the advance billing. The short duration of the eclipse revealed that the object is only 2,326 km (1,445 miles) across. Furthermore, unlike Pluto, Eris lacks an atmosphere, which means the number is accurate to just a few kilometers.

For a time, therefore, astronomers knew the size of newly discovered Eris better than they did that of Pluto. That situation changed in 2015 when the New Horizons spacecraft sped past Pluto, whose diameter proved to be 2,377 km, clearly larger than Eris. The bottom line: Pluto is the ninth-largest world orbiting the Sun; Eris is the tenth largest.

Both Pluto and Eris have moons. Pluto has five, making it the most moon-rich world in the Edgeworth-Kuiper Belt. The closest moon to Pluto is the largest, Charon, followed by Styx, Nix, Kerberos, and Hydra. The discoverers named the outermost moon Hydra after the multi-headed mythological monster that guarded one of the entrances to the Underworld, which Pluto ruled. How many heads did Hydra have? That's right: nine — a sign the discoverers considered Pluto to be the ninth planet.

Eris has one moon but could have more. The orbit of its moon has revealed Eris's mass. Although Pluto is larger than Eris, Eris is more massive. In like fashion, Uranus is larger than Neptune but less massive than its neighbor.

Both Pluto and Eris are probably considerably larger than their nearest known competitors, which in alphabetical order are Gonggong, Haumea, and Makemake. These worlds reveal their sizes when they pass in front of background stars (*S&T:* Sept. 2023, p. 34). The three are roughly one-half to two-thirds the diameter of Pluto.

Just as the mythological Pluto was the god of the Underworld, so the real Pluto is the king of the Edgeworth-Kuiper Belt. And Eris, the mythological goddess of strife and discord, is the trans-Neptunian queen.

In his 1951 paper, Kuiper repeatedly cited Oort's 1950 work but not that of another scientist who, in 1943 and again in 1949, had suggested the continued existence of a trans-Neptunian belt: Irish army officer, engineer, and scientist Kenneth Essex Edgeworth.

The Life of Kenneth Edgeworth

Edgeworth was born on February 26, 1880, at Daramona House, a large country home some 90 km (56 miles) west-northwest of Dublin, into a family with both a literary and a scientific pedigree. His relative Maria Edgeworth had been an early 19th-century novelist, and Kenneth Edgeworth himself was the nephew of William Wilson, an astronomer who built an observatory at Daramona House with 12-inch and 24-inch telescopes (*S&T:* Feb. 1977, p. 108). A small town in Ireland, Edgeworthstown, still bears the family name.

Although Edgeworth's parents moved out of Daramona House when he was a young child, he did visit his uncle's observatory. Edgeworth spent his professional career, however, in the army, entering the Royal Military Academy at Woolwich in southeast London in 1897. After World War I he achieved the rank of lieutenant colonel. He lived many years in Africa before and after the war.

In 1931 Edgeworth returned to Ireland. Now retired, he self-published four books on economics, a subject of great interest during the Great Depression. He also began publishing work on astronomy in *Nature*, *Sky & Telescope*, and elsewhere. He discussed the solar system, star formation, red dwarfs, redshifts, and other topics. He even wrote a book on astronomy, *The Earth the Planets and the Stars: Their Birth and Evolution*, that appeared in 1961.

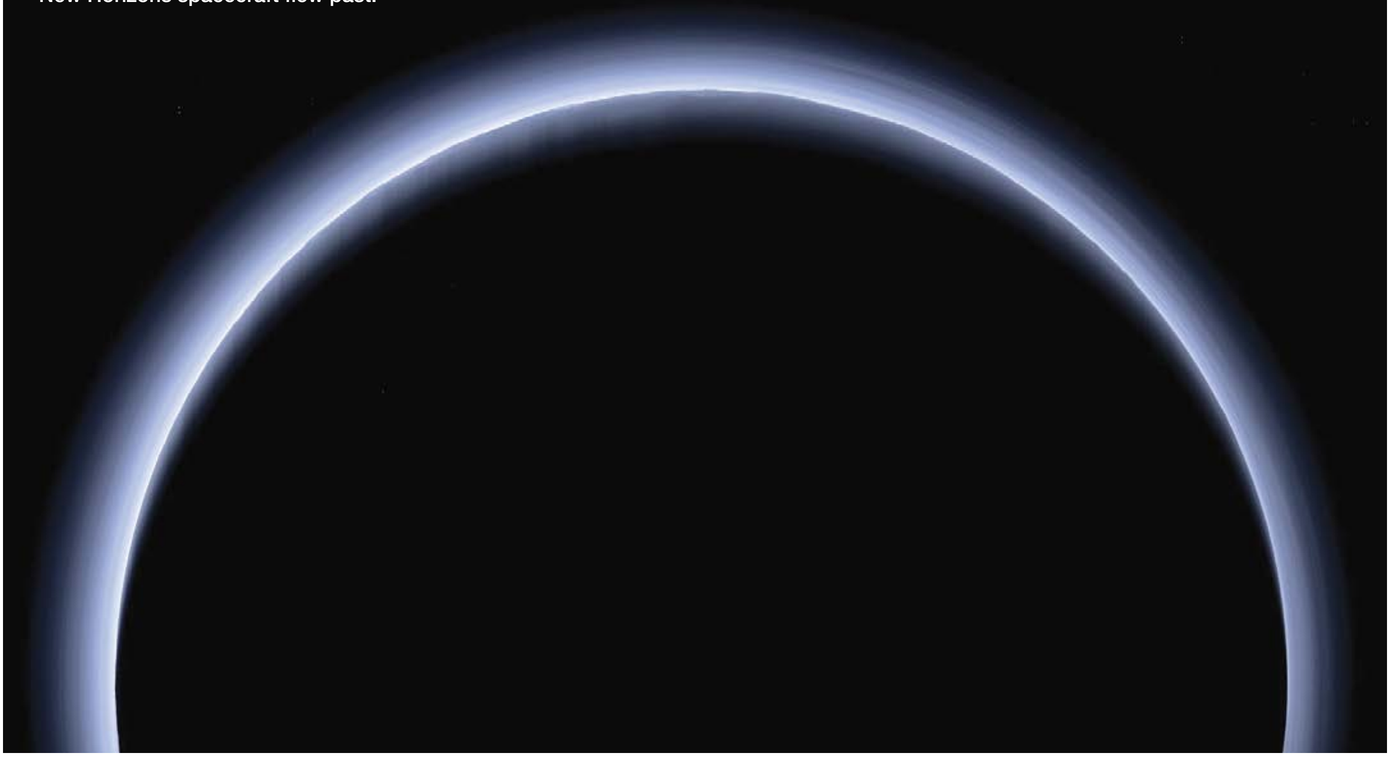
Four years later, at the age of 85, Edgeworth published his autobiography, *Jack of All Trades: The Story of My Life*. The book discusses his military duties but unfortunately not his astronomical work: "I do not propose to inflict on the reader a dissertation on astronomy." He died in Dublin in 1972, at the age of 92. Kuiper died a year later, aged 68.

The Edgeworth-Kuiper Belt

Edgeworth first proposed a trans-Neptunian belt in 1943, the same year that Tombaugh gave up his search for planets beyond Neptune and Pluto. Edgeworth's first sentence reflects wartime scarcity: "This paper was originally written at considerably greater length, but it has been cut down owing to the shortage of paper." Published in the *Journal of the British Astronomical Association*, the article described how the planets had condensed out of a disk of gas and dust that once revolved around the Sun.

In a section entitled "The Comets," he wrote:

> *It is not to be supposed that the cloud of scattered material which ultimately condensed to form the solar system was bounded by the present orbit of the planet Pluto; it is evident that it must have extended to much greater distances. It must*



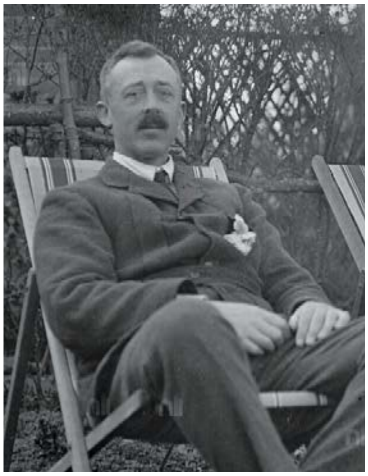
AIR APPARENT In 1988, astronomers discovered Pluto's atmosphere when the far-off world passed in front of a background star. Interesting though the atmosphere is, its presence prevented a firm determination of Pluto's diameter, which had to wait until 2015, when the New Horizons spacecraft flew past.

NASA / JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY / SOUTHWEST RESEARCH INSTITUTE *also be supposed that the opacity of the cloud diminished at greater and greater distances from the Sun. Since the formation of a single large planet is only possible when the opacity is not too low, it is evident that the condensations formed in this outer region would be unable to coalesce; they simply retained their individuality and condensed upon themselves.*

Then he wrote the key sentence: "It may be inferred that the outer region of the solar system, beyond the orbits of the planets, is occupied by a very large number of comparatively small bodies."

And indeed it is. Edgeworth concluded this section by saying, "From time to time a member of this swarm of potential comets wanders from its own sphere and appears as an occasional visitor to the inner regions of the solar system." This, too, is true, at least for most of the short-period comets.

Six years later, in 1949, Edgeworth published a similar paper in the much more widely read *Monthly Notices of the Royal Astronomical Society.* "The Origin and Evolution of the Solar System" again described the solar system's beginnings. Some of his ideas, however, contradict modern ones. For example, he thought that the Sun was born first and the planets only later, after it had captured material from interstellar space. This material not only formed the planets but also fell onto the Sun, ". . . and this explains why the rotation of the Sun is in the same direction as the motion of the planets in their orbits." In addition, Edgeworth took Pluto to be an escaped satellite of Neptune, a scenario that other astronomers had suggested in the 1930s and that Kuiper embraced in the 1950s.



KENNETH EDGEWORTH After retiring from his career in the military, this Irish polymath predicted the existence of a belt of objects in the outer solar system. He also said that these icy bodies can fall sunward and flare up in the Sun's light, thereby becoming visible comets in our sky.

In his 1949 paper, Edgeworth once again said that objects, which he now called "clusters," condensed out of the gas and dust revolving around the Sun. As they contracted, these clusters became planets, and leftover debris orbiting the planets condensed into their satellites.

"It would be unreasonable to suppose that the original rotating disk of scattered material came to an abrupt end outside the orbit of Neptune," he wrote. "There must have been a gradual thinning out of the material at the outer boundary."

And here again he predicted a belt of objects in the outer

DARAMONA OBSERVATORY In his youth, Kenneth Edgeworth visited his uncle's observatory in the village of Streete, County Westmeath, Ireland. The buildings housed 24-inch and 12-inch telescopes.

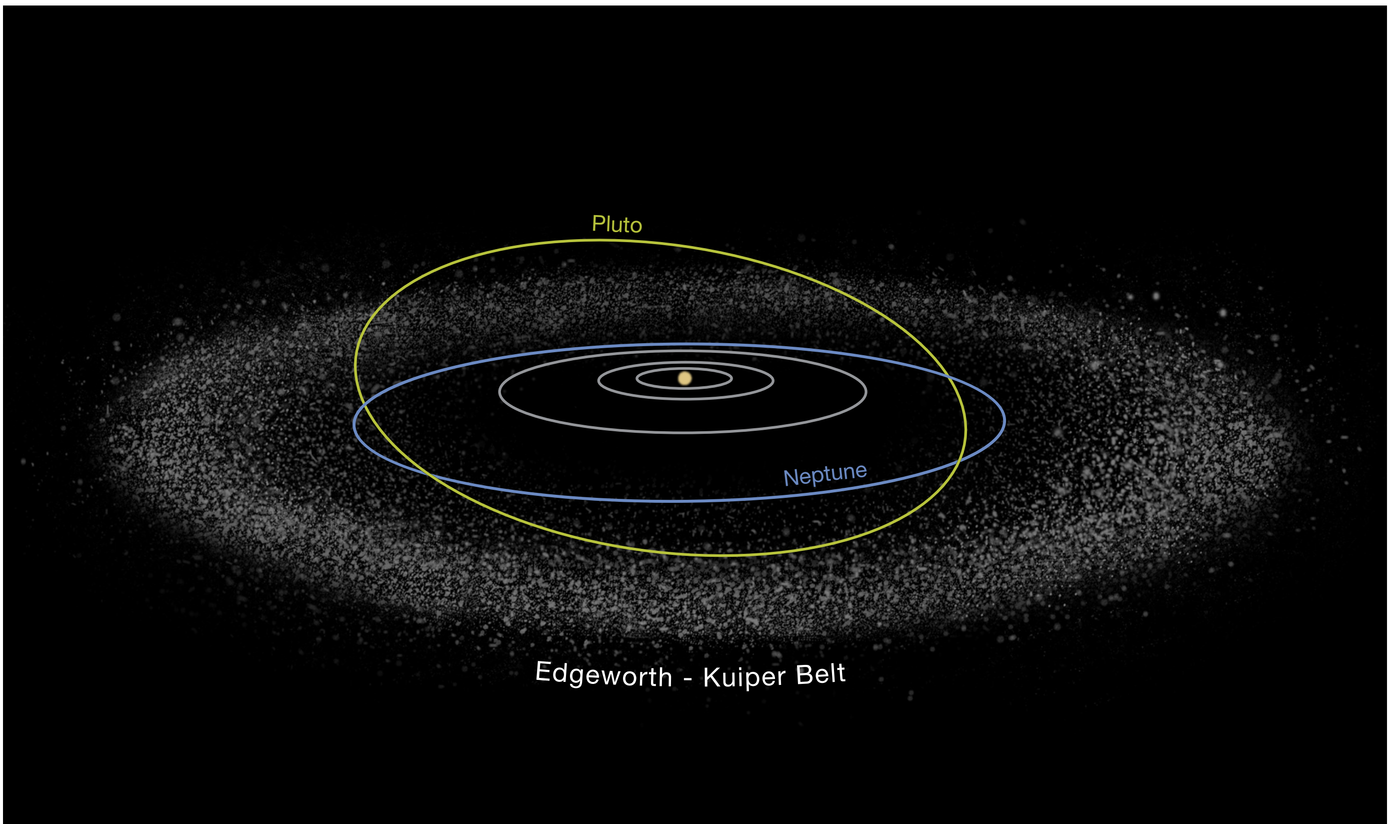
solar system:

It is not unreasonable to suppose that this outer region is now occupied by a large number of comparatively small clusters, and that it is in fact a vast reservoir of potential comets. From time to time one of these clusters is displaced from its position, enters the inner regions of the solar system, and becomes a visible comet.

Why didn't Kuiper mention Edgeworth? Although Edgeworth's first paper appeared in an obscure publication during the war, his 1949 paper was published after the war in a journal that Kuiper surely read. Some have suggested that Kuiper deliberately ignored Edgeworth in order to claim full credit for the idea himself. But because Kuiper thought that most of this belt no longer existed, it's hard to see how he would have ever received credit for it.

In any event, ever since the 1990s, astronomers who know the history and want to honor both scientists often refer to this region as the Edgeworth-Kuiper Belt. Although Edgeworth is still largely unknown, he had the idea well before Kuiper. In like fashion, the Hertzsprung-Russell diagram, which plots stellar luminosity against spectral type, was once known simply as the Russell diagram, named for the astronomer who used it to advance his ideas about stellar

▲ **A PIECE OF THE ACTION** Most short-period comets probably arise in the Edgeworth-Kuiper Belt. This 2017 image by the Rosetta spacecraft shows Comet 67P/Churyumov–Gerasimenko, which orbits the Sun every 6.4 years.



TRANS-NEPTUNIAN SPACE Most known objects orbiting the Sun beyond Neptune reside 38 to 48 times farther out than Earth does, a region Gerard Kuiper thought was empty of everything but Pluto.

COMET 67P/CHURYUMOV-GERASIMENKO: ESA / ROSETTA / MPS FOR OSIRIS TEAM / JUSTIN COWART; EDGEWORTH-KUIPER BELT: BEATRIZ INGLESSIS / S&T

evolution (*S&T:* July 2023, p. 34).

And who was largely responsible for renaming the Russell diagram? None other than Gerard Kuiper!

Russell's Revenge

Kuiper had earned his doctorate in 1933 under Danish astronomer Ejnar Hertzsprung. In 1911, Hertzsprung had plotted color versus apparent magnitude for stars in the Hyades and Pleiades clusters — German astronomer Hans Rosenberg had made a similar plot of the Pleiades the year before. In 1913, Henry Norris Russell, an astronomer at Princeton University, constructed a diagram comparing the spectral types and absolute magnitudes of stars. This came to be called the Russell diagram.

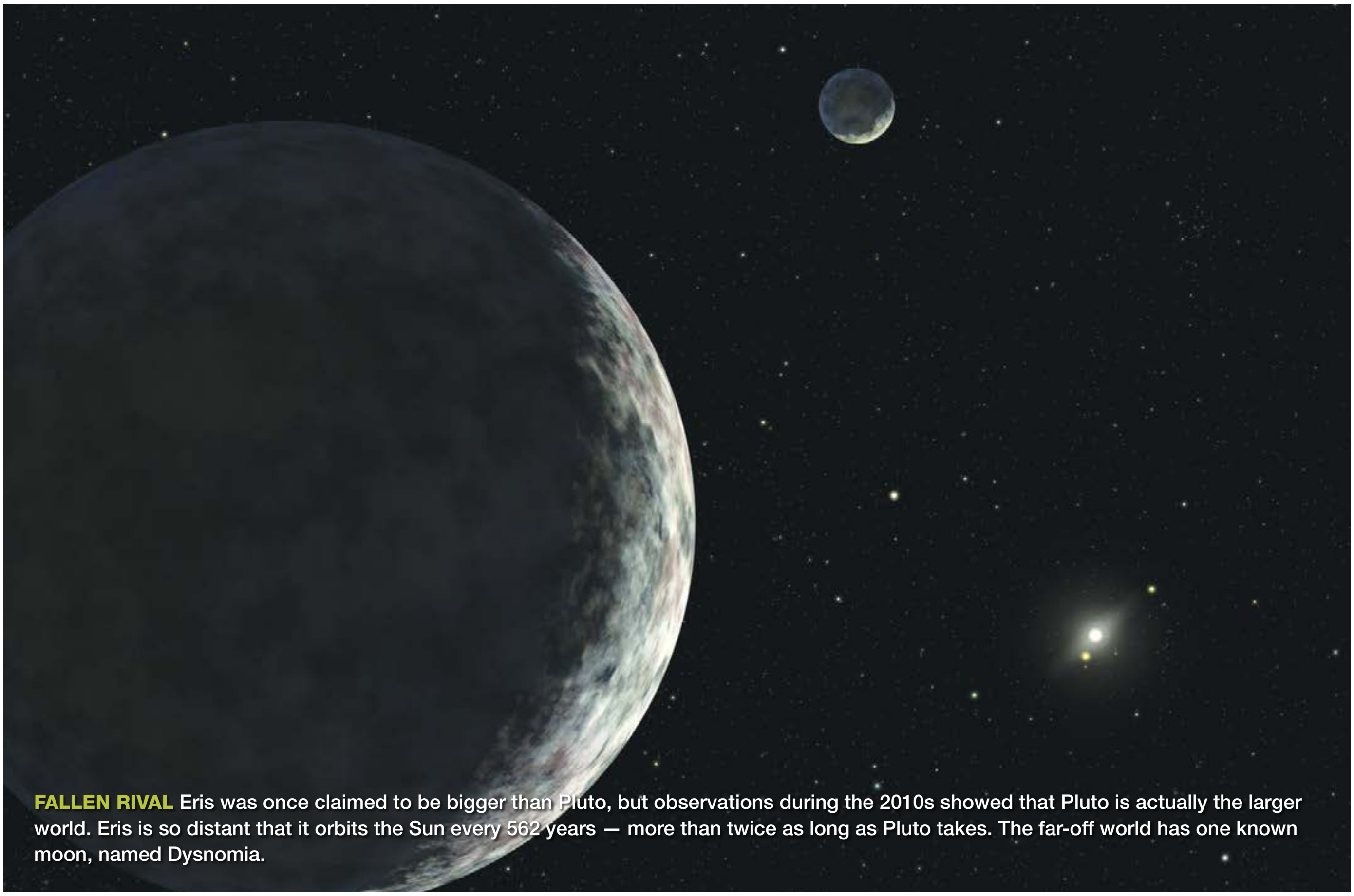
While attending a party in March 1936 near Harvard College Observatory, where he had a one-year appointment, Kuiper got into an argument with both Russell and Harvard astronomer Harlow Shapley, who had received his doctorate under Russell. "Kuiper objected to the 'Russell Diagram,' insisting . . . that it was more properly the 'Hertzsprung-Russell Diagram,'" David DeVorkin (National Air and Space Museum) writes in his book *Henry Norris Russell: Dean of American Astronomers*. "Kuiper later told Hertzsprung and [Subrahmanyan] Chandrasekhar that his suggestion annoyed Russell considerably. Kuiper had demanded top billing for Hertzsprung and was astonished when, he reported, Russell barked back, 'Hertzsprung did not make it!'"

Kuiper was furious. The dispute sent him to Harvard's astronomy library, where he documented Hertzsprung's priority. Kuiper later joined Yerkes Observatory, operated by the University of Chicago, which published the *Astrophysical Journal*. In the late 1940s, under pressure from Kuiper, Chandrasekhar, also at Yerkes, adopted "Hertzsprung-Russell diagram" as the journal's style. And that's how astronomers worldwide now refer to this cornerstone of stellar astronomy.

Given Kenneth Edgeworth's clear priority in predicting the belt of bodies beyond Neptune, one can make an equally convincing case that this region be called the Edgeworth-Kuiper Belt. Moreover, Edgeworth's vision of the trans-Neptunian belt differed from Kuiper's in two key — and correct — ways. First, Edgeworth said the belt still exists today. Second, he said this belt can supply comets to the inner solar system.

Finally, by a happy accident, "Edgeworth-Kuiper Belt" encompasses the concept of the *edge* of the solar system's planetary domain, beyond which reside even farther-flung frigid bodies whose territory likely stretches halfway to Alpha Centauri.

KEN CROSWELL is the author of *Magnificent Universe* and *Ten Worlds*, both of which refer to the region just beyond Neptune's orbit as the Edgeworth-Kuiper Belt.



FALLEN RIVAL Eris was once claimed to be bigger than Pluto, but observations during the 2010s showed that Pluto is actually the larger world. Eris is so distant that it orbits the Sun every 562 years — more than twice as long as Pluto takes. The far-off world has one known moon, named Dysnomia.

NASA / JPL-CALTECH

 by Howard Banich

A Deep Dive into Stephan's Quintet

Let's visit the original compact group of galaxies.

NASA / ESA / CSA / STSCI

MAELSTROM OF GALAXIES This JWST infrared image of Stephan's Quintet was part of the first image release in July 2022 and shows five of the tightly grouped objects that make up this compact galaxy group — the first of its kind ever discovered. From top left and going clockwise they are: NGC 7319, NGC 7318A, NGC 7318B, NGC 7317, and NGC 7320. One of these galaxies — NGC 7320 at bottom — is in the foreground, but a sixth galaxy, just outside on the left of the image, is a gravitational member. There's a lot going on here! In this image, north is at 11 o'clock, but is up in all the other images featured here.

The French astronomer Jean Marie Édouard Stephan was lucky enough to be an early user of the revolutionary 80-cm (31-inch) f/5.8 Foucault reflector at the Marseilles Observatory in southern France. This was the first sizable telescope to use a glass primary mirror with a silver coating instead of one made with polished speculum metal, paving the way toward today's huge reflecting telescopes. Just as importantly, on the night of September 27, 1873, the reflector showed him "Les quatre nébuleuses" (*the four nebulae*) in Pegasus, which turned out to be the first compact group of galaxies ever discovered. They were subsequently named **Stephan's Quintet** in his honor.

Stephan published the results in an 1877 paper using his numbering system (translated from the French):

> *The four nebulae 19, 20, 21 and 22 are excessively, excessively faint; excessively small; very difficult to observe. The most beautiful is 19; then come 20, 21, 22. However 22, although the smallest of the four, is brighter.*

During the course of the next year, astronomers discovered 14 more compact galaxy groups. At one point in his career, Stephan wrote that he was "impressed by the high frequency of groups of nebulae [i.e., galaxies] that populate some regions of the sky." However, other than new discoveries, his main observation program was to measure precisely the positions of nebulous objects so that they could be used as fixed references for determining the proper motions of stars in the Milky Way Galaxy. He even discovered two asteroids.

American astronomer Halton Arp cataloged Stephan's Quintet in his 1966 *Atlas of Peculiar Galaxies* as Arp 319, and Canadian astronomer Paul Hickson listed it in his 1982 publication *Systematic Properties of Compact Groups of Galaxies* as Hickson 92. Both catalogs have become popular observing guides among amateur observers.

Four vs Five

Yes, a quintet is five of something, but Stephan described only *four* galaxies. So why is his discovery called a quintet? He saw NGC 7318 as one glow, instead of the two closely paired galaxies that later observations revealed.

The Galaxies of the Quintet

If you're a fan of the 1946 film *It's a Wonderful Life*, Stephan's Quintet makes a surprise appearance — it's likely the first time the galaxies gained any notice from the general public. It recently re-entered the public's consciousness when the JWST team released the spectacular image on page 28. Since the Quintet's discovery, it has probably been the most intensely studied compact galaxy group of all time.

Before going any further, let's get acquainted with the individual galaxies of Stephan's Quintet:

NGC 7317 This is an elliptical galaxy that may have passed through the center of Stephan's Quintet in the distant past.

NGC 7318A Another elliptical galaxy. It might be connected to NGC 7318B, but it's probably in the background.

NGC 7318B This distorted, barred spiral galaxy is *blueshifted* because it's moving rapidly from behind the compact group *toward* us and is crashing into the dense intergalactic medium, triggering star formation and creating a shocked ridge of material that's bright in infrared and X-rays — this is the curved, reddish bar between NGC 7318B and NGC 7319 in the JWST image. Its movement is also throwing tendrils of gas and dust in front of NGC 7319.

NGC 7319 The only confirmed active galaxy in the group, this distorted, barred spiral is a Seyfert I galaxy with a 24-million-solar-mass black hole in its core and has two tidal tails probably caused by a close pass with NGC 7320C long ago.

NGC 7320 This spiral galaxy is well in the foreground. It's at about the same distance as the fantastic spiral galaxy NGC 7331, which lies about ½° to the north-northeast (see the photo on page 41). Because NGC 7320 lies in the foreground, it isn't interacting gravitationally with the other members of Stephan's Quintet — but it does give the grouping a distinctive composition. This is the largest and brightest galaxy in Stephan's original discovery. Without it, the Quintet would have a distinctly linear shape.

NGC 7320C A sixth galaxy? Although not part of the *compact* group, NGC 7320C is a gravitational member. In a true sense, this is the fifth galaxy of Stephan's Quintet (and not NGC 7320). It's also the faintest and most difficult to see.

A Brief Kinematic History of the Quintet

The measured redshifts of each galaxy allow us to calculate their distances. But we need to take the redshifts with a pinch of salt as we construct a 3D configuration of Stephan's Quintet. That's because, in a compact group, each galaxy can also have a significant inter-group velocity — either away from or toward us — that gets folded into its measured redshift.

We have no way of knowing how much the redshifts of the two elliptical galaxies, NGC 7317 and NGC 7318A, are modified by their inter-group motions. However, the distances to two other galaxies in Stephan's Quintet are definitely affected by their local velocities.

First, let's look at NGC 7320C. Computer models show that this surprising fifth gravitational member of the Quintet is the probable cause of NGC 7319's tidal tail. Make that *tails*: There are actually two — an inner and an outer tidal tail, both of which are the likely result of a close passage of NGC 7320C about 500 million years ago.

The measured redshifts put about 36 million light-years between NGC 7319 and NGC 7320C, yet there hasn't been enough time for NGC 7320C to actually get that far from NGC 7319. Based on that, and the computer simulations showing that NGC 7320C is the likely cause of NGC 7319's

tidal tails, it's reasonable to suppose that NGC 7320C has significant motion toward us and is at a similar distance as NGC 7319. More than that, it may have also created the Northern Starburst Region, which is a gigantic area of intergalactic gas it generated when zooming by NGC 7319 that has been energized by the more recent passage of NGC 7318B.

The case of this galaxy is perhaps even more fascinating. Its redshift places it at a similar distance as NGC 7320C, but a 150,000-light-year-long ridge of shocked gas and star formation tells a different story. NGC 7318B is compressing the intergalactic medium (composed mostly of hydrogen and carbon monoxide) to such an extent that it's not only causing star formation but is also heating the gas so that it glows in X-rays.

The only way for NGC 7318B to do this is to have a significant component of motion toward us. It does, and it's been measured at about 900 km/s. This ongoing, high-speed physical interaction is also evident in visual and infrared images, and simulations place NGC 7318B at about the same distance as NGC 7319, NGC 7318A, and NGC 7317.

A close examination of the Hubble and JWST images also shows that tendrils of gas and dust from the shocked ridge of gas are in front of NGC 7319. Computer simulations suggest that as NGC 7318B hurtled toward both NGC 7319 and NGC 7318A from behind, along the way it may have briefly interacted with NGC 7318A before crashing into the intergalactic medium, creating the ridge. It then zipped between NGC 7319 and NGC 7318A about 300 million years ago.

Another sign of the gravitational game of Twister being played in Stephan's Quintet is that NGC 7319's stellar disk and gas disk are nearly perpendicular to each other.

Astronomers expect that in a few billion years NGC 7317, NGC 7318A, and NGC 7319 will merge and form a single elliptical galaxy. NGC 7320C may or may not get caught up in this merger, but NGC 7318B definitely won't — speeding through at 900 km/s it will escape into intergalactic space.

Cool beans, huh?!

Observations

Can any of these galaxies, let alone the entire compact group, be seen visually with an amateur telescope? The good news is "yes, but . . ." The catch, as always, is that you must be under a truly dark and transparent sky to see Stephan's Quintet well. Remember, the *brightest* galaxy in the group is magnitude 12.6.

I've seen the four brightest galaxies through a smoky but dark sky by putting a 10-inch aperture mask on my 30-inch scope, temporarily turning it into a 10-inch f/8 unobstructed reflector. I was unable to split NGC 7318A and NGC 7318B, but in the spirit of Stephan's original discovery, I'm (*ahem*) giving myself, and many other observers, credit for both.

During that observation, NGC 7320 — the closest and brightest of the group — was the easiest to detect, followed by the combined glow of NGC 7318A/B, and finally NGC 7319. I couldn't detect NGC 7317, probably because of the wildfire smoke. This observation has become motivation for me to try again on a dark night with better transparency.

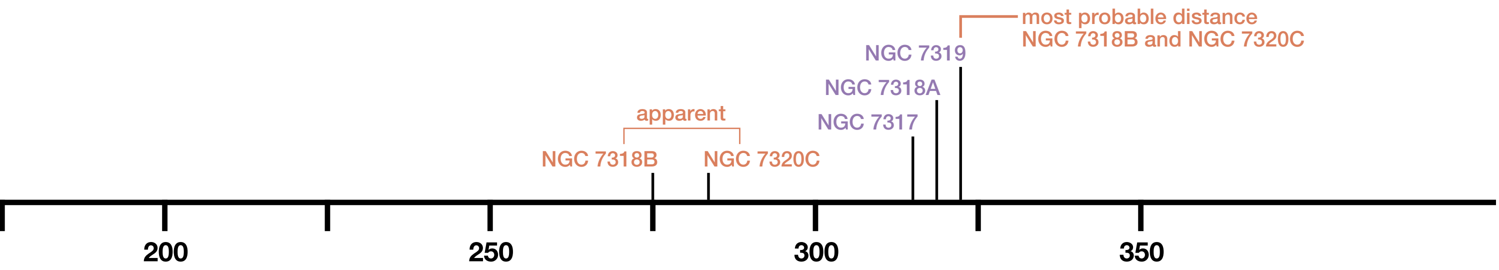
Views with my 20-inch, 28-inch, and 30-inch scopes have all been rather similar — the main difference lay in that the larger apertures showed the galaxies as progressively more substantial glows. I've seen precious little internal detail in any of these targets, except that NGC 7320C is easier to see

Quintet Plus One

Object	Type	Stephan No.	Surface Brightness	Mag(v)	Size/Sep	Distance (Ml-y)	RA	Dec.
NGC 7317	Elliptical	19	13.8	13.6	0.4′ × 0.4′	314	$22^h 35.9^m$	+33° 57′
NGC 7318A	Elliptical	20	13.1	13.4	1.2′ × 1.0′	317	$22^h 35.9^m$	+33° 59′
NGC 7318B	Barred spiral	20	13.2	13.1	1.6′ × 1.1′	275	$22^h 36.0^m$	+33° 58′
NGC 7319	Barred spiral	21	13.8	13.1	1.4′ × 1.1′	321	$22^h 36.1^m$	+33° 59′
NGC 7320	Spiral	22	13.5	12.6	2.2′ × 1.1′	37	$22^h 36.1^m$	+33° 57′
NGC 7320C	Barred spiral	—	13.4	15.5	0.6′ × 0.4′	285	$22^h 36.3^m$	+33° 59′

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.

BEATRIZ INGLESSIS / *S&T*



with increasing aperture. That's nice, but I really hoped to see more features!

Even so, I've even seen a bit of detail under the best conditions with my 30-inch scope at 396×:

NGC 7317 This roundish elliptical galaxy has a tiny, starlike core, which gradually fades to an indistinct perimeter.

NGC 7318A Slightly brighter, this elliptical has a much broader core area that slowly condenses to its brightest at its center, without appearing stellar. The rest of the galaxy transitions into a more distinct faint perimeter than NGC 7317.

NGC 7318B A powerhouse barred spiral galaxy, it looks like a near twin to NGC 7318A but has a slightly smaller and dimmer core area. I detected a trace of its northern spiral arm but nothing of the shocked ridge of gas and dust, darn it.

NGC 7320 Not a gravitational member of the compact group, this much closer, tilted spiral galaxy has an overall oval shape and shows no detail other than a slightly brighter interior and an irregular perimeter.

NGC 7319 Appearing as the second largest of the group, this disturbed barred spiral galaxy looks like an oval smudge with a slightly brighter core.

NGC 7320C The fifth gravitational member of the group, this little barred spiral has only shown me a fuzzy perimeter and a slightly brighter core.

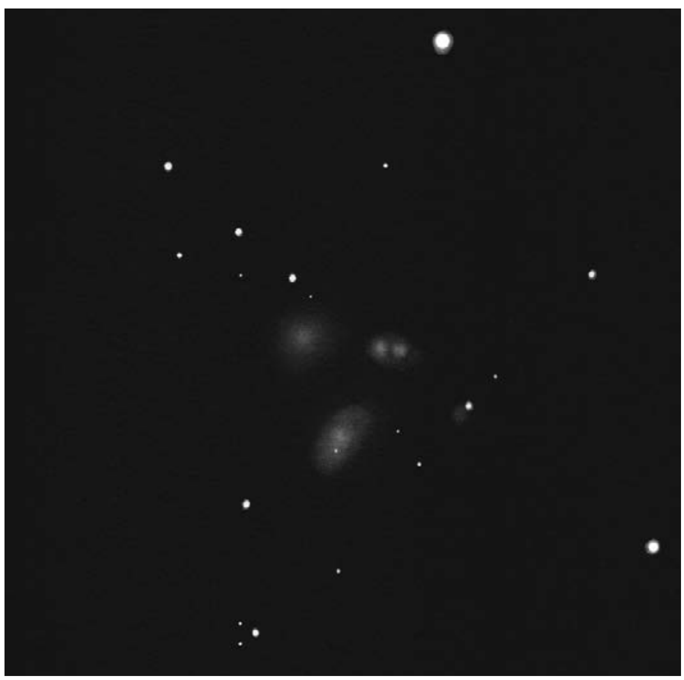
By comparison, the observations of German amateur Uwe Glahn are remarkable. With his 27-inch telescope and an assist from a 36-inch, he saw almost *everything* at a site high in the Austrian Alps:

The sky conditions were very good. We were at a High Alpine location called Edelweißspitze at 2,560 meters (8,400 ft) . . . Transparency was very good, but not perfect. Limiting magnitude was around 7 mag. The Seeing was average. The blob north of 7318 was similar bright and clear like the arm of 7319. The brightening between 7318 and 7319 was only suspected. I could not see the long tidal SE of 7318 but could confirm this detail in a later 36-inch observation. 419×

Uwe's observation of all five galaxies using his 8-inch f/4 Newtonian is also outstanding, as he recounted in an email:

The 8-inch observation was made from only rural skies here. Limiting magnitude was around 6.5 mag. The Seeing was above

▲ **IN THE FLYING HORSE** You'll find Stephan's Quintet in northwestern Pegasus. Use either 3rd-magnitude Eta Pegasi or NGC 7331 to navigate to the galaxy group — page 41 shows the area in the black box above.



▲ **SMALLER APERTURES YIELD VIEWS, TOO** You don't need a huge scope to spot Stephan's Quintet, as this sketch made with views through an 8-inch telescope demonstrates.

UWE GLAHN

average. Most difficult galaxy to confirm was 7317. In my notes I wrote: "difficult to separate from the 13 mag star, very faint glow just south of the star, looks like a faint Double Star companion." Beside the galaxies I tried to catch up all visible stars to classify the observed galaxy magnitudes. 160×

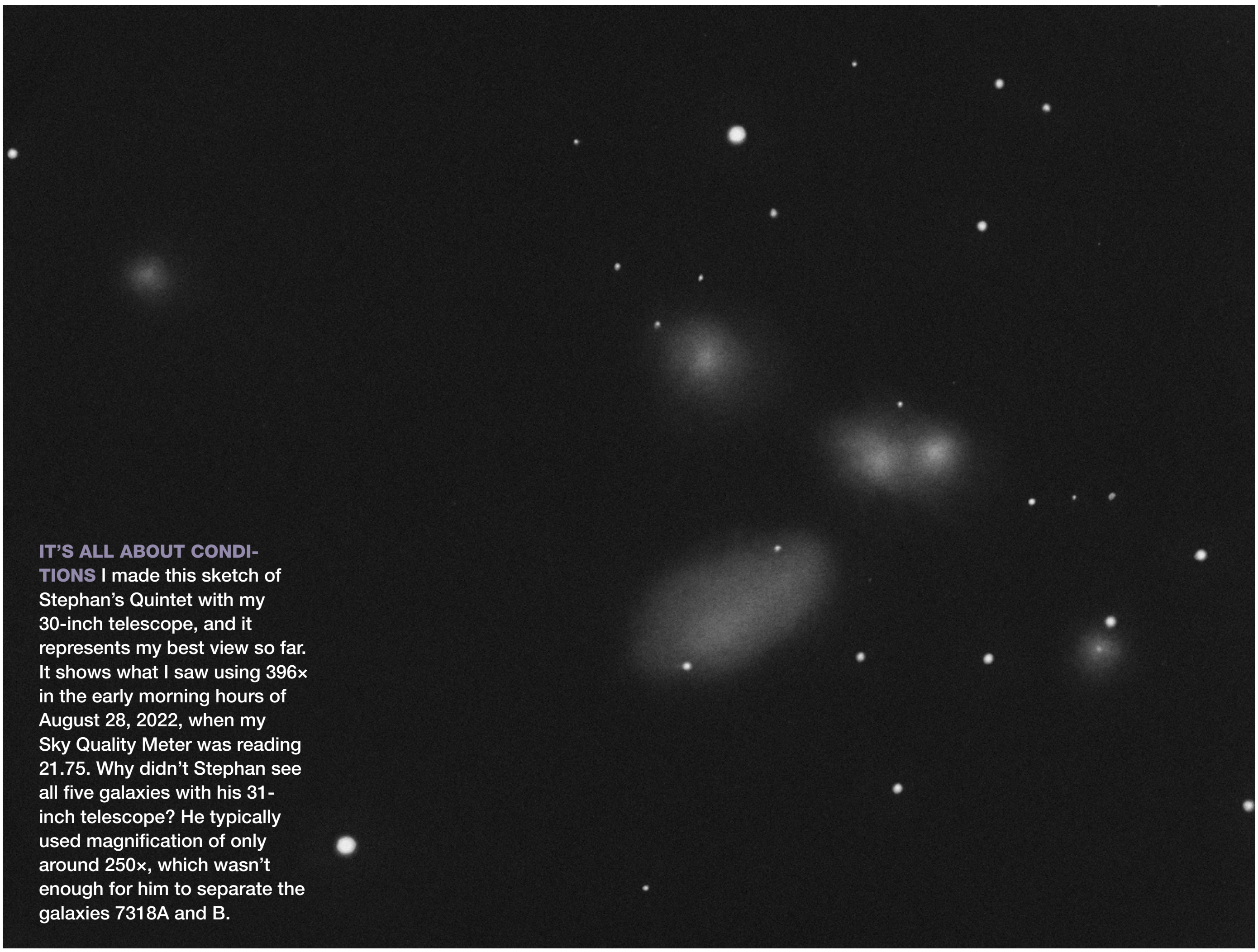
Former *Sky & Telescope* Contributing Editor Sue French reported seeing all five members of Stephan's Quintet with her 10-inch reflector using 311×.

As legendary observer and Contributing Editor Steve Gottlieb underscores, Stephan's Quintet is within reach of many amateur telescopes: He saw four members with an 8-inch and three members with a 6-inch scope. Indeed, Uwe was able to detect the overall glow of the group and two very faint individual glimmerings within it while using a 4-inch reflector.

Give It a Go!

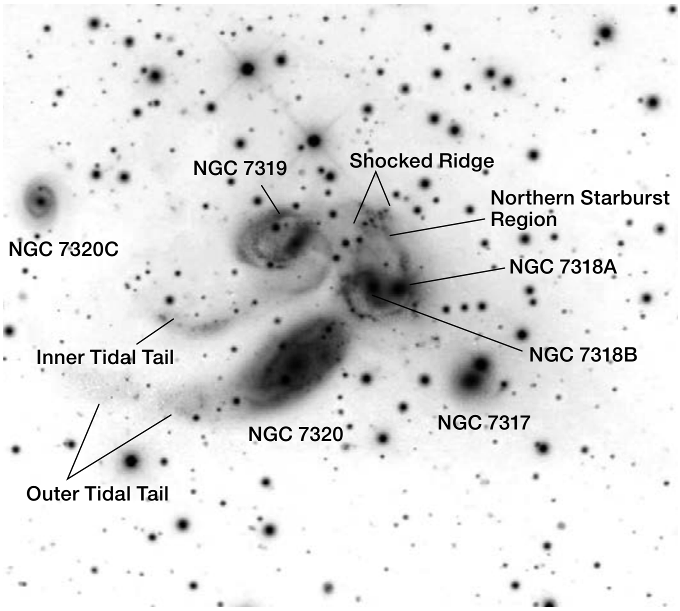
The location of the Quintet makes it a pretty easy object to find. Look for it 4° north-northwest of 3rd-magnitude Eta (η) Pegasi. Alternatively, drop ½° south-southwest of the 9.5-magnitude galaxy NGC 7331. The Quintet can, however,

▲ **PRETTY AS A PICTURE** Above is a ground-based visible-light image captured with a 24-inch f/8 telescope.



IT'S ALL ABOUT CONDITIONS I made this sketch of Stephan's Quintet with my 30-inch telescope, and it represents my best view so far. It shows what I saw using 396× in the early morning hours of August 28, 2022, when my Sky Quality Meter was reading 21.75. Why didn't Stephan see all five galaxies with his 31-inch telescope? He typically used magnification of only around 250×, which wasn't enough for him to separate the galaxies 7318A and B.

VISIBLE-LIGHT IMAGE: JOSEF PÖPSEL / STEFAN BINNEWIES / RAINER SPARENBERG; SKETCH: HOWARD BANICH



▲ **OF RIDGES AND TAILS** You can use this image to identify the various features discussed in the text, as well as the galaxies.

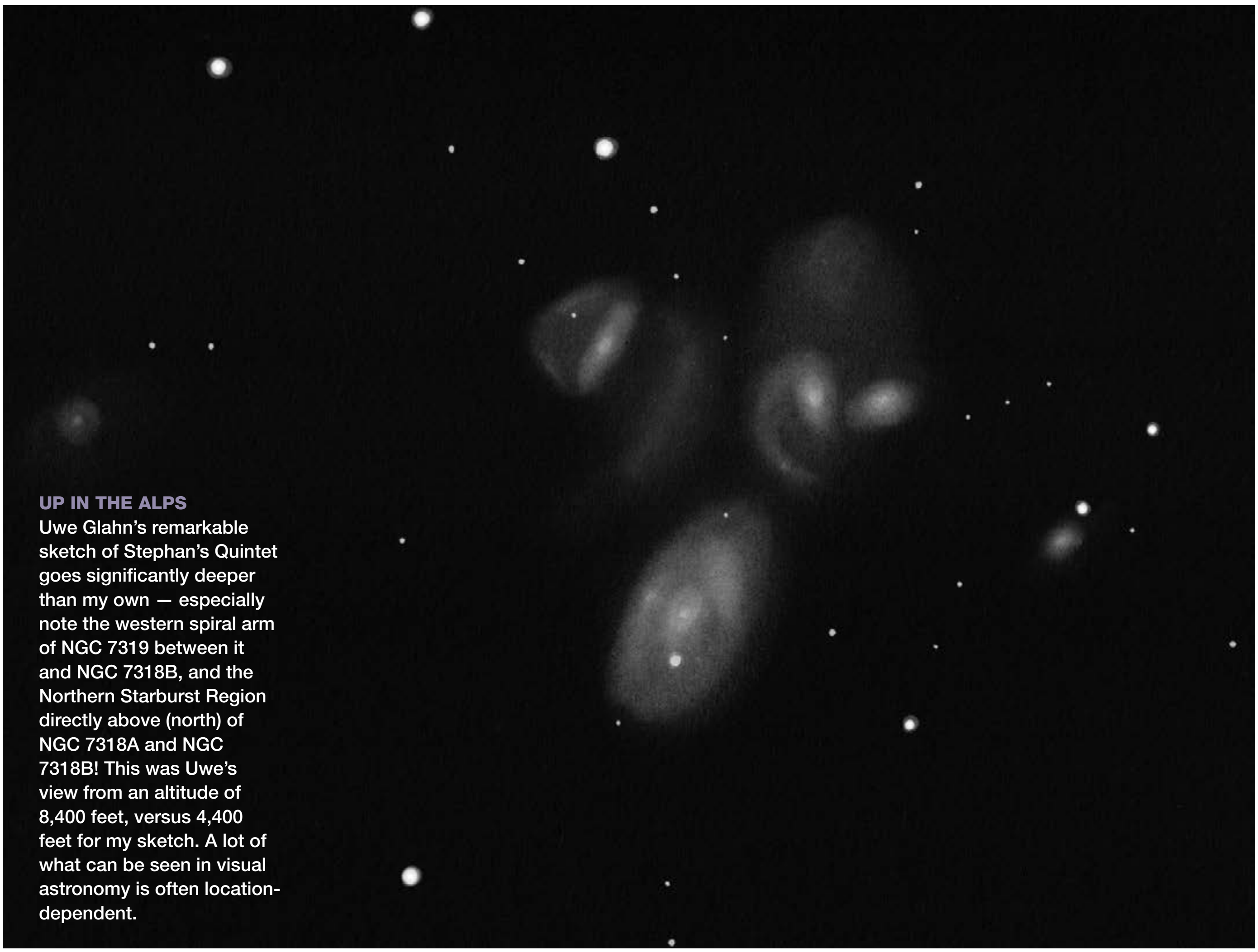
ascend to near the zenith for mid-northern latitude observers in late summer and early fall, and this can get uncomfortably close to *Dobson's Hole* — the area of sky near the zenith where the motions of an alt-az mount like a Dobsonian make it difficult to maneuver. Just something to watch out for.

The Quintet inspired me to observe the other 99 compact groups in Hickson's catalog, and then tackle Arp's *Atlas*, which I'm still observing my way through. Even though Stephan's Quintet was just the start for me, it remains one of my favorite wonders of the night sky.

Remember that word — wonder — while you're observing Stephan's Quintet, or any compact galaxy group for that matter. Imagine what the night sky might look like from an Earth-like planet in one these galaxies on a dark, transparent night.

■ Contributing Editor **HOWARD BANICH** loves seeing a handful of galaxies in the same high-power field of view. You can reach him at **hbanich@gmail.com**.

GLAHN'S SKETCHES To see more of Uwe Glahn's phenomenal sketches, head to **www.deepsky-visuell.de**.

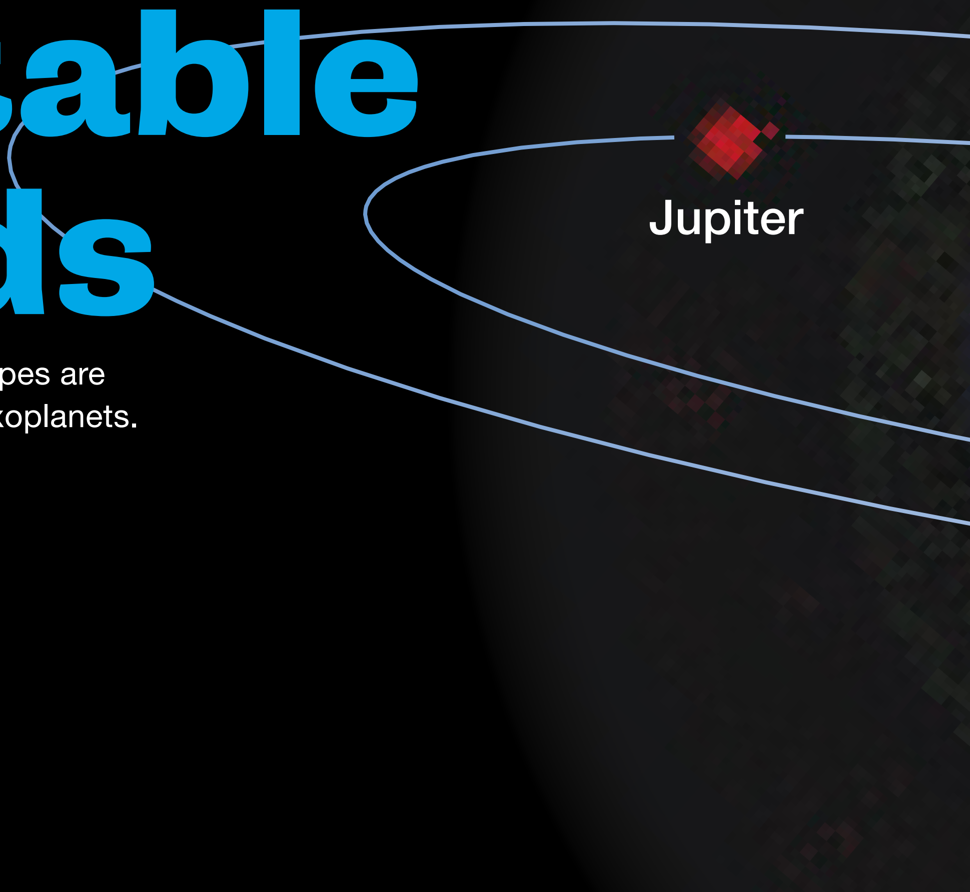


UP IN THE ALPS
Uwe Glahn's remarkable sketch of Stephan's Quintet goes significantly deeper than my own — especially note the western spiral arm of NGC 7319 between it and NGC 7318B, and the Northern Starburst Region directly above (north) of NGC 7318A and NGC 7318B! This was Uwe's view from an altitude of 8,400 feet, versus 4,400 feet for my sketch. A lot of what can be seen in visual astronomy is often location-dependent.

ROB GENDLER

Seeing Habitable Worlds

Bigger and better upcoming telescopes are primed to snap images of diverse exoplanets.



SPACE TELESCOPE SCIENCE INSTITUTE AND NASA GODDARD SPACE FLIGHT CENTER

Imagine being asked to pick out the glow of a tiny firefly's derriere as it buzzed around the dazzling brilliance of a lighthouse beacon. Could you do it?

It sounds like an impossible task, but it's the equivalent of what astronomers do every time they attempt to take an image of an exoplanet.

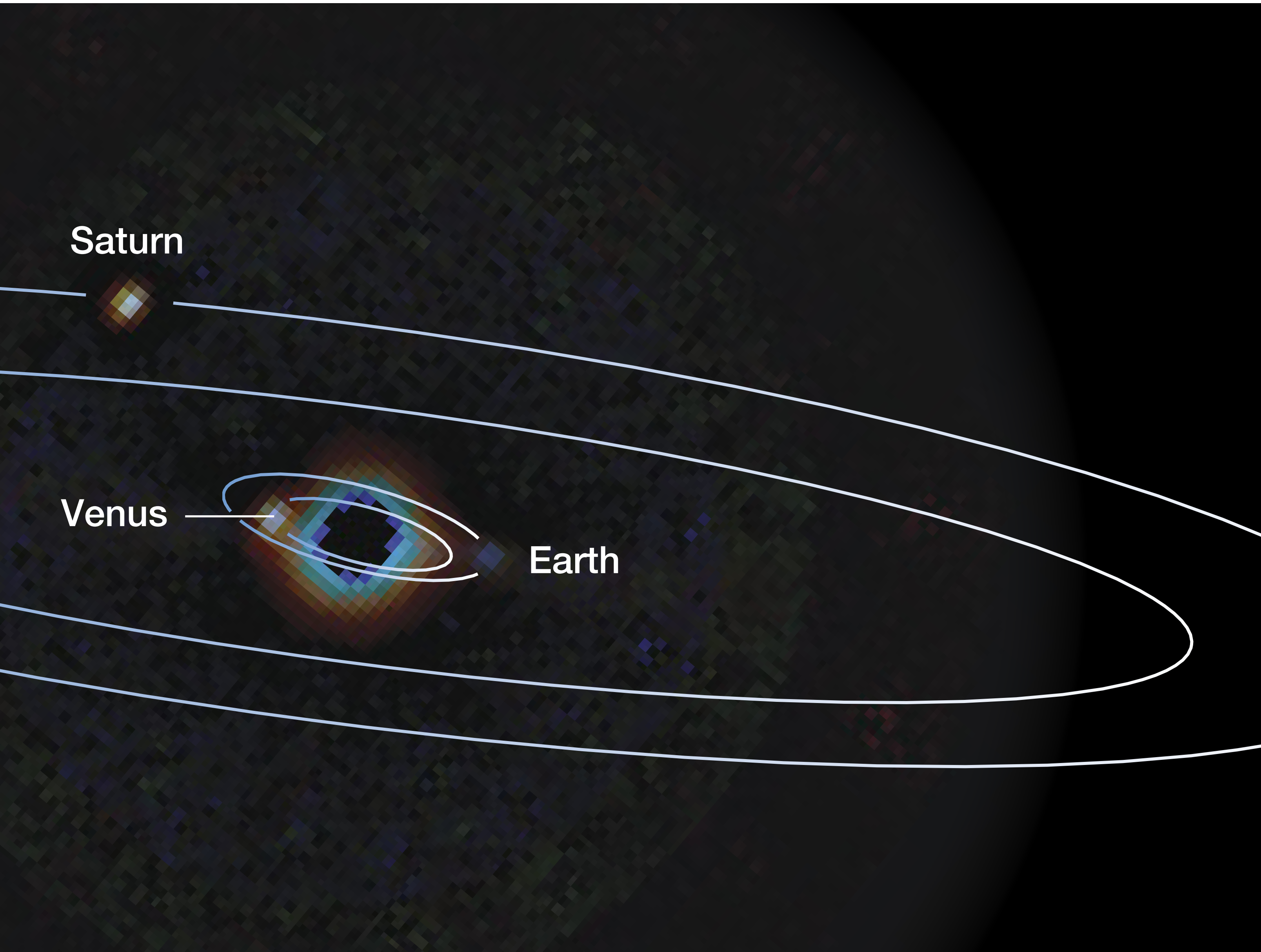
So far, more than 5,600 worlds outside the solar system have been detected around other stars. Astronomers have found most of them indirectly, usually by observing the small dip in starlight when the planet passes in front of its sun, in an event called a transit. But a small minority (a few dozen) have been directly imaged.

Although other ways of detecting exoplanets exist, these two methods can be used to determine the composition of an alien world's atmosphere and tell us if it could support life as we know it. They therefore offer the best hope of addressing the big question most people expect exoplanet science to answer: Are we alone in the universe?

To narrow the playing field, astronomers focus on finding and characterizing planets orbiting the right distance from their stars such that, with an Earth-like atmosphere, the planet's surface temperature would be just right for stable liquid water to exist. This range of orbits is known as the habitable (or "Goldilocks") zone.

The transit method is useful if we want to look at the habitable zones around very small stars. Here, planets regularly pass in front of their star from our perspective, perhaps circling once every 10 days, because they must tuck in close to benefit from their star's lukewarm glow.

Using the transit method to find planets orbiting big-



ger, Sun-like stars is more difficult, though. Here, the habitable zone is farther out, and the chances of a potentially habitable planet passing in front of its star while we are looking are slim. What's more, characterizing that planet's atmosphere would require repeated measurements of its spectrum every orbit for decades, making the whole endeavor impractical.

Thus, despite the relative rarity of successes so far, astronomers are turning to direct imaging to help them find potentially habitable worlds. Switching to direct imaging comes with benefits. "We can get orbital information without having to disentangle overlapping signals, we can get an estimate of the size of the planet based on evolutionary models for how bright it should be, and we can get information about the atmosphere from spectra," explains exoplanet imaging expert Briley Lewis (University of California, Los Angeles).

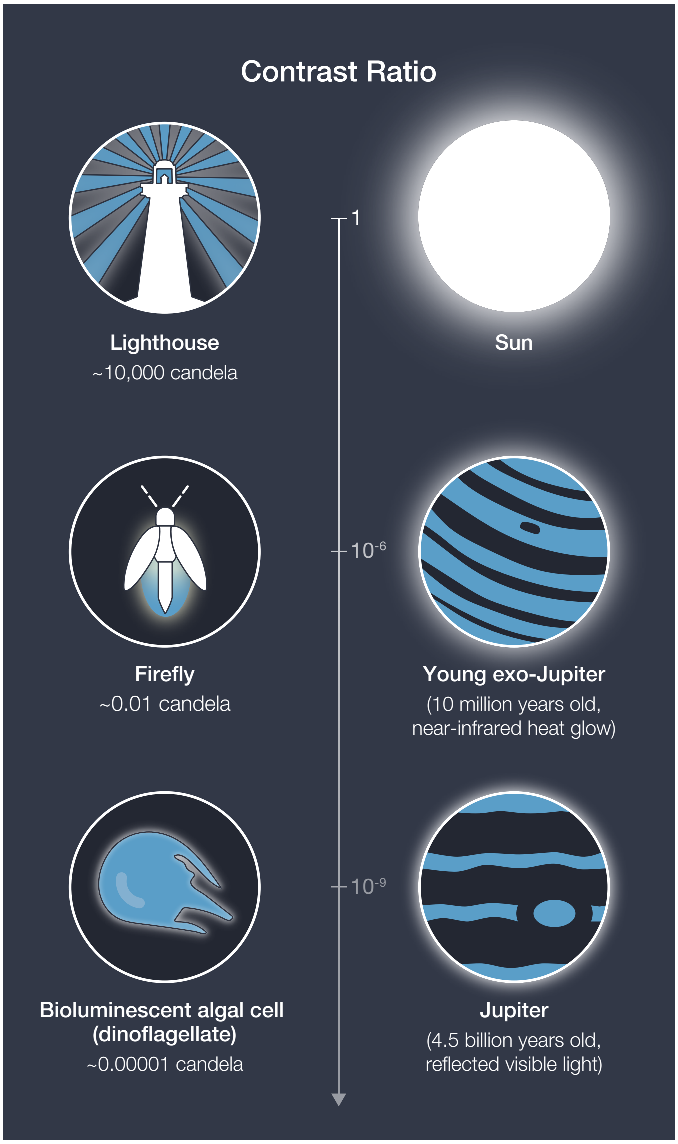
Yet it's also arguably the most challenging technique to pull off. So far, only the brightest, biggest planets — gas giants with no prospect of harboring our kind of life — have been directly imaged. In the coming years, astronomers hope to change that.

▲ **FAINT DOTS** This simulated image shows what the solar system would look like as seen from 30 light-years away by a space telescope like the proposed Habitable Worlds Observatory — that is, with a primary mirror approximately 6 meters wide and a coronagraph that enables the detection of planets one-ten-billionth as bright as their host stars.

Ten Billion to One

Up to now, the exoplanets that astronomers have imaged have been at most 1 million times dimmer than their host star — the firefly around the lighthouse. When we try to directly image an Earth-like exoplanet, though, we're actually looking for something much fainter. We need to replace our firefly with the infinitesimally dim glow of a single bioluminescent alga cell — and even that is still a little too bright. Put another way, any Earth analog will be at least 10 billion times fainter than its sun.

Spotting such a puny signal requires extreme precision in blocking out as much of the star's light as possible, much as you would do by holding up your hand to block out the dazzle from the lighthouse. This must be done without obstructing the precious photons coming from the planet.



▲ **IF YOU SQUINT** A young gas giant, still glowing with the heat of its formation, is a millionth as bright as the Sun. A more mature gas giant, like Jupiter, no longer glows brightly in infrared; its brightness primarily comes from reflected starlight. This gleam is even fainter — a thousandth as bright as the young planet and a billionth as bright as the Sun.

As light from a planetary system enters an exoplanet-imaging telescope, it is first corrected by *adaptive optics*, a continuous monitoring system linked to actuators that intentionally warp the telescope's mirror to compensate for any aberration in the captured light (*S&T:* May 2016, p. 30).

For space telescopes, this system corrects for things like polishing errors and slow drifts in the system. For ground-based telescopes, it also crucially corrects for turbulence in Earth's atmosphere — the primary confounding factor when conducting any astronomical studies from terra firma.

Once all the aberrations are removed and the light from the star is exquisitely focused, the next step is (ironically) to block most of that light out. This is done using an instrument called a coronagraph.

"The name coronagraph harkens all the way back to the first application of this technology, which was by Bernard Lyot in the 1930s, who wanted to block out the disk of the Sun to create an artificial eclipse," explains Vanessa Bailey (NASA Jet Propulsion Laboratory).

Lyot essentially installed a spot or "mask" inside his telescope to exactly cover the disk of the Sun. Combined with other optical elements, the design enabled him to observe our star's outer atmosphere, called the corona. "We can adapt that technology from being applied to the Sun to a small, point-like distant star and have the same goal of blocking the bright starlight to see something faint around it."

Amateur astronomers may have done something similar, using an occulting bar to hide bright stars in order to see a faint planetary nebula or other deep-sky object in the same field of view. But seeing a planet nestled up close to its star requires something more. Although the principle remains the same, today's professional coronagraphs are significantly more sophisticated than a physical bar or disk, incorporating various optical principles of interference using multiple masks and deformable mirrors.

After passing through the instrument's adaptive optics and coronagraph, the tiny amount of remaining light coming from the planet (as well as the final dregs of stray starlight) feeds into a spectrograph and image-processing equipment. These extract every last piece of information from every last photon, including which compounds may exist in the exoplanet's atmosphere.

Unwelcoming Worlds

In all, somewhere between 25 and 80 exoplanets have been directly imaged using this process. The uncertainty comes from how we define a planet: Some candidates are so massive that they appear to be more akin to failed stars, known as brown dwarfs, while other "rogue planets" wander the galaxy without a host star.

Bruce Macintosh (University of California, Santa Cruz) has had a hand in many of these exoplanet discoveries. Among his favorites are the proverbial poster children for direct imaging: the planets that form the multi-planet system around HR 8799, a main-sequence star visible to the naked eye and located about 133 light-years from Earth in the constellation Pegasus.

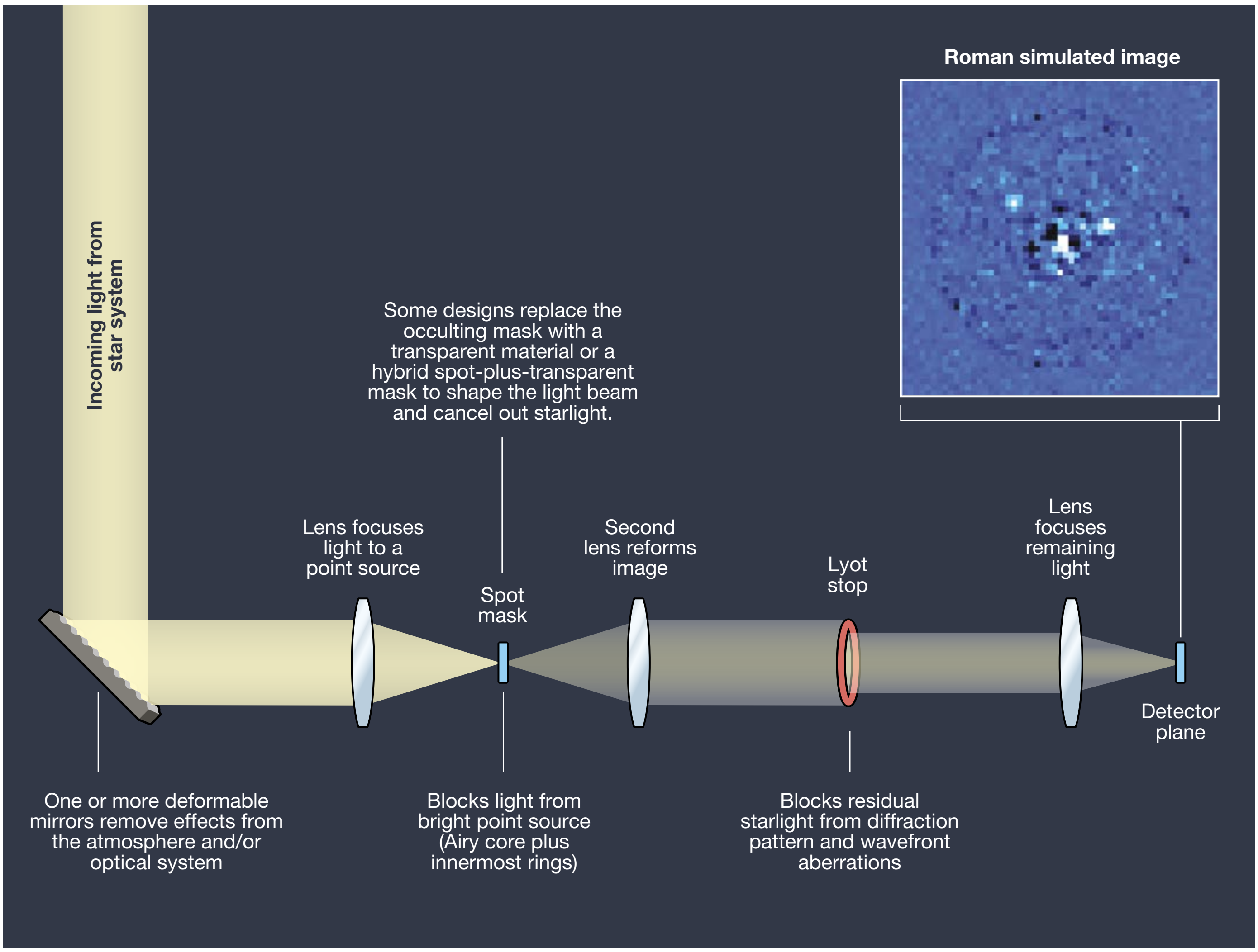
These four worlds have masses between 3 and 10 times that of Jupiter, orbital periods ranging from about 50 to 500 years, and orbital distances ranging from 15 to 70 astronomical units (a.u.). Astronomers have even stitched together more than a decade of observations to watch the planets move in their orbits around HR 8799.

Like other directly imaged exoplanets so far, all four worlds are still young and radiating heat from their formation. The latest near-infrared spectra of their glowing atmospheres, collected from one of the Keck ground-based telescopes, provide few details. The atmospheres contain carbon monoxide and water, but no methane. "The amounts of carbon and oxygen are kind of like the Sun — as opposed to planets in our solar system that have different composition," Macintosh explains. "So this may be a clue as to how the planets formed."

Another favorite for Macintosh is 51 Eridani b, whose 2015 discovery he led. The work used the Gemini Planet Imager (GPI), one of a handful of instruments installed at ground-based telescopes around the world that combine adaptive optics with coronagraphic masks. The exoplanet that GPI spied has a mass twice that of Jupiter and orbits a young host star at 13 a.u. (a little farther than Saturn's orbit around the Sun) in the constellation Eridanus.

51 Eridani b is one of the most Jupiter-like worlds discovered so far. "It's one of the lowest-temperature planets ever directly imaged, meaning that its atmosphere looks more like Jupiter's, and it's cooling off to the point where we see methane, which is one of the dominant components of Jupiter's atmosphere," says Macintosh.

Yet even this planet is still vastly different than any solar system planet. Macintosh's team estimates that 51 Eridani b is less than 25 million years old, with clouds roughly 400°C; Jupiter, by comparison, is roughly 4.5 billion years old and



▲ **HOW A CORONAGRAPH WORKS** To block a star's overwhelming light and see its planets, astronomers use a complex optical system called a coronagraph. Different instruments adapt or add to the components shown here — for example, most coronagraphs today use mirrors instead of lenses. The image shows the simulated view of two gas giants (10 o'clock and 2 o'clock) around a Sun-like star, as the Roman Coronagraph might see them.

LEAH TISCIONE / *S&T*, SIMULATED IMAGE: NASA / JPL-CALTECH

−150°C at its cloudtops. Seeing Earth-like, potentially habitable worlds — much smaller, cooler, and closer to their host star than anything spotted so far — will be even tougher.

Searching the Neighborhood

Astronomers cannot currently separate the visible light an Earth-like planet reflects from the 10-billion-times-brighter glare of its star. Instead, they can only take an infrared image of the heat a planet emits. Therefore, the only way to image older, Earth-like planets today is by searching our nearby solar neighborhood, where the faint thermal signal coming from such a planet — only 10 million times fainter than its host star — might just be resolvable.

This was precisely the aim when in 2019 astronomers installed the New Earths in the Alpha Centauri Region (NEAR) instrument at the Very Large Telescope (VLT) in Chile. The project spent 100 hours looking for potentially habitable planets in the Alpha Centauri system, the star system closest to Earth. Supported by Breakthrough Watch — one of several initiatives created by billionaire Yuri Milner aiming to explore life beyond Earth — NEAR was capable of spotting infrared light from planets about twice Earth's size or bigger, under the right conditions. "From very rough literature estimates, we thought we had maybe a 10–20% chance that there will be an Earth-like planet that we could see," recalls adaptive-optics scientist Markus Kasper (European Southern Observatory). "So we gave it a try."

At the time, astronomers knew of one terrestrial planet — Proxima Centauri b — around the red dwarf Proxima Centauri, the smallest star in the triple system and the closest star to Earth, at 4.2 light-years. Since then, two other candidate exoplanets — Proxima c and Proxima d — have been put forward. However, Proxima Centauri was a washout for NEAR from the get-go. Kasper explains that Proxima b and d orbit too close to their host star for NEAR to resolve, and Proxima c is too distant and cold for NEAR to detect it: "NEAR was not the right instrument to observe any of the Proxima Centauri planets," he confirms.

Searching the neighborhood of the two Sun-like stars Alpha Centauri A and B proved more fruitful. Though no rocky worlds were identified, the NEAR team did spot a blip in the data around Alpha Centauri A that could potentially be a gas giant. "It's not what could be considered a safe detection, it certainly needs to be followed up," Kasper says. "Unfortunately, NEAR does not exist anymore, there is no other ground-based instrument at the moment that has a similar sensitivity, and [the James Webb Space Telescope] has not yet demonstrated that it can achieve the necessary contrast."

More importantly, confirming NEAR's blip will not bring us any closer to detecting potentially habitable exoplanets. What astronomers really need is a new crop of bigger and better telescopes primed for directly imaging older and smaller exoplanets — which is exactly what is on the horizon.

Bigger and Better

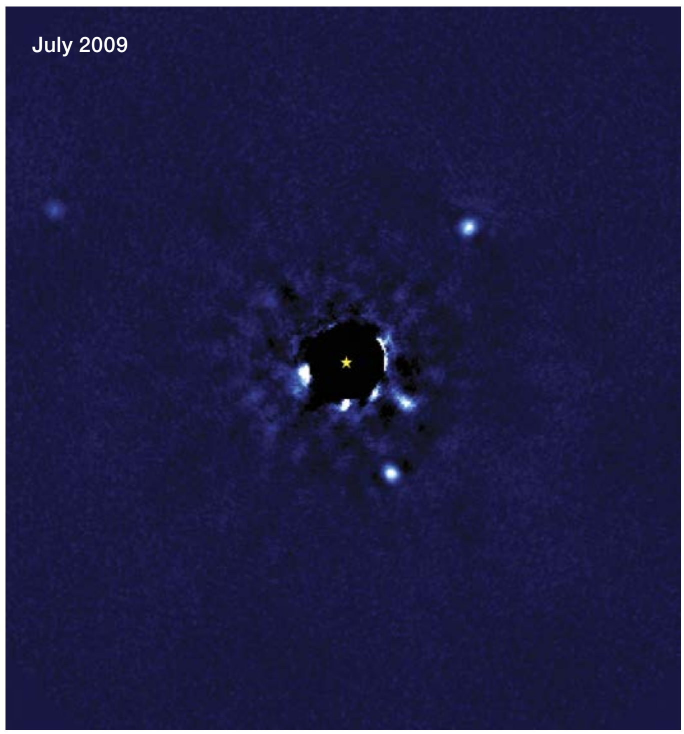
On the ground, the best prospect is the Extremely Large Telescope (ELT), under construction in Chile and expecting first light in 2028. ELT will dwarf today's biggest telescopes. The current largest professional telescopes boast primary mirrors with diameters in the 8- to 10-meter range. ELT's will be 39.3 meters. "It will be the biggest eye ever built by humanity," says ELT Programme Scientist Michele Cirasuolo (ESO).

Size matters for two reasons. First, angular resolution scales with diameter. "The angular resolution of the ELT with adaptive optics is about 10 milliarcseconds," explains Cirasuolo. "This is five times better than VLT with adaptive optics, and six times better than JWST."

Equally important, a larger mirror means more photons can be collected. Spectroscopy with current telescopes can resolve only peak features in a narrow infrared band of the electromagnetic spectrum. Larger mirrors will deliver the photons needed to enable astronomers to split the light from an exoplanet into a wider and more granular spectrum and to look at the individual elements and compounds — such as oxygen, ozone, carbon dioxide, carbon monoxide, and methane — that characterize their atmospheres.

Yet despite ELT pushing every technology to the limit, contending with the atmosphere overhead remains a limiting factor. The only way ELT will image an Earth analog is if the exoplanet is relatively nearby.

"We will mostly image hot Jupiters and super-Earths,"



JASON WANG (NORTHWESTERN) / WILLIAM THOMPSON (UVIC) / CHRISTIAN MAROIS (NRC HERZBERG) / QUINN KONOPACKY (UCSD) (3)

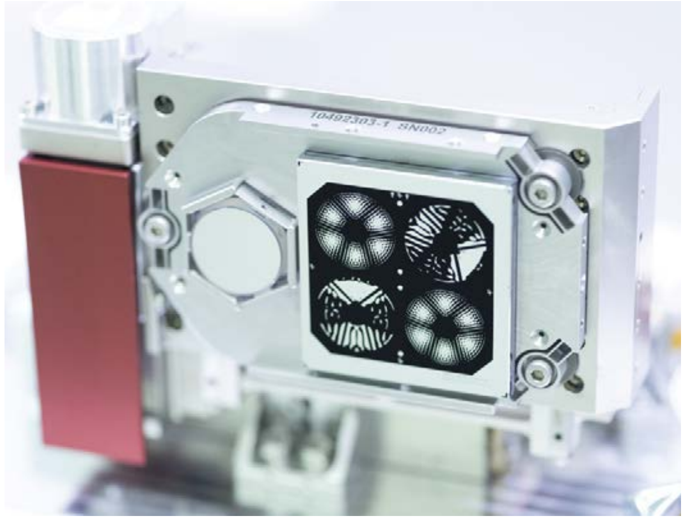
▶ **PLANETS ON THE MOVE** Caught over eight years, these near-infrared Keck Observatory images show the four gas giants around the star HR 8799. The star is an *A*-type star, about 50% larger than the Sun. Watch a video of these and other exoplanets orbiting their stars at **jasonwang.space/orbits.html**.

confirms Cirasuolo. “But we can start to push towards Proxima Centauri or Alpha Centauri, looking at the very nearby universe for an Earth-like planet in the habitable zone of an *M*-type star.” Future ELT instruments might be able to detect an Earth-Sun system somewhere within 15 to 30 light-years of us, he adds.

Macintosh personally does not expect the discovery of an Earth-Sun system to come from ELT. “Even with really good adaptive optics, ELT won’t get to the 10-billion-to-one contrast level you need to [see] an Earth-like planet around a Sun-like star, unless it’s really close,” he says. “Instead, ELT and other ground-based telescopes will complement transits and help us probe the Goldilocks zones of low-mass stars, and then space missions will explore the Goldilocks zones of Sun-like stars.”

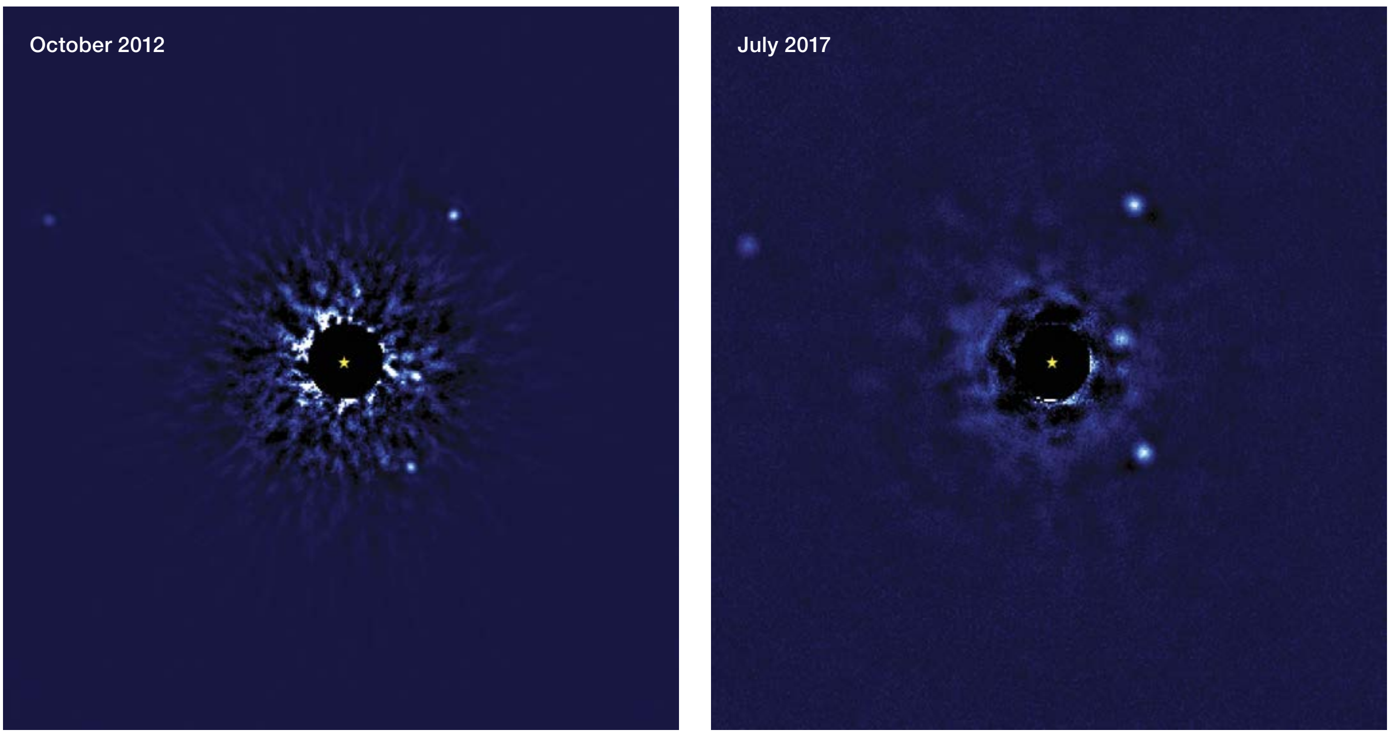
Efforts in space will be spearheaded initially by the Nancy Grace Roman Space Telescope, beginning in 2027. Roman — named after NASA’s first chief of astronomy and first female executive — will be a transformational mission, with its primary Wide Field Instrument (WFI) expected to deliver new insights into cosmology, dark energy, and a host of other open questions in astronomy.

Tucked alongside the WFI will be a technology demonstrator called the Roman Coronagraph. “We’re here to be a stepping stone on NASA’s path to finding life outside of our solar system,” says Bailey, who is the instrument’s technologist. “We’re kind of the astrophysics equivalent of the Mars Helicopter. It was there to demonstrate that you could have a helicopter flying on another planet, and that then went beyond expectations; it was able to continue and do other interesting tests.”



▲ **PUPIL MASKS** This mechanism will sit in the Roman Coronagraph between the deformable mirrors and the series of optics and masks. The small silver disk is a plain flat mirror. The four black-and-white circles are pupil masks, which shape the incoming beam of light in different ways. The black is actually a forest of microscopic silicon needles that absorb scattered starlight, akin to the foam pyramids that absorb sound in a recording studio. The silicon wafer is about 4½ cm wide.

Light from the telescope will enter the coronagraph and then be channeled, reflected, and manipulated by a host of mirrors, lenses, filters, and masks, before hitting the instrument’s photon-counting CCD detectors. Roman’s relatively small 2.4-meter main mirror — the same size as the Hubble Space Telescope’s — will set the physical limit to the instrument’s resolving power. However, the coronagraph will har-



PUPIL MASKS: NASA / JPL-CALTECH

TYC 8998-760-1 Two gas giants flank this young, Sun-like star in the southern constellation Musca, the Fly. The bright and dark rings on the star's image (upper left) are optical artifacts. The planets lie about 160 and 320 a.u. from the star — well beyond the solar system's classical Kuiper Belt.

ESO / BOHN ET AL.

bor technology 100 to 1,000 times more effective at blocking starlight than what has previously flown in space, and it will include deformable mirrors so precise they can compensate for errors smaller than the width of a strand of DNA.

Therefore, even with a relatively small primary mirror, Roman's coronagraph should be capable of making discoveries at contrast levels beyond what is currently possible, going from imaging red-hot super-Jupiters to imaging the reflected starlight from older and smaller planets. "I think we have a shot at taking the first image of a true Jupiter twin around a nearby star," concludes Bailey.

Seeing Earth 2.0

What about an Earth twin? That will be a bridge too far for Roman, but not for its planned successor, the Habitable Worlds Observatory (HWO). Specifically designed to search for signs of life on exoplanets, HWO is a concept for NASA's next astrophysics flagship mission.

Like JWST, HWO would feature a large, segmented primary mirror and take up a position at the L_2 Lagrangian point, 1.5 million km beyond Earth's nightside from the Sun's perspective. But instead of primarily seeing in infrared, as JWST does, HWO would take in a much broader range of light, including visible and ultraviolet light, where spectroscopic biosignatures could be detected. It would also feature precision adaptive optics, offering exquisite control to the picometer level (10^{-12} meter). Finally, astronomers would reach the magic 10-billion-to-one contrast ratio needed to characterize Earth-like planets around Sun-like stars. These attributes would allow HWO to interrogate at least 100 promising star systems to hopefully find around 25 potentially habitable exoplanets.

Although HWO awaits approval and would only launch in the early 2040s, excitement is already palpable in the astronomy community, where plans and preparations are in full swing. "When you go to astronomy meetings, so many talks are about preparing for HWO; many exoplanet astronomers of my generation see HWO as the big thing of our careers," says Lewis. "HWO will actually look for biosignatures on exoplanets. It's a slightly sensational way of saying it, but I always tell my students that if there's life out there, we should be able to see signs of it within our lifetimes with HWO."

Macintosh is equally excited about what the space telescope could reveal. "We know we can build it and it will basically work, but we don't know what the odds are of actually finding life on one of these planets," he says. "We might discover life forming is very common, we might discover it's rare and unlikely. Either way, that's an important transformation in our view of the universe."

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

SKY AT A GLANCE
September 2024

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

5 DUSK: The three-day-old Moon sits about 6½° left of Venus. You'll need an unobstructed view to the west-southwest as the pair slowly set. Turn to page 46 for more on this and other events listed here.

6 EVENING: Low in the west-southwest the waxing crescent Moon sets roughly 3° left of Spica, Virgo's brightest star.

7–8 ALL NIGHT: Saturn arrives at opposition. This month the Ringed Planet shines throughout the night in Aquarius.

9 DAWN: Mercury and Regulus rise close together in the east-northeast — the tiny world glimmers a mere ½° left of the star. Make sure you have a clear view to the horizon.

10 DUSK: The first-quarter Moon sits a bit less than 6° left of the red supergiant Antares. Watch as the pair drops toward the southwestern horizon in deepening twilight.

17 MORNING: Look to the southwest to see the almost-full Moon gleaming less than 2° below Saturn. Turn to page 48 for occultation details.

17 FULL MOON (10:34 P.M. EDT): A partial lunar eclipse will be visible all across the Americas except for westernmost Alaska (go to page 50).

17 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:42 p.m. PDT (see page 50).

20 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:31 p.m. EDT.

22 MORNING: High in the southeast the waning gibbous Moon passes through the Pleiades in Taurus.

22 AUTUMN BEGINS in the Northern Hemisphere at the equinox, at 8:44 a.m. EDT.

25 MORNING: Face east to see the waning lunar crescent and Mars in Gemini climbing higher as dawn approaches. The Moon sits a bit more than 4° upper left of the Red Planet.

26 DAWN: The Moon, still in Gemini, poses 1½° below Pollux, the brightest light in the celestial Twins.

29 DAWN: The thin lunar crescent rises in the east-northeast about 2½° left of Leo's brightest star, Regulus.
—DIANA HANNIKAINEN

▲ The 9.5-magnitude spiral galaxy NGC 7331 in Pegasus can serve as a hopping-off point for locating Stephan's Quintet (see page 28). Look for the galaxy some 4⅓° north-northwest of Eta (η) Pegasi. NGC 7331 and the four galaxies east of it are collectively known as the Deer Lick Group.
JOSEF PÖPSEL / STEFAN BINNEWIES / CAPELLA OBSERVATORY

SEPTEMBER 2024 OBSERVING
Lunar Almanac
Northern Hemisphere Sky Chart

September 18

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

MOON PHASES

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

NEW MOON
September 3
01:56 UT

FIRST QUARTER
September 11
06:06 UT

FULL MOON
September 18
02:34 UT

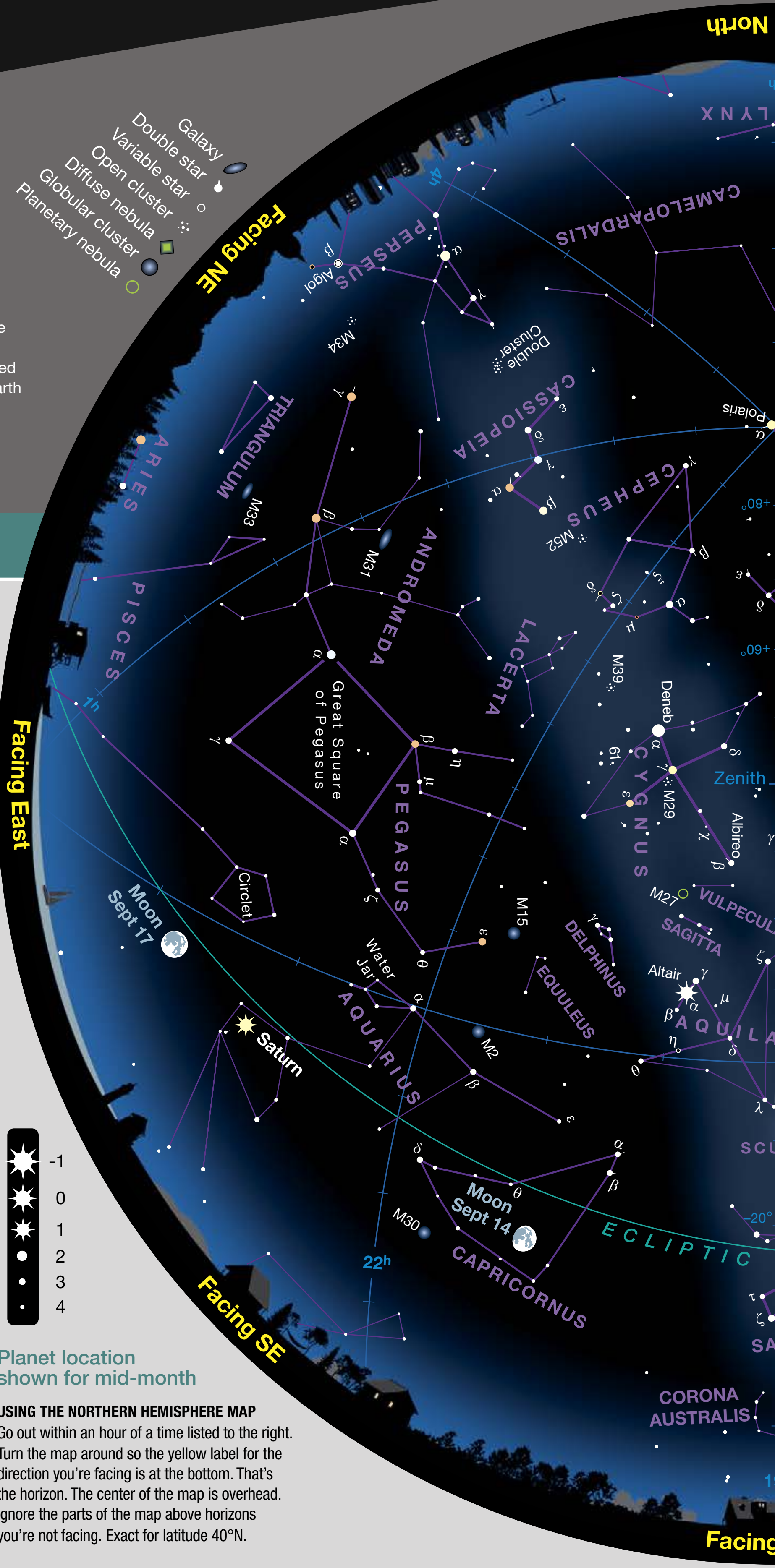
LAST QUARTER
September 24
18:50 UT

DISTANCES

Apogee	September 5, 15^h UT
406,211 km	Diameter 29′ 25″
Perigee	September 18, 13^h UT
357,289 km	Diameter 33′ 26″

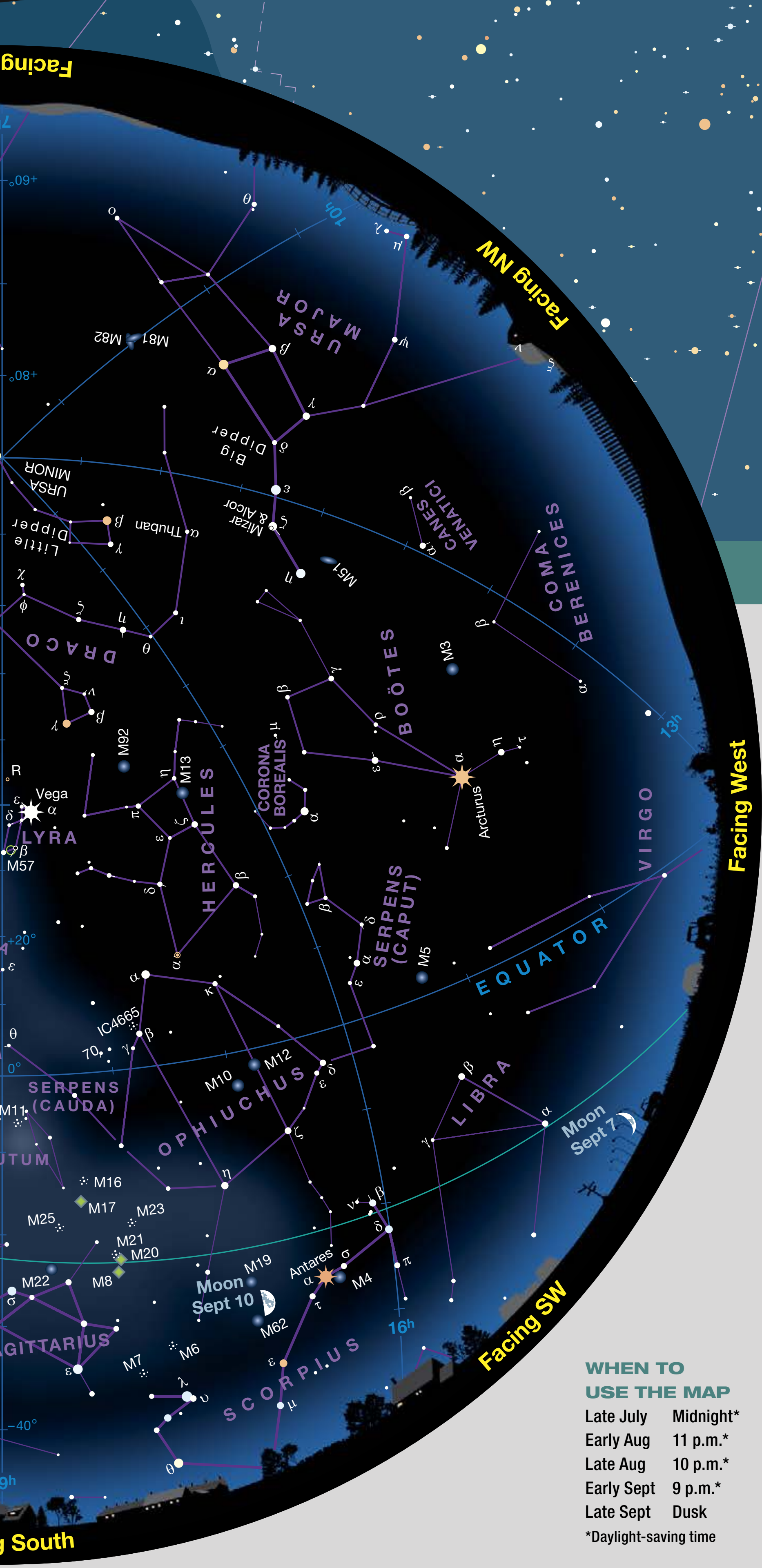
FAVORABLE LIBRATIONS

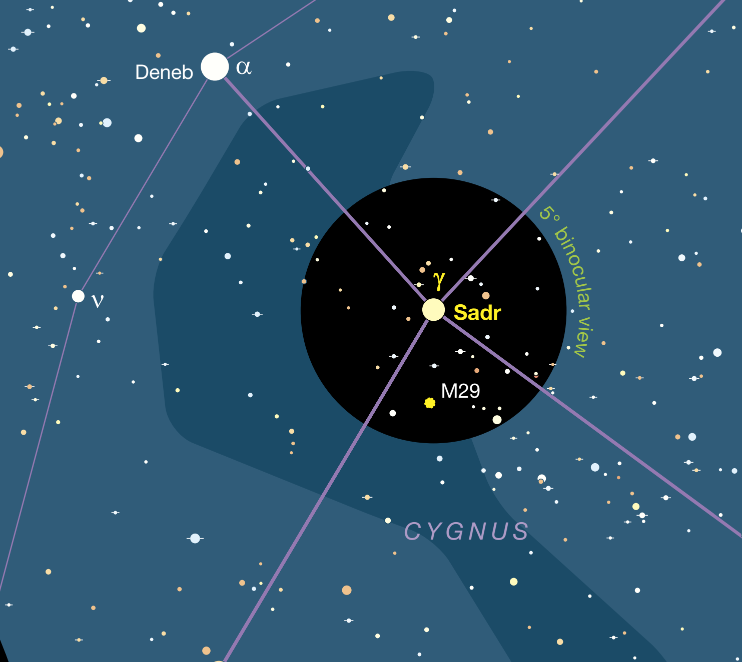
• Xenophanes Crater	September 18
• Cleostratus Crater	September 18
• La Pérouse Crater	September 19
• Ansgarius Crater	September 19



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

Where Secrets Are Kept

This is my 100th column, and to celebrate I'm going to revisit my all-time favorite target: the heart asterism at the center of Cygnus, the Swan.

Cygnus is a phenomenal hunting ground for binocular observers. It has star clusters, bright and dark nebulae, double stars, and asterisms, all piled together to achieve a staggering density of spectacle (see, e.g., *S&T:* Sept. 2021, p. 34). But the jewel that keeps drawing me back to Cygnus is **Sadr**, or Gamma (γ) Cygni, and its associated asterism. The word *sadr* means "chest" or "heart" in Arabic, and there's a neat linguistic turn in its meaning. Sadr is the place where secrets are kept: It's the anatomical chest, but it's also a treasure chest — just like the human heart.

The star Sadr is located at the center — or heart — of the celestial Swan, but the story gets stranger still, for around the star is a 2° ring of stars and star clusters that bends inward at the northeast to form a heart shape. The *star* at the heart of Cygnus is surrounded by an *asterism* in the shape of a heart. That asterism is visible in binoculars but not to the naked eye, so it is a secret held in the chest of the Swan — or *sadr*, where treasures are kept. Those multiple reflections of meaning, like mirrors facing each other, make my hair stand on end.

By the time you read these words, I'll be out in the late summer dark with my binoculars, once more teasing out the secrets of the night sky. One hundred columns is a good start, but the celestial ocean stretches inexhaustibly before us. Let's see how much more is out there.

■ The Binocular Highlight paradox: The longer **MATT WEDEL** writes this column, the less he worries over finding things to write about.

WHEN TO USE THE MAP

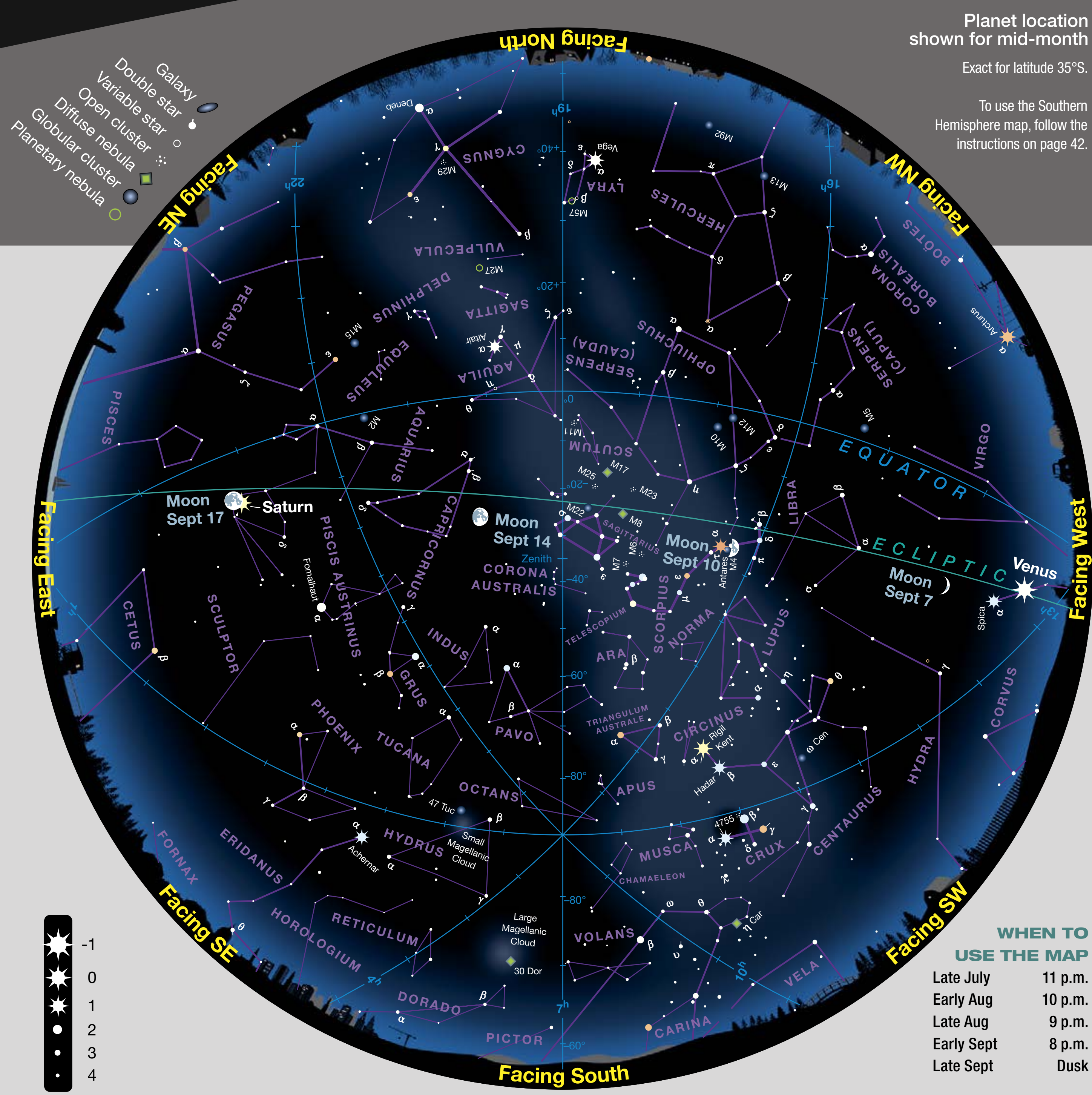
Late July	Midnight*
Early Aug	11 p.m.*
Late Aug	10 p.m.*
Early Sept	9 p.m.*
Late Sept	Dusk

*Daylight-saving time

SEPTEMBER 2024 OBSERVING

Southern Hemisphere Sky Chart

by Jonathan Nally



Pavo, the Peacock, is one of the four constellation figures known collectively as the Southern Birds. The other three are Grus (the Crane), Phoenix (the Phoenix), and Tucana (the Toucan). All four are presented on this month's star map.

The Peacock's brightest star is bluish-white, 1.9-magnitude Alpha (α) Pavonis. Alpha is actually a spectroscopic binary system, in which a tiny companion orbits too close to the primary star to see. The binary resides some 180 light-years from Earth. Pavo is also home to the fourth-brightest globular star cluster in the night sky, NGC 6752. At magnitude 5.4, it's faintly visible to the naked eye, but you'll need skies free from light pollution to glimpse it. Although the cluster isn't marked on the map above, its position is located just left of the –60° declination tick mark. ■

Looking for Chaos?

A dark void in Cygnus serves as a visual reminder of what chaos really means.

▲ Phaethon strains to control the chariot of the Sun in this 1776 mezzotint print by British artist Benjamin Green. Too weak to control the powerful steeds, Phaethon is helpless as the chariot's flaming wheels set fire to the heavens, leaving behind a trail of smoke.

THE METROPOLITAN MUSEUM OF ART, NEW YORK / THE ELISHA WHITTELSEY COLLECTION, THE ELISHA WHITTELSEY FUND, 1967 / PUBLIC DOMAIN

Chaos can be a wonderful thing, especially when seeing myriad stars for the first time under a dark sky. Creating order from chaos is why the ancients linked bright stars together to form constellations. Yet areas of the night sky still exist where we can see chaos in its most fundamental form: vast pools of darkness known as *dark nebulae*.

Among its many definitions, the word chaos can mean formless and empty, or a disorderly mass, or a gaping void. In *Metamorphoses*, written in AD 8 by the Roman poet Ovid, we find chaos referred to as a "thick darkness," a "shapeless uncoordinated mass . . . whose ill-assorted elements were indiscriminately heaped together in one place." This shadowy realm of mass and energy was the beginning of everything, ultimately giving birth to the first primordial Greek gods: Gaia (Earth), Tartarus (the Underworld), and Eros (Love). And "the stars," Ovid wrote, "which had long been buried in darkness and obscurity began to blaze forth all through the sky."

Known to naked-eye stargazers since antiquity, these bleak patches in the heavens became scientific curiosities as early as 1784, when the German-born British astronomer William Herschel discovered a telescopic *Loch im Himmel*, which translates to a "hole in the sky." His was the first inquiry into the nature of these dark and mystifying voids.

In 1889 Arthur Cowper Ranyard, editor of the London scientific magazine *Knowledge*, proposed that the holes weren't empty regions but "opaque matter, dust clouds or fog-filled space." It wasn't until 1930, however, that Robert J. Trumpler at Lick Observatory in California firmly established that dark nebulae are indeed clouds of "fine cosmic dust."

The most conspicuous dark patch in the Milky Way is the Coalsack Nebula abutting Crux, the Southern Cross. But an equally magnificent void graces Cygnus, the Swan. Far away from city lights, the Northern Coalsack appears to the unaided eyes as an ill-defined patch of darkness, spanning roughly 8° × 5°, between the stars Deneb, Gamma (γ), and Epsilon (ε) Cygni. Keep the Northern Coalsack in mind as we explore a myth associated with Helios, the ancient Greek god who carried the Sun in a horse-drawn chariot.

To keep a promise to his mortal son, Helios allowed Phaethon to ride his fiery chariot. Helios warned Phaethon of the dangers involved, but the rebellious youth paid little heed to his father's instructions and too late realized he wasn't strong enough to control the steeds. When the horses plunged toward the celestial Scorpion — with its pincers snapping and stinger raised — a fearful Phaethon let loose the reigns and the horses flew off course. The chariot's wheels set fire to the high heavens, leaving behind a trail of smoke. When Earth caught fire, Zeus ended the chaotic ride by smiting Phaethon with a lightning bolt.

Today when we gaze skywards, we can see where the solar steeds lost their way in Scorpius. According to the 1st-century BC Greek historian Diodorus of Sicily, "first they turned aside to traverse the heavens, setting it afire and creating what is now called the Milky Way." With imagination we can add the scorched and still smoldering tracks of the chariot's fiery wheels. Known as the Great Rift, these dark interstellar dust lanes bisect the bright star clouds of the Milky Way from Scorpius to Cygnus. We can even imagine the black pool of the Northern Coalsack as the spot where Zeus ended Phaethon's fateful ride.

In a 2019 *Publications of the Astronomical Society of Japan* article, Kazuhito Dobashi and colleagues reported that the Northern Coalsack has a molecular mass of one thousand Suns. Their research suggests we are seeing the Northern Coalsack just after the onset of a rapid gravitational collapse that will eventually lead to the creation of a star cluster. So, as in the Greek myth of Chaos — from darkness, one day in the distant future, comes light.

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

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

Catch Mercury's Morning Show

The solar system's smallest planet has two notable conjunctions this month.

SUNDAY, SEPTEMBER 1

Mercury is in the midst of a favorable dawn apparition — the third of four such appearances in 2024. It reaches greatest elongation (18° west of the Sun) on the 4th, though it's actually at its best on the 6th, when it stands 10° above the east-northeastern horizon 30 minutes before sunrise.

But there's a good reason to look in on Mercury as the month begins. On the 1st it's joined by a razor-thin waning crescent **Moon**, which sits just 4° upper left of the planet. The Moon is a mere 2% illuminated and some 40 hours from new phase. Mercury shines at magnitude +0.4, so it stands up reasonably well to morning twilight. However, you might want to use your binoculars for this conjunction since optics will help you see Mercury as the sky brightens and will allow you to fully appreciate earthshine illuminating the "unlit" portion of the Moon. It'll be a lovely sight. Keep watching Mercury on the following mornings as it climbs modestly higher and continues to rapidly brighten. By the 5th it will have gained a full magnitude!

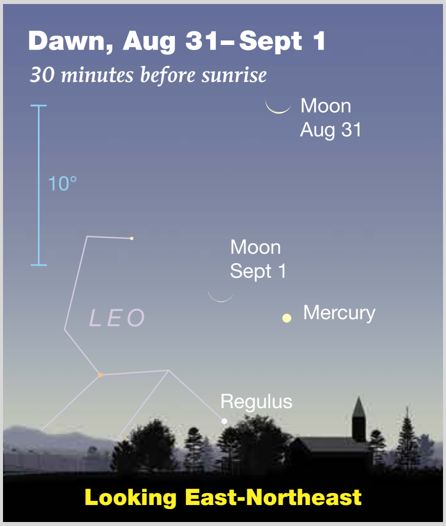
WEDNESDAY, SEPTEMBER 4

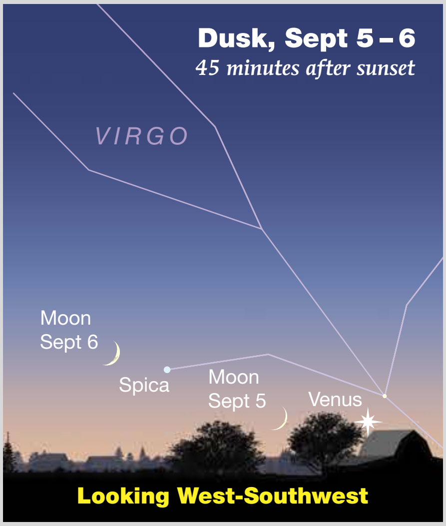
Fresh from its morning encounter with Mercury, the **Moon** reappears at dusk for a get-together with **Venus**. Once again, the lunar crescent is very thin — 3% illuminated and only two days old. Also once again, the Moon sits about 4° from its planetary partner. This time it's positioned to the lower right of the Evening Star, which means the Moon will be a bit harder to pick out as it's setting during twilight. Indeed, half an hour after sunset the crescent is only 2° above the western horizon! Thankfully, Venus should be easier to spot. Its altitude at that time is 5°, and it gleams brilliantly at magnitude –3.8. You might even end up having to use Venus to locate the Moon. The best strategy is to get out your binoculars and begin hunting right after sunset when the Moon and Venus are slightly higher than during twilight. Both objects fit into the same bino field. Place Venus at the 1 o'clock position and you should be able to see the ghostly crescent Moon at the edge of the field at around 5 o'clock. You can try again the following evening (the 5th) when the Moon is a bit less than 7° left of the Evening Star. The setup isn't quite as spectacular, but it's likely easier to see.

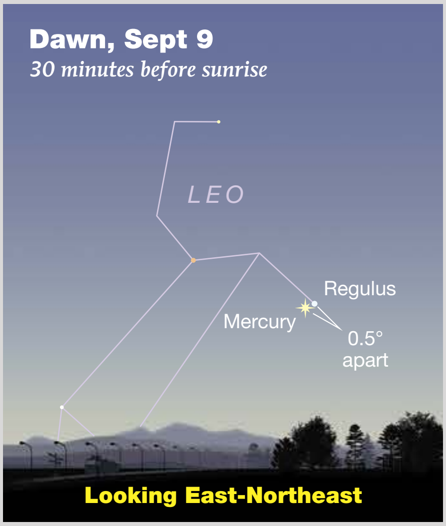
MONDAY, SEPTEMBER 9

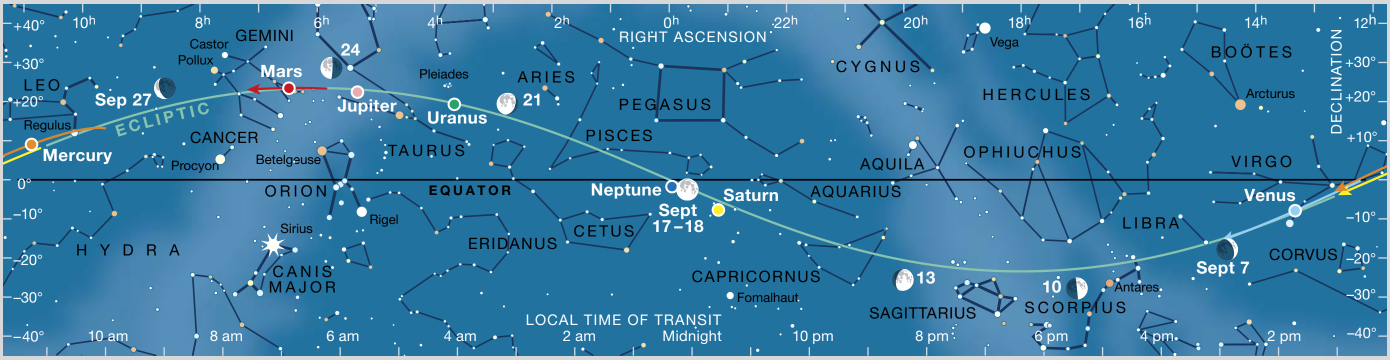
The second act of the **Mercury** Morning Show takes place at dawn today,

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





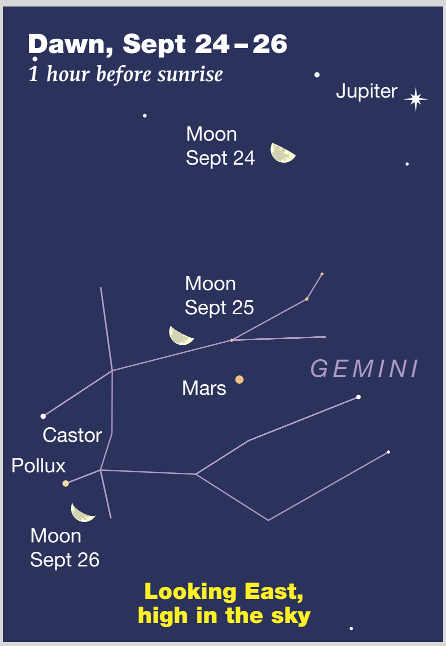




▲ The Sun and planets are positioned for mid-September; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of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

when the fast-moving little planet pulls up alongside **Regulus**, the brightest star in Leo, the Lion. There will be just one Moon diameter (30′) between the two objects.

It's indeed a tight pairing, but the brightness difference will be quite stark. At magnitude 1.4, Regulus is technically a 1st-magnitude star, but only barely. And it's in tough against morning twilight and the glare from Mercury, which has now reached magnitude –0.8. The disparity between the two glints amounts to nearly 8×! Regulus will look like a satellite of the moonless innermost planet. Mercury is already slightly past its peak for this apparition, but even so it still rises roughly 1½ hours ahead of the Sun. Once again, you'll find binoculars very handy — especially if you have to wait for the pair to rise high enough to clear your local horizon as twilight brightens.



Mercury continues to gain luminosity throughout the waning days of its apparition as the gap between it and the Sun closes. You'll likely lose sight of the planet around the 20th. Don't despair, though — it'll reappear at dusk in mid-November.

TUESDAY, SEPTEMBER 17

The best encounter this month between a planet and the **Moon** occurs in the predawn hours today. That's when the nearly full, waxing gibbous Moon sets with **Saturn** trailing closely behind. Of course, just how small the gap between them will be depends on when you look and just how far west you are. As noted on page 48, for much of the western half of the U.S. and Canada and northern Mexico, the Moon actually covers the Ringed Planet!

On the evening of the 17th you have the chance to see another fine sky event, as **Venus** lies less than 2½° upper right of 1st-magnitude **Spica**, in Virgo. On the following night, the Evening Star is roughly the same distance from Spica, but almost directly above it. On either date, key in on Venus first then see if you can fish Spica from twilight's glow. Here again, binoculars are your friend. And if you succeed with optics, see if you can manage to spot the star with your eyes alone.

Venus is in the early phases of an evening apparition that will last through the remainder of 2024 and well into 2025. However, during September it gains altitude with painful slowness, ending the month only a bit more than 3° higher than at the start of the month. Thankfully, its visibility begins to improve swiftly in October, when it at lasts climbs high into the dusk sky.

THURSDAY, SEPTEMBER 26

The month winds down with one more noteworthy morning event. This time it's the waning crescent **Moon** passing below **Pollux**, the brightest star in Gemini, the Twins. Although the Moon approaches to within less than 2° of the 1.1-magnitude star, it's all the glitter from nearby luminaries that makes this dawn scene so appealing. Indeed, if you zoom out far enough, the lunar crescent marks the end of a brilliant, ragged string that includes Mars (magnitude +0.5), and Jupiter (–2.5) and Aldebaran (+0.9) in Taurus. Or you can picture the Moon and Pollux as holding down the upper-left corner of an isosceles triangle with Mars and +0.4-magnitude Procyon marking the other points. And let's not forget all the bright stars in nearby Orion, as well as Capella and Sirius (magnitudes –0.1 and –1.4, respectively), which also adorn the eastern sky at dawn.

■ Consulting Editor **GARY SERONIK** has a moth-like attraction to bright lights — especially the celestial kind.

Comet Tsuchinshan-ATLAS on the Morning Stage

The dawn sky is briefly adorned with a low-hanging icy visitor.

Hope is an essential ingredient in amateur astronomy. We hope the sky will clear for the next meteor shower or eclipse, but until the moment arrives, we survive on the quiet thrill of not knowing exactly what to expect. And if you're like me, this month you're hoping that Comet Tsuchinshan-ATLAS (C/2023 A3) develops into a memorable sight.

The comet was discovered at Purple Mountain Observatory in China on January 9, 2023, and independently on February 22nd by the Asteroid Terrestrial-impact Last Alert System (ATLAS). A new visitor from the Oort Cloud, in spring the comet became an easy telescopic object. Now it's poised to potentially brighten to magnitude +0.5 by the end of September.

Provided the comet remains intact as it dives sunward toward its September 27th perihelion, we can expect a brief but bright appearance at dawn in the final week of the month. For observers at mid-northern latitudes, Tsuchinshan-ATLAS will be at its highest on the morning of the 29th, but even then, it sits only about 5° above the east-southeastern horizon 45 minutes before sunrise.

▲ On May 8, 2024, Comet Tsuchinshan-ATLAS (C/2023 A3) exhibited a well-developed dust tail, as shown in this photo by Dan Bartlett. The comet glowed at 10th magnitude at the time but could reach magnitude +0.5 later this month in morning twilight.

You'll need a cloudless, unobstructed horizon and a pair of binoculars to catch sight of the comet in the brightening twilight. The best mornings will be those after a weather front has moved through and whisked the sky clear of haze and smoke. Given the possibility that Tsuchinshan-ATLAS may display a significant, westward-

Oppositions and Occultations for Saturn and Neptune

SATURN AND NEPTUNE both come to opposition in September, and both will be occulted by the Moon. Saturn shines at magnitude +0.6 opposite the Sun on the 8th in eastern Aquarius.

The planet's famous rings give only the slightest tip of the hat earthward, their inclination varying from 3.5° on the first of the month to 4.5° by month's end. But the lack of ring glare makes it easier to spot faint moons near the planet. If you've already seen the brighter ones — Titan (magnitude 8.3), Rhea (9.7), Tethys (10.2), Dione (10.4), Iapetus (variable, 10 to 12) — this season is the time to hunt for closer-orbiting Enceladus (11.7) and Mimas (12.9), and distant Hyperion (14.2). And when you run out of those, Saturn's got 138 more moons — just don't expect to make much of a dent in that number. After Hyperion the next brightest satellite is Janus at magnitude 14.5. Precious few have made its visual acquaintance.

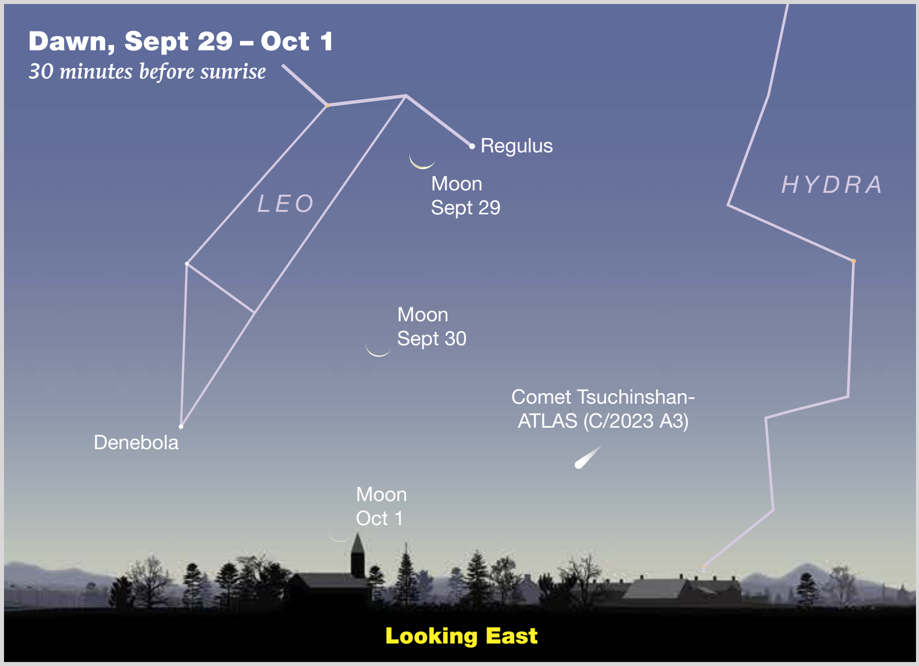
Iapetus is an interesting target. When it's at eastern elongation on September 3rd, it presents its dark face and glows dimly at around magnitude 12. Exactly the opposite occurs at western elongation — its icy hemisphere faces our direction, and the moon brightens to 10th magnitude. That occurs on October 12th when Iapetus sits 9.4′ (or 13 ring widths) from the planet.

Saturn's near face-on presentation at opposition also means its moons will queue up in a straight line more often this season instead of being arrayed above and below the planet. For that same reason, the visibility of the diaphanous crepe ring (also called ring C), the innermost of the three major rings, may be enhanced.

Where the crepe ring crosses in front of the planet, it appears as a gray line that can be tricky to distinguish from the main rings and their shadows. But when viewed near opposition, the particles that form the ring stack up along our line of sight, increasing the crepe ring's visibility. Look for a filmy, grayish arc between the inner edge of the ring plane and Saturn's globe.

On the morning of September 17th, observers in the western half of the U.S. and Canada can watch the nearly full Moon occult Saturn. From San Francisco, California, the disappearance begins at 4:06:38 a.m. PDT, and the lunar disk takes about 60 seconds to completely cover the planet and its rings. Saturn returns to view an hour later just as twilight gets underway. For a list of cities and times, go to the International Occultation Timing Association's

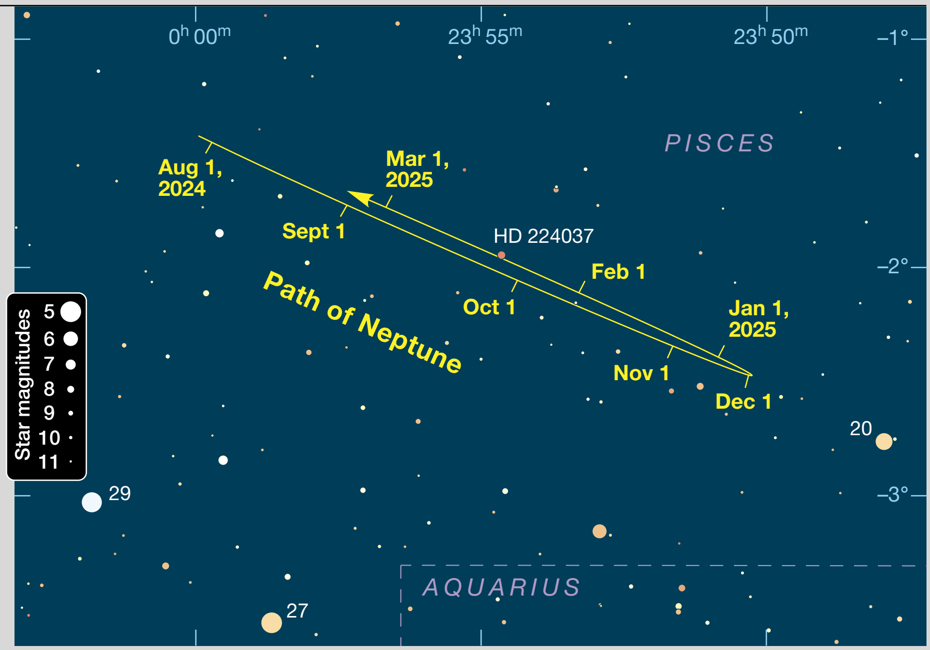
▶ Comet Tsuchinshan-ATLAS (C/2023 A3) is joined by a thin, waning crescent Moon in dawn twilight at the end of September. The comet's position is plotted for the morning of the 29th, when it rises 76 minutes before the Sun, as seen from mid-northern latitudes. On that date it will have an altitude of roughly 8° half an hour before sunrise. By October 1st, it will be ½° closer to the horizon as it begins to rapidly drift sunward and become lost in the solar glare.



pointing tail, consider heading out early (when the sky is darker) to see if you can spot the comet's dusty appendage before its head even rises.

As each day passes, Tsuchinshan-ATLAS's *phase angle* — the angle the comet makes relative to a line connecting Earth and the Sun — increases. When an object lies in the same direction as the Sun, its phase angle approaches 180°. That's when dusty objects like comets can really light up due to forward-scattering of sunlight. Observations of pink and yellow hues in the comet's tail made at the end of May indicate that the nucleus possesses a modicum of dust, perhaps enough to ignite into a bright plume as the comet's phase angle rapidly increases from 90° on September 27th to a maximum of 172° on October 8th.

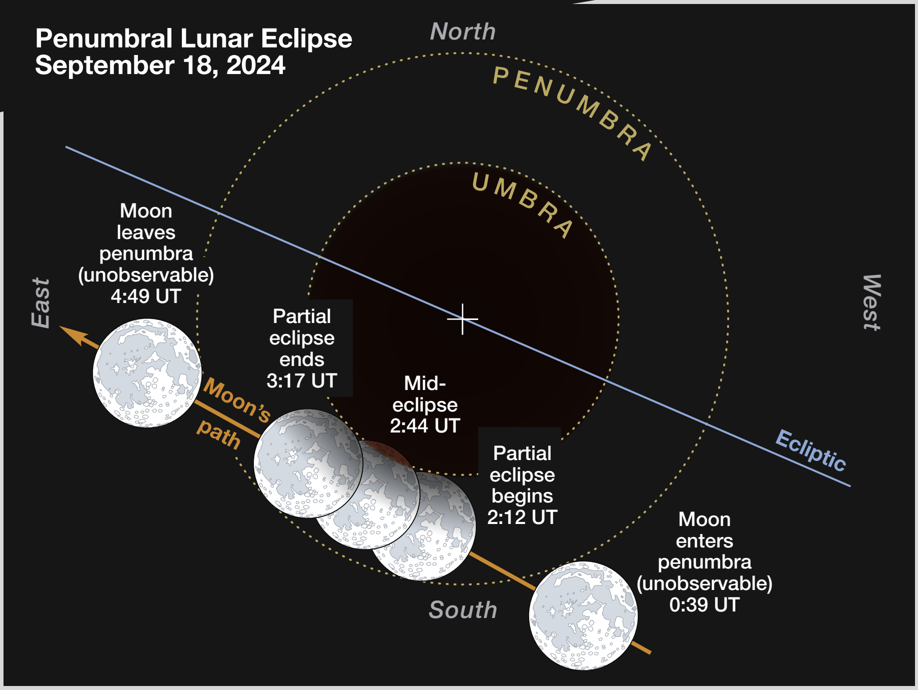
Watch for the old Moon to join the dawn scene on September 29th through to October 1st. On the latter date, a very thin waning lunar crescent rises about 12° to the left of the comet in mid-twilight. This month's appearance is just the beginning. The show's climax comes in October when Tsuchinshan-ATLAS slingshots into the evening sky. More on that in the next issue.



site, **https://is.gd/IOTASaturn2024**.

Coincidentally, the full Moon occults Neptune on the night of September 17–18. This occultation will be much more challenging to observe because even at opposition (which occurs a few days later, on the 21st) Neptune glows dimly at magnitude 7.8 and is tricky to see next to the overwhelming glare of the full Moon. No dedicated IOTA page is available for this event, so I suggest you use a stargazing app to play out the scenario from your location.

Neptune slipped into Pisces last year and continues to slowly gain altitude with each new observing season.
For me, the most fascinating visual aspects of this cold, distant planet is its invitingly Earth-like blue color resulting from sunlight being absorbed by atmospheric methane. The planet's minute 2.4″ disk gives one a visceral feel for its chilling remoteness of 4.3 billion kilometers (2.7 billion miles). Amazingly, even at that distance we can see Neptune's largest satellite, Triton. The cryovolcanic moon orbits the planet every 5.9 days and at magnitude 13.4 is within reach of an 8-inch or larger telescope. If you routinely observe Neptune, you'll eventually catch Triton at its greatest elongation, about 17″ from the planet. Consult the Track Triton app on the Tools page at **skyandtelescope.org** to keep tabs on the big moon.



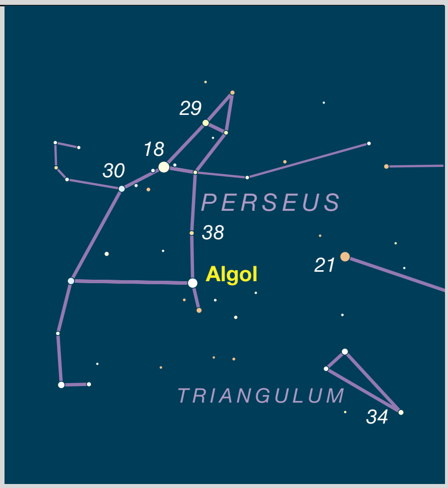
A Short Partial Lunar Eclipse

THE FIRST LUNAR ECLIPSE of 2024 was penumbral. The next, on September 17–18, is umbral — barely! This partial eclipse is visible across the Americas, Africa, and Europe. Except for the Pacific time zone, where the Moon rises around the time of maximum eclipse, most U.S. observers will witness all phases of the event. Greatest eclipse occurs on September 18th at 2:44 UT (10:44 p.m. EDT on September 17th). While no prominent lunar craters will be immersed in Earth's umbra, the shadow's fuzzy border will just reach the northern edge of the crater Plato around the time of maximum eclipse.

Minima of Algol

Aug.	UT	Sept.	UT
3	8:44	1	0:50
6	5:33	3	21:39
9	2:21	6	18:27
11	23:10	9	15:16
14	19:58	12	12:05
17	16:47	15	8:53
20	13:36	18	5:42
23	10:24	21	2:31
26	7:13	23	23:19
29	4:02	26	20:08
		29	16:57

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



▲ Perseus reaches the zenith during pre-dawn hours in September. Every 2.87 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back again. Use this chart to estimate its brightness in respect to comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).

Action at Jupiter

ALTHOUGH JUPITER is still months away from opposition, during September it well and truly enters the telescopic prime of its current apparition. As the month opens, the planet is a conspicuous –2.3-magnitude gleam set neatly between the horns of Taurus, the Bull, where it presents a disk spanning 38.5″. Although Jupiter doesn't reach the meridian until one hour after sunrise on September 1st, by the 30th it attains that lofty position just as the first blush of twilight begins to brighten the sky.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify them by their relative positions on any given date and time. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for when Jupiter is at its highest.

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

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

September 1: 1:21, 11:17, 21:12; **2:** 7:08, 17:04; **3:** 2:59, 12:55, 22:51; **4:** 8:46, 18:42; **5:** 4:38, 14:34; **6:** 0:29, 10:25, 20:21; **7:** 6:16, 16:12; **8:** 2:08, 12:03, 21:59; **9:** 7:55, 17:50; **10**: 3:46, 13:42, 23:38; **11**: 9:33, 19:29; **12**: 5:25,

LEAH TISCIONE / *S&T*, SOURCE: USNO

15:20; **13**: 1:16, 11:12, 21:07; **14**: 7:03, 16:59; **15**: 2:54, 12:50, 22:46; **16**: 8:41, 18:37; **17**: 4:33, 14:28; **18**: 0:24, 10:20, 20:15; **19**: 6:11, 16:07; **20**: 2:02, 11:58, 21:54; **21**: 7:49, 17:45; **22**: 3:41, 13:36, 23:32; **23**: 9:28, 19:23; **24**: 5:19, 15:15; **25**: 1:10, 11:06, 21:02; **26**: 6:57, 16:53; **27**: 2:49, 12:44, 22:40; **28**: 8:36, 18:31; **29**: 4:27, 14:23; **30**: 0:18, 10:14, 20:10

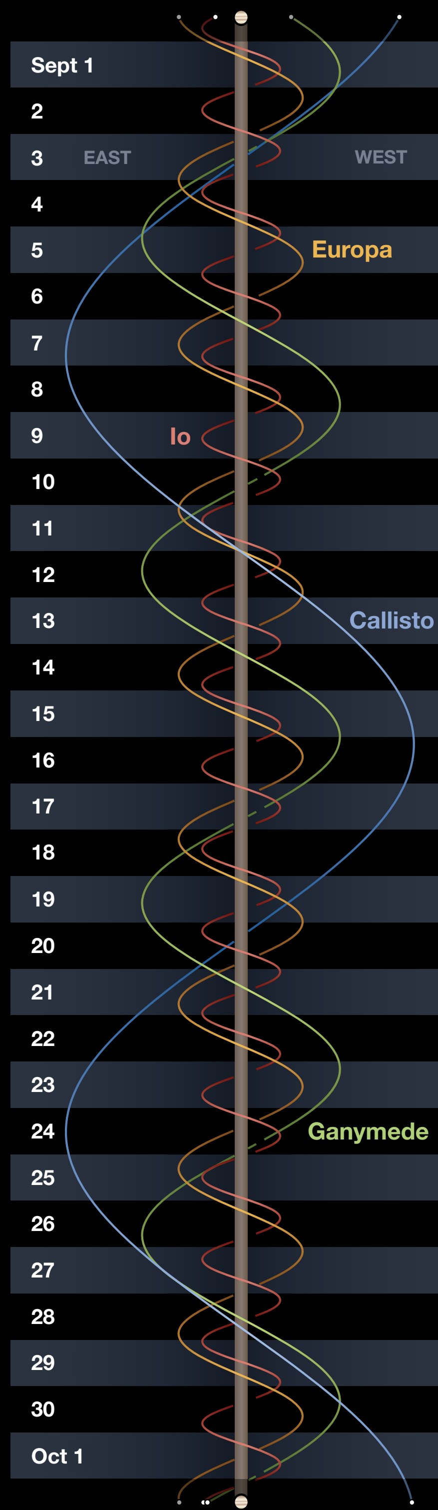
These times assume that the spot will be centered at System II longitude 64° on September 1st. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 64° and 1²/₃ minutes later for each degree more than 64°.

Phenomena of Jupiter's Moons, September 2024

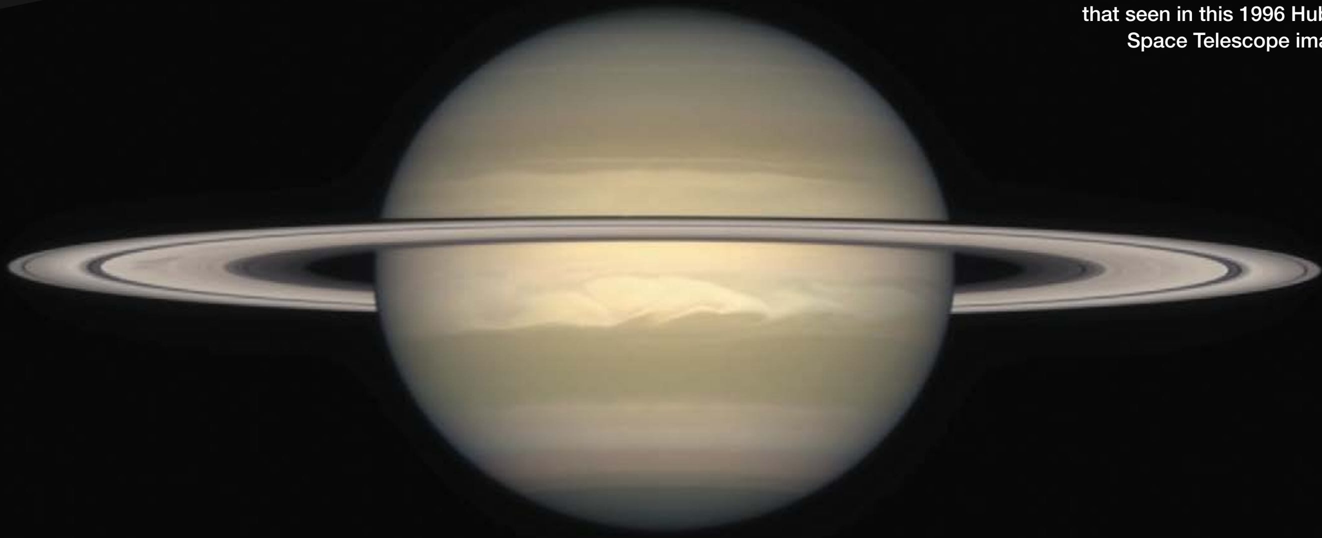
Sept. 1	1:25	I.Sh.I
	2:43	I.Tr.I
	3:34	I.Sh.E
	4:03	II.Sh.I
	4:53	I.Tr.E
	6:31	II.Sh.E
	6:45	II.Tr.I
	9:16	II.Tr.E
	22:40	I.Ec.D
Sept. 2	2:13	I.Oc.R
	19:53	I.Sh.I
	21:12	I.Tr.I
	22:02	I.Sh.E
	22:29	II.Ec.D
	23:21	I.Tr.E
Sept. 3	0:58	II.Ec.R
	1:08	II.Oc.D
	3:38	II.Oc.R
	4:35	III.Ec.D
	6:32	III.Ec.R
	10:01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

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Jupiter's Moons



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



During the 2024 Saturn observing season, the apparent tilt of the planet's rings will resemble that seen in this 1996 Hubble Space Telescope image.

NASA AND THE HUBBLE HERITAGE TEAM (STSCI / AURA) / R. G. FRENCH (WELLESLEY COLLEGE) / J. CUZZI (NASA / AMES) / L. DONES (SWRI) / J. LISSAUER (NASA / AMES)

A Narrowing View of Saturn's Rings

This year may present a rare opportunity to glimpse the planet's ever-changing F ring.

In late March of 2025, Earth will pass through the plane of Saturn's rings, when the planet will be less than 10° from the Sun. Observers will miss a rare opportunity to witness the edgewise presentation of the rings as they gradually fold up into a delicate sliver of light and briefly disappear through all but the largest telescopes.

As the rings approach edgewise presentation, their apparent tilt becomes very sensitive to Earth's orbital position. The rings will be inclined by only 2° to our line of sight when Saturn is well placed in the predawn sky this July, but by opposition in early September they reopen to 4°. At low power, Saturn will look like a ball of yarn pierced by a knitting needle.

Although we will be deprived of the spectacle of the intricate ring structures that are visible when the rings appear more open, there will be compensations. The diminished glare of the rings will make it much easier to glimpse the planet's faint inner moons and watch an array of satellite transits, eclipses, and occultations like those of Jupiter's Galilean satellites.

At glancing viewing angles you may notice that Saturn's outer A ring seems to brighten relative to the denser, more brilliant B ring. The C ring will also look unusually bright compared to both the A and B rings because its sparse particles are compressed by perspective when seen very obliquely.

This apparent brightening of tenuous rings calls to mind controversial 20th-century observations of an exceedingly faint, narrow ring bordering the outer edge of ring A made when the rings were near-edgewise.

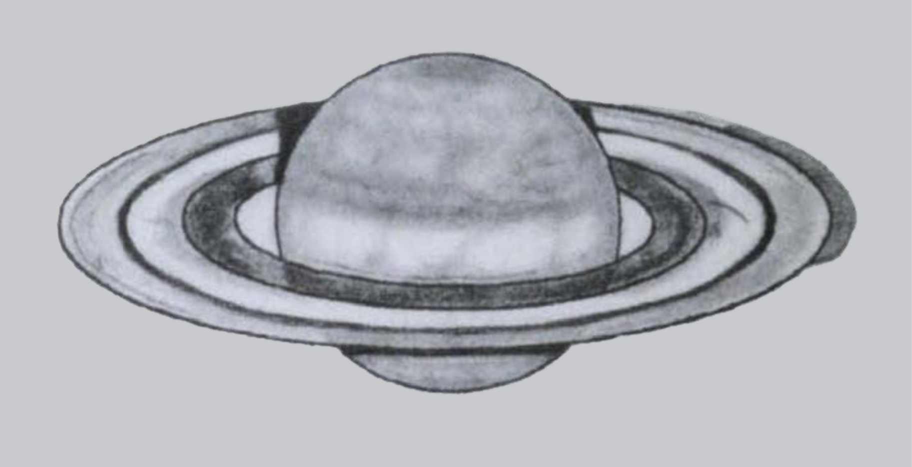
One month before Earth's passage through the ring plane in 1907, one of France's leading planetary observers, Georges Fournier, reported that on two nights of nearly perfect seeing he had glimpsed a "very pale, luminous zone" containing "tiny bright points of light" through the 11.4-inch refractor at the Jarry Desloges Observatory close to the summit of Mont Revard near Aix-les-Bains in Savoie, France.

Eleven months later, when the rings were inclined by 5°, Swiss astronomer Emile Schaer detected a thin, dusky outer ring just beyond the edge of ring A using the Geneva Observatory's 16-inch (40-centimeter) Cassegrain reflector. Unaware of Fournier's observations and convinced that he'd made a remarkable discovery, Schaer telegraphed his findings to the Central Bureau at Kiel, Germany, then the world's principal clearinghouse for announcing astronomical discoveries.

In response to Schaer's announcement, a team of British observers trained the Royal Greenwich Observatory's 28-inch refractor on Saturn. On seven nights they caught momentary glimpses of a "hazy border" along portions of the outer edge of ring A.

In 1910, Belgian astronomer Robert Jonckheere reported a "nebulous projection against the sky" at the eastern extremity of ring A using the 14-inch refractor at the Observatory of Lille University, in France. Years later Jonckheere would recall that he was unaware of the prior reports of similar phenomena when he observed this anomaly.

Another spate of independent exterior-ring sightings came in 1952, when the rings were inclined by 8° to Earth's line of sight. Richard Baum of the British Astronomical Association and two members of the Association of Lunar and Planetary Observers in the United States, Thomas Cave and Thomas Cragg, all suspected the presence of a narrow exterior ring that was fainter than ring C and not uniformly bright around the circumference of the rings. Cave had no knowledge that such a feature had ever been reported previously, so expectation bias was definitely not at work.



▲ Eagle-eyed observer and *S&T* Contributing Editor Stephen James O'Meara spotted a luminous arc of material beyond ring A using the Harvard Observatory's 9-inch Clark refractor on the night of November 28, 1976.

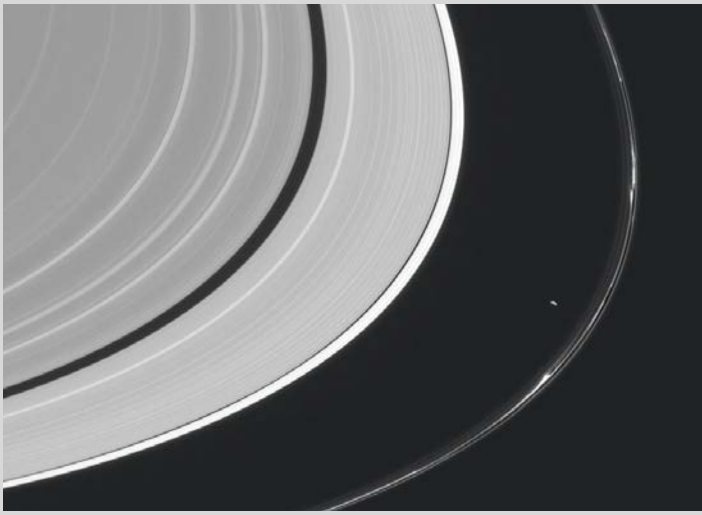
Despite credible testimony from experienced observers, Arthur Francis O'Donel Alexander, in his classic 1962 book *The Planet Saturn: A History of Observation, Theory and Discovery*, dismissed the exterior ring as ". . . a sort of 'Loch Ness monster' of Saturn in which some believe, but of whose existence most astronomers are very skeptical." Three years later the German astronomer Werner Sandner countered that there was a "strong possibility" that the exterior ring really existed "from time to time at any rate."

In 1979 NASA's Pioneer 11 probe flew past Saturn's rings at a distance of less than 3,500 kilometers (roughly 2,200 miles) and returned tantalizing images of a faint ring less than 500 km wide and centered just 3,600 km beyond the outer edge of the A ring. Although its location coincided perfectly with the reported exterior ring, this narrow wisp of light could not possibly have been detected by a telescopic observer.

Pioneer 11 was followed by the Voyager 1 and Voyager 2 spacecraft, both of which flew past Saturn, in 1980 and 1981, respectively. Equipped with far more powerful cameras than Pioneer 11, the Voyagers resolved ring F into a bewildering array of warps, kinks, knots, and braids, flanked by a pair of "shepherd" moons orbiting to either side. Christened Pandora and Prometheus, these irregularly shaped icy satellites, each less than 100 km across, seemed to herd most of ring F's particles into a band only 100 km wide.

Images taken by the Hubble Space Telescope during the 1995 ring-plane passage recorded several elongated clumps of material in ring F. These fleeting aggregations of ring material were reminiscent of the faint, fragmentary arcs reported by telescopic observers.

When the Cassini spacecraft swung into orbit around Saturn in 2004, ring F appeared twice as bright and three times as wide as it had during the Voyager flybys. In 2006, the Cassini spacecraft recorded a transient bright feature that almost doubled the F ring's overall mean brightness for a period of several weeks.

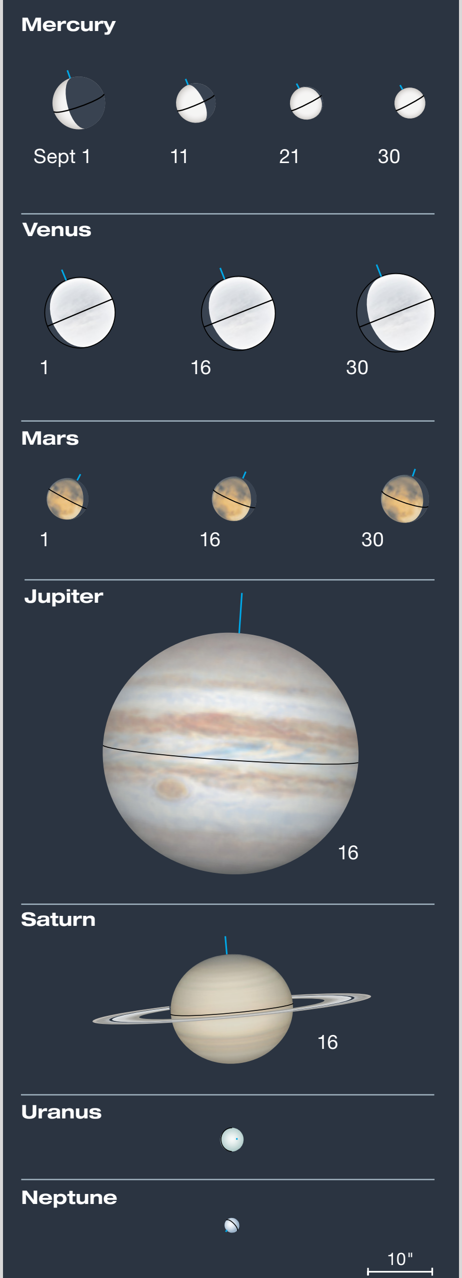


In 2004 the Cassini spacecraft's Narrow Angle Camera recorded this image of the shepherd moon Prometheus orbiting just inside the clumpy F ring.

RING ARC: NASA / JPL / SPACE SCIENCE INSTITUTE; SKETCH: STEPHEN JAMES O'MEARA

Cassini spacecraft images revealed that the clumpy structure of the F ring is caused by a halo of thousands of moonlets that frequently collide, producing dense strands of icy particles that re-accrete over several months back onto their parent bodies. Could unusually violent collisions in this cosmic demolition derby render material in the F ring briefly visible to telescopic observers? Perhaps. I'll be keeping a very close eye on the outer edge of ring A during this Saturn observing season.

■ Contributing Editor **TOM DOBBINS** co-authored *Epic Moon: A History of Lunar Exploration in the Age of the Telescope*, available at **shopatsky.com**.



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

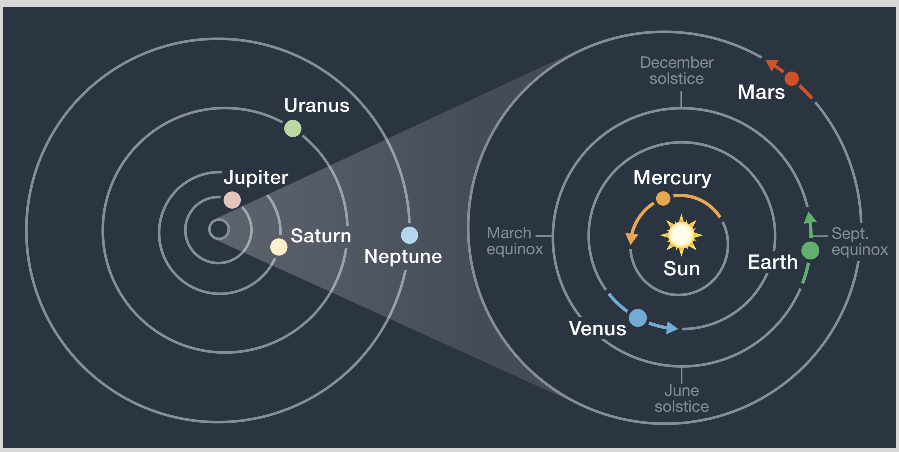
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during September. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dawn until the 20th • **Venus** visible at dusk all month • **Mars** visible in the predawn hours all month • **Jupiter** rises before midnight and transits the meridian at sunrise • **Saturn** rises at sunset and transits around midnight.

September Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$10^h\,41.3^m$	+8° 18′	—	–26.8	31′ 42″	—	1.009
	30	$12^h\,25.7^m$	–2° 46′	—	–26.8	31′ 56″	—	1.002
Mercury	1	$9^h\,35.0^m$	+13° 13′	17° Mo	+0.5	8.2″	28%	0.819
	11	$10^h\,18.5^m$	+11° 49′	16° Mo	–0.9	6.2″	70%	1.091
	21	$11^h\,25.3^m$	+5° 44′	9° Mo	–1.3	5.2″	95%	1.301
	30	$12^h\,25.2^m$	–1° 14′	2° Mo	–1.7	4.8″	100%	1.394
Venus	1	$12^h\,11.4^m$	–0° 07′	24° Ev	–3.8	11.0″	91%	1.518
	11	$12^h\,55.9^m$	–5° 15′	26° Ev	–3.8	11.4″	89%	1.469
	21	$13^h\,40.9^m$	–10° 13′	29° Ev	–3.9	11.8″	87%	1.418
	30	$14^h\,22.4^m$	–14° 24′	31° Ev	–3.9	12.2″	85%	1.368
Mars	1	$5^h\,48.4^m$	+23° 19′	71° Mo	+0.7	6.5″	88%	1.431
	16	$6^h\,27.3^m$	+23° 29′	77° Mo	+0.6	7.0″	88%	1.339
	30	$7^h\,00.9^m$	+23° 12′	83° Mo	+0.5	7.5″	87%	1.247
Jupiter	1	$5^h\,11.0^m$	+22° 15′	80° Mo	–2.3	38.5″	99%	5.120
	30	$5^h\,20.4^m$	+22° 24′	106° Mo	–2.5	42.1″	99%	4.683
Saturn	1	$23^h\,12.7^m$	–7° 27′	172° Mo	+0.6	19.2″	100%	8.666
	30	$23^h\,04.7^m$	–8° 17′	157° Ev	+0.7	19.0″	100%	8.729
Uranus	16	$3^h\,38.4^m$	+19° 11′	116° Mo	+5.7	3.7″	100%	19.103
Neptune	16	$23^h\,55.9^m$	–1° 53′	175° Mo	+7.8	2.4″	100%	28.896

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



A Ghostly Bubble in Space

The brightest planetary nebula in the northern heavens rides high this month.

RON BRECHER

▲ **MORE THAN A DUMBBELL** Located some 1,200 light-years from Earth, the famous Dumbbell Nebula exudes a complex structure in astrophotos. Lying at the center of the reddish hourglass structure is a dim and degenerate white dwarf star — the remains of a once-healthy sun that sloughed off its outer layers to form the enormous nebula. Its central star isn't visible in backyard telescopes. The twin lobes of M27 resemble hazy surface features on a ghostly planet adrift in space.

I call September the Goldilocks month: not too hot, not too cold. For mid-northerners like myself, this is the fair-weather interim between summer mosquitos and autumn rains. It's "just right" for some deep-sky scoping.

A clear September night opens with the glittering Milky Way arching overhead. Or so I'm told. There's no Milky Way crowning my suburban neighborhood, just a milky sky. But despite the pervasive polluting light, many denizens of our home galaxy are city-accessible at this time of year. A favorite of mine crosses the meridian shortly after nightfall. It's the 7.4-magnitude planetary nebula **M27**, popularly known as the Dumbbell Nebula.

M27 is basically an oblate bubble of gas sloughed off by a shrunken, dying sun. Bipolar outflows from the remnant white dwarf star dominate the nebula's telescopic appearance, and the resulting twin-lobed shape fires my imagination. I see the weightlifting dumbbell, sure, but I also picture an old-fashioned hourglass or, if I'm hungry, a partially eaten apple! And when I apply a nebula filter, M27 morphs into something ethereal, as I'll describe later.

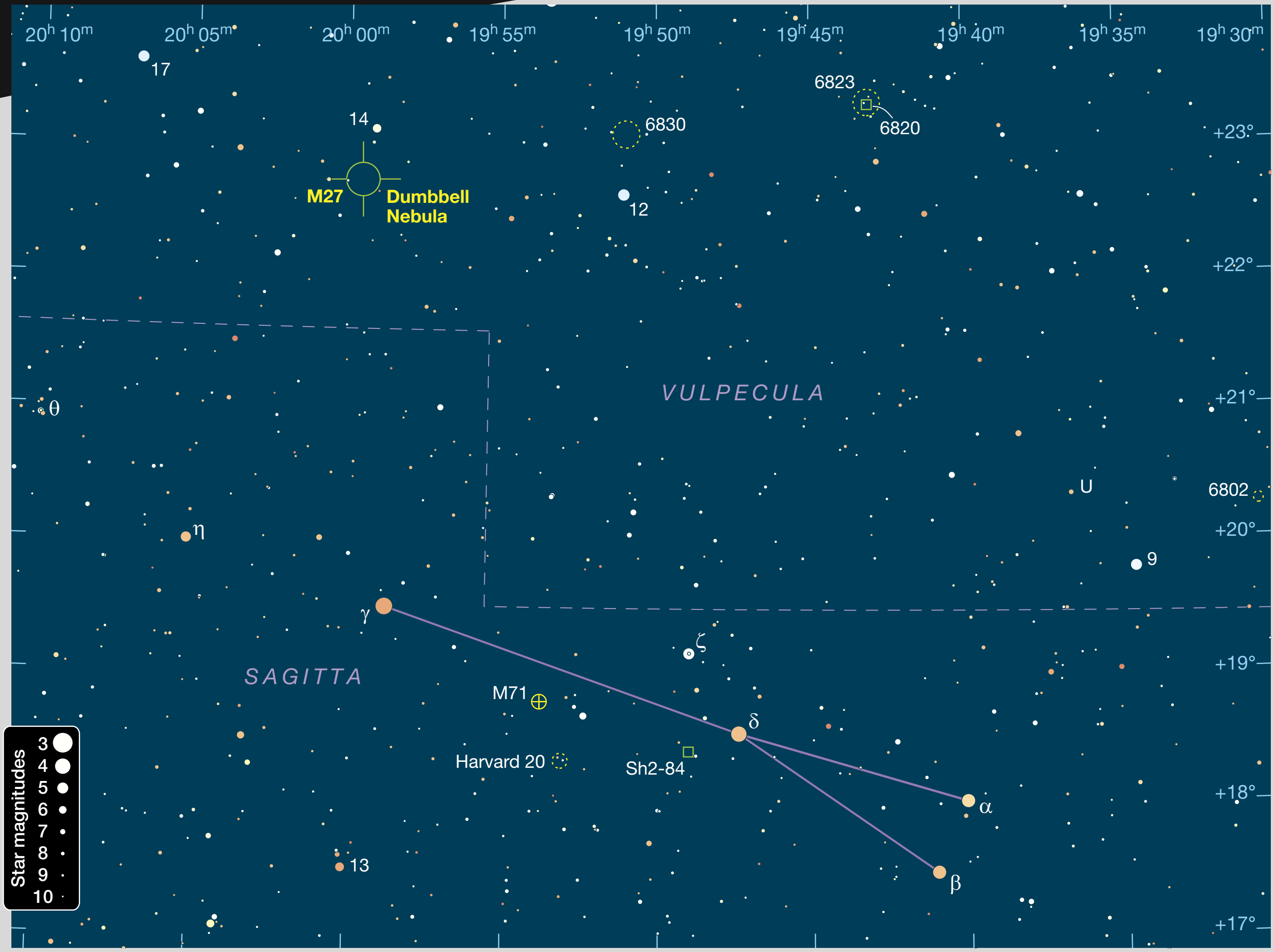
Last September I made my most recent, detailed exploration of the Dumbbell with a 4.7-inch (120-mm) f/7.5 apochromatic refractor and an 8-inch f/6 Newtonian reflector. Let's have a look at this evocative celestial object and compare telescopic impressions at different magnifications.

Easy to Find

If you have a computerized Go To telescope, with a few key presses you'll quickly have M27 in your eyepiece. But for star-hoppers like me, the pace is slower due to one small speed bump. The Dumbbell is located in Vulpecula, the Fox, an inconspicuous constellation lacking bright stars and buried in the Milky Way. Thankfully, there's a simple route to our nebulous target.

My two-step star-hop originates in neighboring Sagitta, the Arrow. Gazing skyward from my light-polluted backyard, though, I can barely identify the tiny Arrow. It's outlined by four shy stars, the two dimmest — ironically, Alpha (α) and Beta (β) Sagittae — are each magnitude 4.4, which is near the naked-eye limit of my suburban sky. Thankfully, the faint Sagitta foursome fit snugly in the 5° field of my 8×50 finderscope.

Step 1 is to center the finder's crosshairs on 3.5-magnitude Gamma (γ) Sagittae, the star at the arrow's pointy end. Step 2 is easy-peasy. From Gamma, I shift the finder due north across the Sagitta/Vulpecula border toward 5.7-magnitude 14 Vulpeculae — a distance of just 3.6°. The nebula lies 23′ south-southeast of 14 Vul.



▲ **ARROW BELOW THE TARGET** This chart highlights the attractive Arrow asterism at the heart of the constellation Sagitta. The Dumbbell Nebula, M27, lies a few degrees north of the 3.5-magnitude star Gamma (γ) Sagittae at the tip of the arrow.

M27 isn't always visible in city-based finderscopes (not mine, anyway), but it shows in just about any telescope at low power. My mantra is: "Find 14 and you've found the fuzzy."

If you have a red-dot (or similar) unit-power finder, my advice is simple: aim right at Gamma Sagittae. Next, use your telescope at its lowest magnification to sweep very slowly northward toward the aforementioned 14 Vulpeculae. You'll probably recognize the nebula before the star.

First Impressions

M27 is big. The Dumbbell's shell of ejected gas is 6.7′ in diameter — about five times bigger than the famous Ring Nebula, in Lyra. But M27 isn't uniformly round; the hourglass structure dominates until an overall roundness emerges with longer looks. The shape and size you perceive depend on essentially four factors: sky condition, telescope aperture, magnification, and the use (or not) of filters.

Let's examine our quarry first sans filter. In my 4.7-inch refractor at 38×, the nebula is a compact, rectangular haze, elongated northeast-southwest. Tellingly, it seems slightly pinched in the middle. At 100×, the pinch is obvious, and M27 becomes a double-lobed nebula set among a sea of stars. A 11.3-magnitude pinpoint flickers on and off, immediately west of the southwest lobe.

My 8-inch reflector operating at 51× reveals M27 as a prominent rectangular cloud, thinning at the waist. I see lots of field stars, including the 11.3-magnitude attendant noted above. At 135×, the Dumbbell's bi-lobed form is unmistakable. Moreover, one curious aspect emerges with increasing magnification — the southwest lobe is marginally smaller and brighter than the northeast one. Cool — details that survive the light pollution!

Survive, yes, but I can't overstate the benefits of eyepiece filters — accessories that really bring M27 to life. A broadband light-pollution reduction (LPR) filter provides modest relief from city lights by slightly darkening the field, thus improving the contrast between the gray sky and the diffuse planetary.

Narrowband nebula filters, such as the Lumicon Ultra-High Contrast (UHC) and doubly ionized oxygen (O III) filters deliver an even greater degree of enhancement.

The UHC and O III filters are subtly different, however. The UHC spiffs up faint nebulae without blunting too many stars. An O III favors the oxygen emission lines of planetary nebulae but kills most stars. The Dumbbell makes an excellent test case for comparing the effectiveness of each filter type.

Filter Magic

A UHC filter used with my 4.7-inch refractor doesn't disappoint. The increased contrast is stunning: at 38×, M27 is a fat, fuzzy hourglass juxtaposed against a darkish sky strewn with stars. Bumping the power up to 56×, the Dumbbell's middle looks strongly pinched. Better yet, my averted vision picks up some extremely pale nebulosity on either side of the pinch. At 100×, the central portion is fuller.

An O III filter adds improvements — and limitations. At 38×, M27's signature hourglass is superbly contrasted against a black sky, though the stronger O III blocks out all the faint stars. At 56×, the hourglass is distinctly enveloped in an oval bubble of vaporous nebulosity. Amazing! However, a limitation hits at approximately 100×: The tenuous bubble is harder to hold, and the background is reduced to just the brightest stars. The overall image is awfully dark in my little suburban refractor.

The 8-inch reflector equipped with the O III filter and medium power offers a well-defined, contrasty nebula. The twin lobes are subtly textured; the foggy fill between them blends smoothly into the Milky Way. But again, higher magnification erodes the nuanced detail. The field is dark and lacks starlight. M27's swollen middle is barely apparent even with averted vision. Conversely, the UHC retains decent contrast — plus a scattering of stars. The hourglass-in-a-bubble effect is evident at 51× and strengthens with each step up in magnification. At 135×, the nebula is impressively large, and its middle portion is nicely filled out. The object has morphed into a ghostly planet bulging at the equator, the textured lobes mimicking surface features.

ALAN DYER

▲ **HOURGLASS IN THE EYEPIECE** This simulated, 1°-wide telescopic view of the Dumbbell Nebula nicely captures the shape of M27 in good sky conditions. The brightest field star is 14 Vulpeculae, and the 11.3-magnitude star mentioned by the author is visible immediately to the right of the nebula's southwest lobe.

I've also studied M27 using a couple of Tele Vue Bandmate Type 2 Series narrowband filters. The Bandmate Nebustar, a refinement of the original UHC design, provides superior contrast. M27's wispy equatorial extensions swell; the hourglass portion likewise seems brighter. The Bandmate O III yields better contrast and broader equatorial extensions than the Lumicon O III. In addition, both Bandmates block out fewer stars than the venerable UHC and O III filters.

More Than a Dumbbell

Ultimately, any narrowband filter will maximize your appreciation of the Dumbbell. This classic planetary nebula truly lives up to its "planetary" label. To my eye, its overall oval form is similar in shape to the oblate globe of Saturn, whose equatorial girth is noticeably greater than its span from pole to pole. The misty equatorial extensions of M27 exude a hazy, atmospheric feel, while the bipolar lobes resemble a pair of massive continents connected by a slender isthmus, much like North and South America. Gorgeous!

As the old saying goes, beauty is in the eye of the beholder. So, get outside and behold the Dumbbell-Hourglass-Apple-Earth Nebula for yourself. You won't be disappointed.

■ Contributing Editor **KEN HEWITT-WHITE** has been scoping the Dumbbell Nebula since the summer of 1968.

Filling in the Blanks

Amateur astronomers provide crucial data about a mysterious kind of stellar binary.

Some objects in the universe shine steadily for eons: Every time you take a peek at them, they look pretty much the same as they did last month, last decade — heck, last millennium. Others, instead, lurk unseen in the vast darkness of space until they pop brilliantly and then fizzle back into obscurity. Blink and you'll miss the excitement.

Which is why when one of these *transient* sources suddenly appears in the sky, astronomers scramble to gather as much data as possible during its outburst.

One such class of objects comprises a white dwarf in orbit with a low-mass companion (which can sometimes be another white dwarf). Dubbed for their prototype, AM Canum Venaticorum, AM CVn stars have very short orbital periods, of the order of an hour or less. Consequently, the two components are physically very close, leading to all manner of interesting interactions between them as one star swills gas from the other.

For most of the time, the two stars spin quietly through their celestial dance. But every now and then something disrupts the status quo and they break into visual acrobatics, their brightnesses soaring. AM CVn eruptions can be observed at many wavelengths — which is great for constructing a big-picture view of the physics involved. But it's not that straightforward for astronomers to collect data across the electromagnetic spectrum.

ASASSN-21au goes bang. When the AM CVn star prosaically called ASASSN-21au brightened by about 8 magnitudes in 2021, Liliana Rivera Sandoval (University of Texas, Rio Grande Valley) sprang into action. She requested observations with NASA's Swift satellite and obtained data of ASASSN-21au in the X-ray, ultraviolet, and visual bands.

Only about 70 AM CVn stars are known to date, and so getting complete coverage of ASASSN-21au's outburst was vital for better understanding what transpires during these violent events. Swift, however, didn't capture the beginning of the outburst. So Rivera Sandoval turned to the American Association of Variable Star Observers database. She banked on the chances that someone somewhere had observed her target during the event.

And she hit the jackpot. It turned out that amateur astronomers had indeed recorded ASASSN-21au's outburst not only at different points during the event, but also in different filters!

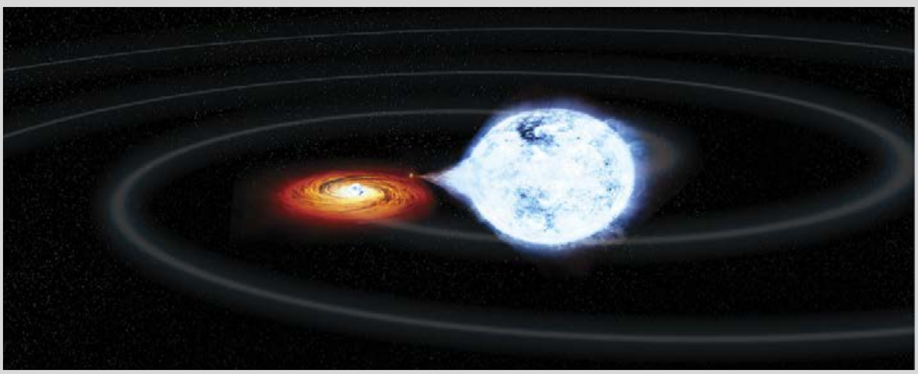
Armed with data coverage ranging from X-rays down to the visual V magnitudes familiar to backyard observers the world over, Rivera Sandoval and her colleagues documented the behavior of ASASSN-21au during its outburst in unprecedented detail. The event showed a slow rise over three months followed by a "superoutburst" of 19 days. The AAVSO data constrained the start and duration of the superoutburst. This tracking could not have been done with Swift data alone.

Never seen before. The double outburst is rather peculiar. AM CVn stars can be roughly divided into two categories: those with orbital periods shorter than 50 minutes, and those with periods longer than 50 minutes (of which very few are known). With its two stars orbiting each other every 58 minutes, ASASSN-21au belongs to the latter category. Historically, astronomers have reported that the short-period systems experience larger outbursts of shorter duration, while the long-period systems have smaller outbursts that last longer.

"ASASSN-21au showed *both* behaviors at different stages of the outburst, something never seen before," Rivera Sandoval says. Perhaps a variable amount of gas flowing from the companion star caused the disk surrounding the white dwarf to become unstable.

When writing the research paper, Rivera Sandoval invited the AAVSO observers who contributed to the study to be coauthors. "I think the synergies between professionals and amateurs are really important — it's a win-win for everyone," she says.

It would behoove professional astronomers to take heed of Rivera Sandoval's words — you never know what blanks amateurs might help fill.



▲**TIGHT PAIR** In AM CVn stars, a white dwarf pulls — or *accretes* — matter from a companion. This gas swirls into an *accretion disk* around the white dwarf, resulting in much interesting physics.

NASA / CXC / M. WEISS

■ Observing Editor **DIANA HANNIKAINEN** continues to be inspired by pro-am collaborative efforts.

▶ PREMIUM TRIPLET

Airy Disk, a relative newcomer to the industry, unveils its line of premium apochromatic refractors. The smallest in the series is the Pro APO AP 85/510 Triplet ED FCD-100 ($999). It's an 85-mm (3⅓-inch) f/6 triplet apochromat with a FCD-100 super-low-dispersion element. The telescope weighs 3.4 kilograms (7½ pounds) and features a 2½-inch-format, 10:1 dual-speed focuser that includes both 2-inch and 1¼-inch eyepiece adapters fitted with non-marring compression rings. The scope accepts the optional 0.92× Full-Frame Reducer / Flattener 85 mm – 140 mm ($250), which produces a corrected field large enough to accommodate APS-C-sized detectors. Each purchase includes a pair of mounting rings, a Vixen-style dovetail bar, a universal finder mounting bracket, and an aluminum lens cap.

Airy Disk Photoelectric Instruments
Airy-disk.com

▶ STRAIN-WAVE MOUNT

Sky-Watcher USA adds a new model to its line of equatorial telescope mounts. The Wave 100i ($1,695) is a Go To mount designed to take advantage of the high-torque capabilities of strain-wave gearing. The mount features fast drives in each axis, allowing slewing and tracking speeds of 10° per second. The mount head weighs 4.3 kg and can bear an instrument load of 10 kg and up to 15 kg with an optional counterweight kit ($110). The mount operates in both equatorial and alt-azimuth modes. Its dual-format saddle accepts both Losmandy-D and Vixen-style dovetail mounting bars. The Wave 100i is controlled with Sky-Watcher's upgradable SynScan Go To hand paddle, which includes a database of more than 42,000 objects, and its built-in Wi-Fi allows control using Sky-Watcher's *SynScan* app for Android and iOS devices. A 12-volt, 2-amp power supply is required.

Sky-Watcher USA
475 Alaska Ave., Torrance, CA 90503
310-803-5953; skywatcherusa.com

▶ COMPACT ASTROGRAPH

Starfield Optics now offers a compact astrograph for mobile astrophotographers. The Starfield Gear60Q (CAN $1,165.14) is a 4-element, 60-mm f/5 Petzval refractor that utilizes two elements of FPL-53 extra-dispersion glass to produce sharp, color-free stars across a 44-mm fully corrected image circle. The telescope weighs 2 kg and features a 2½-inch-format, dual-speed, rack-and-pinion focuser with rotator and tilt adapter. A reduction adapter is included with 48-mm threads to attach your camera, and it accepts 2-inch photographic filters. Also included are a Vixen-style mounting bar, a quick-release universal finder bracket, a saddle-handle bar that accepts Synta-style removable guidescope brackets, and an aluminum lens cover.

Starfield Optics
670 Hardwick Rd., Unit 5, Bolton, Ontario L7E5R5 Canada
store.starfieldoptics.com

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

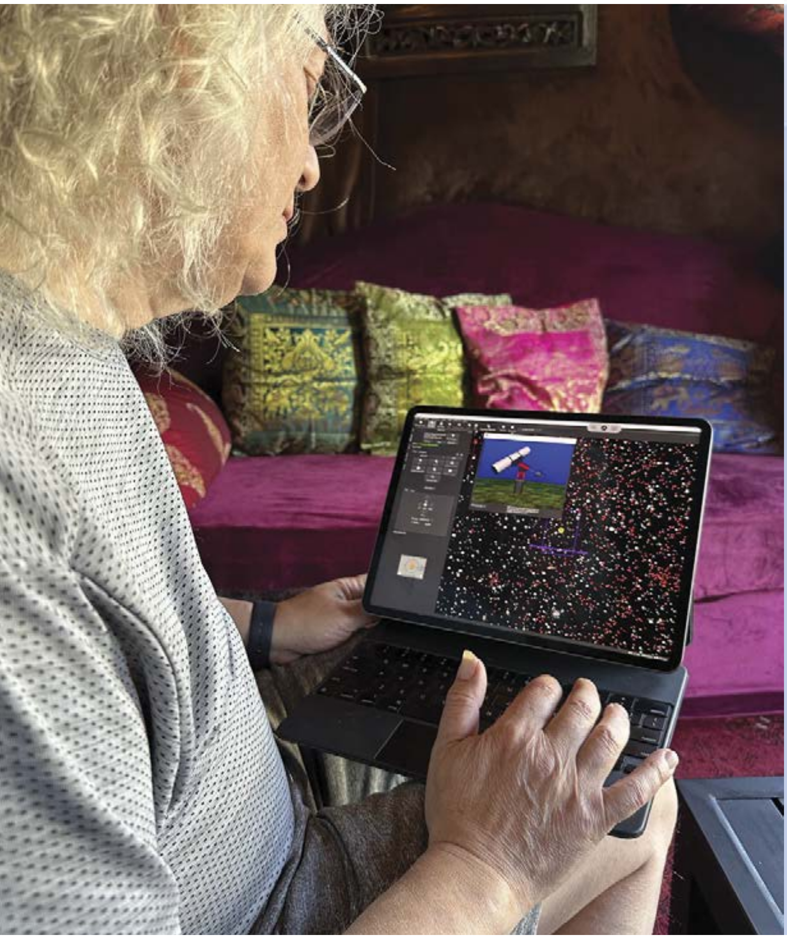
Going Remote

Set up your gear so you can operate it from anywhere in the world.

Astrophotography is often challenging. For many of us, the summer months bring sweltering temperatures and swarms of biting insects at night. Those of us who live farther north struggle with bitter temperatures in the winter, making it uncomfortable to be outside with our gear. Building a backyard observatory or other permanent setup only solves some of the problems. My observatory is conveniently located only about 24 meters (80 feet) from my house. And while it's easy for me to get to, the mosquitos have no problem finding me there. So, rather than sacrifice many otherwise good nights, I decided to change my setup so that I could control all my imaging gear from inside my house. And with some investment, you can go remote, too.

For many, the term remote imaging conjures up thoughts of an ultra-high-end setup perched atop a faraway mountain. That's certainly a good option for apartment dwellers or others looking to acquire top-notch data from dark skies. But the equipment can just as easily be nearby, with the imaging session controlled and monitored from the comfort of your home. And once set up, you don't even have to be home. For instance, I image remotely when I travel, managing my scopes and cameras from my hotel room or anywhere else where I have an internet connection. With the right equipment and software, you can automate every action necessary to take beautiful deep-sky imagery, from dusk to dawn, and in hot and cold weather.

Although setting up a remote system requires some planning, you don't need to be a computer wizard to do it yourself. Here are some of the essentials you'll need to take advantage of every calm, clear night.



Connecting from Afar

Any piece of computer-controlled equipment can be part of your remote setup. This includes the obvious, such as your telescope mount, camera, focuser, and filter wheel. It also includes less obvious elements, like using dew-prevention devices, opening and closing the roof or dome shutter, and even monitoring the power to the equipment in your observatory. The computer itself that is controlling all your gear is also capable of remote operation.

The key to remote imaging is to locate one computer at the telescope, which all your electronically controlled gear physically connects to. This is the heart of your observatory — the main hub where commands are sent to the peripheral components. This computer (let's call it the "imaging PC"), must be connected to the device you'll be controlling it with either directly, through your home network, or via the internet. You undoubtedly already use a computer positioned close to your imaging equipment, so the first change you

IMAGING IN COMFORT Regardless of where your telescope is located, you'll be much more productive if you can control your equipment remotely. Author Ron Brecher shares tips to make all your imaging equipment accessible from wherever you happen to be on a clear night.

UNLESS OTHERWISE NOTED, ALL IMAGES COURTESY OF THE AUTHOR; SWOOSH: ARENA CREATIVE / SHUTTERSTOCK.COM need is to make it accessible online from another device — be it a second computer, a smartphone, or a tablet. (I'll call this your "remote device.") Since all your equipment control and image-acquisition software is already installed on the imaging PC, you'll need just a few additions to allow you to control your imaging setup remotely.

So how powerful does the remote device controlling your observatory computer need to be? Not very, if all you're doing is accessing the imaging PC. After all, the only things exchanged between the two devices are keystrokes, mouse clicks, and screen displays. The imaging PC, however, must be powerful enough to reliably control all your equipment and run your camera-control software smoothly. It also needs to have enough storage space to hold at least an entire night's worth of imaging data, or more if you can't access the imaging PC frequently. Your current control computer should suffice, but with camera sensors and pixel counts rising, file sizes are also increasing, so you might want to consider an upgrade. Several companies, including iOptron (**ioptron.com**), PrimaLuceLab (**primalucelab.us**), Software Bisque (**bisque.com**), ZWO (**zwoastro.com**), and others all offer ride-along computers designed with lots of modern inputs suitable for imaging equipment.

Getting onto the imaging PC remotely requires that you grant your control device authorization to access your imaging software. The process is a little different for each operating system, but it's not difficult. Search online for "enable remote access" followed by your operating system's name (for example, Windows 11). Once the appropriate permissions are granted, there are a few options for connecting to the imaging PC, depending on whether the remote device and imaging PC are connected to the same local network.

If the imaging PC and remote device are both connected to the same local network, you can use the free program *Microsoft Remote Desktop*, available for download at **https://is.gd/MSremote**. There are versions of the program that run in Windows, MacOS, iOS, iPadOS, and Android operating systems. If either the imaging PC or remote device run on another operating system, you can find both free and paid software options online.

If the computers are connected to different networks, you'll need a different approach. My preferred remote access software when I travel is the program *AnyDesk* (**anydesk.com**). Another option is *TeamViewer* (**teamviewer.com**), both of which are free for personal use. (Some *TeamViewer* users, including me, report getting mistakenly flagged as commercial users and have had their access restricted — not ideal in the middle of an imaging run!) When the two computers are connected, both programs open a window that is a direct portal to your imaging PC's desktop, and you then run all your control programs there, just as you would if you were sitting at the telescope.

Note that the imaging PC and remote device can run different operating systems. For example, I often access my

Windows-based imaging computer from my Mac laptop using either *Microsoft Remote Desktop* or *AnyDesk*.

Electronic Peripherals

With the control computer and accessibility addressed, let's look at the parts that you'll need to complete your remote setup. We already mentioned focusers, cameras, and your mount. But other devices need to be accessible to your imaging PC to both control your equipment and to protect it from inclement weather.

For example, there are electrical outlets available with Wi-Fi connectivity known as *smart plugs*. With these outlets, you'll be able to turn the entire observatory power supply on or off from anywhere with the touch of your phone screen. Be sure to check the specifications before purchasing and choose models with enough amperage to supply power to all your equipment. I use a 15-amp plug that is rated to –10°C (14°F), though I haven't had any issues with temperatures as low as –35°C. These smart plugs protect your gear from some power surges and also reduce electricity use when your equipment is idle.

These days, motorized roofs and dome shutters are typically designed with computer-triggered switches, making them easy to integrate into a remote operation workflow. There are also retrofit automation motors and software available. And depending on how accessible your setup is, you might also need a weather monitor like the ones offered by Diffraction Limited

▲ **WIRED FOR ACTION** In addition to his robotic telescope mount, all the author's equipment is connected to the Eagle 4 Pro imaging PC and accessed wirelessly. The control box for the focuser is located atop the smaller scope.

(**diffractionlimited.com**) and several other manufacturers. Such devices keep a watchful eye on the sky and can trigger a shutdown command as conditions dictate.

Other devices can help improve the versatility of your setup. For instance, you'll likely want to have the option to rotate your camera so that your targets are properly framed. Several companies offer electronic camera rotators, includ-

▲ **CONTROL HUB** While most any computer is suitable for controlling an imaging setup, a dedicated, ride-along unit such as the PrimaLuceLab Eagle 4 Pro seen above can be a versatile upgrade from a regular desktop or laptop. These devices also include connections to power and control all your devices, while reducing the number of cables that can potentially snag as your unattended scope slews from target to target.

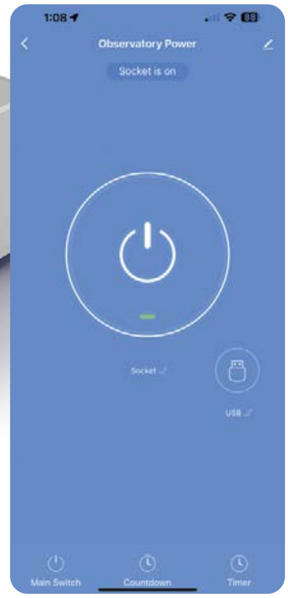
▲ **BUSY IMAGING TRAIN** Several devices are necessary to permit imagers to have the most options when composing astrophotos. Seen from left to right are PrimaLuceLab's ESATTO low-profile focuser and ARCO camera rotator, an off-axis guider with a QHYCCD guide camera, a 7-position filter wheel, and the main QHY600M imaging camera.

ing Optec (**optecinc.us**), Pegasus Astro (**pegasusastro.com**), PlaneWave Instruments (**planewave.com**), and PrimaLuceLab.

And then there is the problem of recording calibration frames. While you can shoot flat-field images during twilight, a better option is to use an electroluminescent panel. These devices provide a dependable and uniform light source that you aim your telescope at to record flats.

Both Optec and PrimaLuceLab offer electroluminescent flat-fielding panels. These devices can be installed on a wall inside your observatory, or you can get models that mount on the front of your telescope. These computer-controlled flat panels open at the start of your imaging session and close when the night's plan is completed.

Acquiring dark frames may be a little more challenging, particularly if your camera lacks an internal shutter. Since you likely have a filter wheel in your imaging train, consider installing an opaque piece of plastic or sheet metal in one of the slots to use as a makeshift shutter.



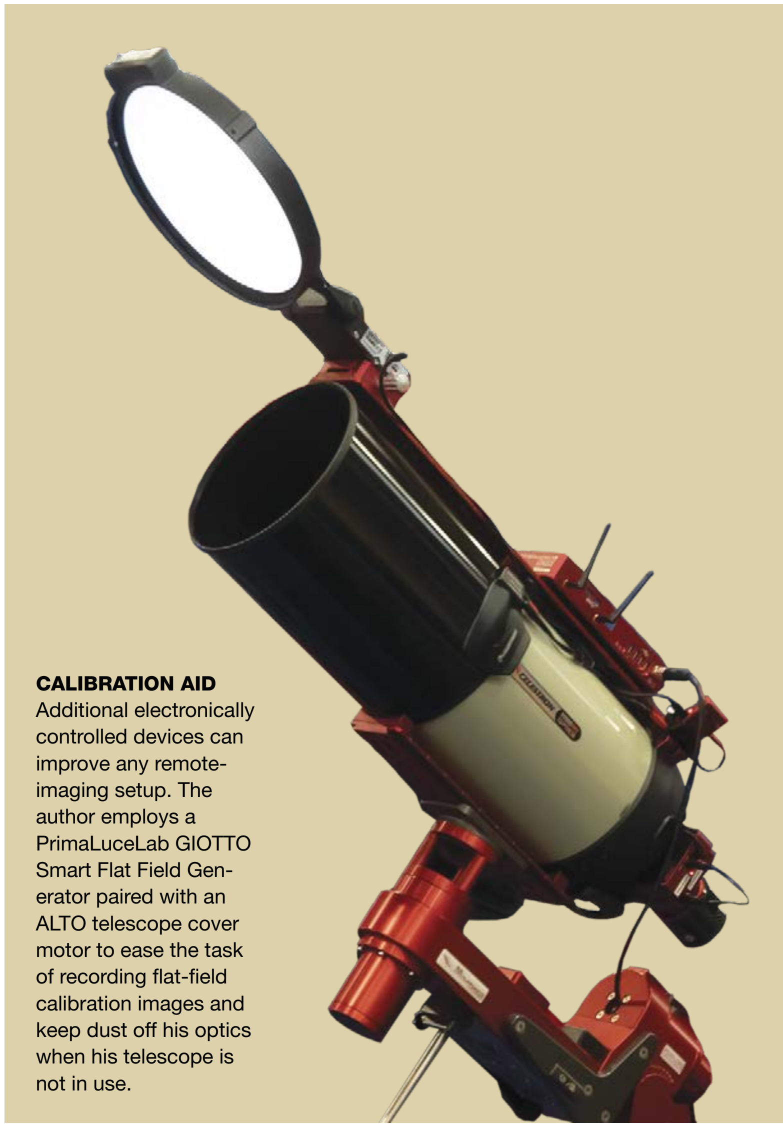
▶ **WI-FI OUTLET** Smart plugs like the Atomi device seen above connect to your local network via Wi-Fi and enable you power up any plugged-in device using a simple smartphone app (inset).

Putting It All to Work

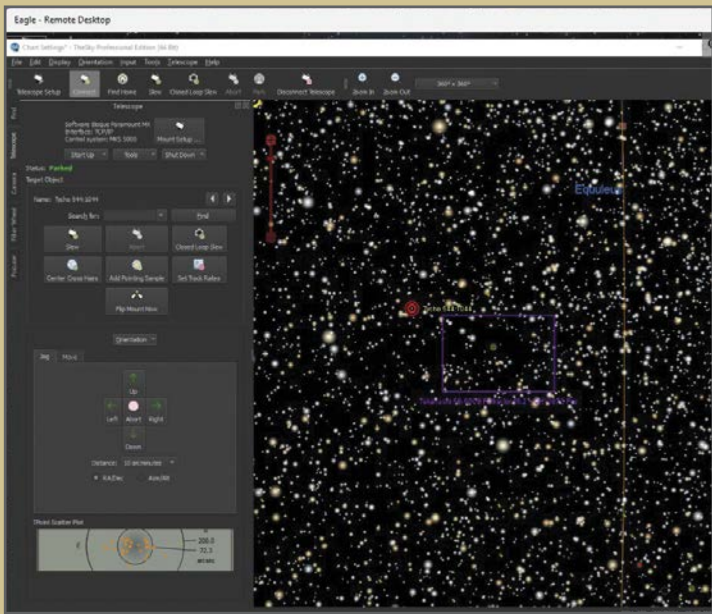
Once you have all your gear ready, you need a management program that will make each part of your observatory work when needed. Again, there are several options available, including DC-3 Dreams' *Astronomers Control Panel* or *ACP* (**acpx.dc3.com**), Main Sequence Software's *Sequence Generator Pro* (**sequencegeneratorpro.com**), *Nighttime Imaging 'N' Astronomy* or *N.I.N.A.* (**nighttime-imaging.eu**), and *Voyager* (**software.starkeeper.it**). Any of these programs can control every aspect of your remote-imaging sessions. I've written about N.I.N.A. recently (*S&T:* June 2023, p. 60), and most work in a similar fashion — each program implements the same general steps that you would apply in a non-remote setup. There's a startup sequence, multiple imaging actions, and then a shut-down sequence.

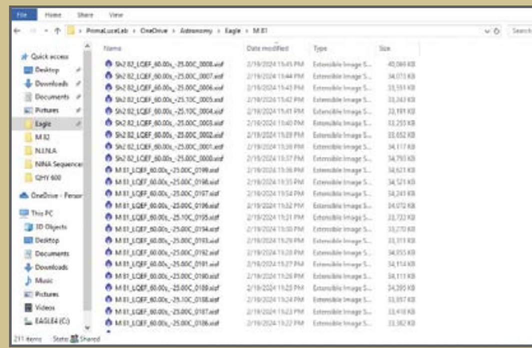
The startup sequence is used to prepare the equipment to do your astrophotographic bidding. The first thing necessary each night is to power up and connect to the imaging PC. For this I use an internet-accessible smart plug controlled with an app on my smartphone. The smart plug provides power to my imaging PC, which in turn distributes power to my other imaging devices. After it has booted up and my device establishes contact with the imaging PC using *Microsoft Remote Desktop* or *AnyDesk*, I then launch *N.I.N.A.* and activate the startup routine. This opens the roof, removes the lens cap from the telescope, and powers up the camera, mount, focuser, rotator, guide camera, and dew-control devices and prepares them for use. It's really just as though you were sitting beside your telescope with a keyboard, mouse, and monitor plugged in to the imaging PC.

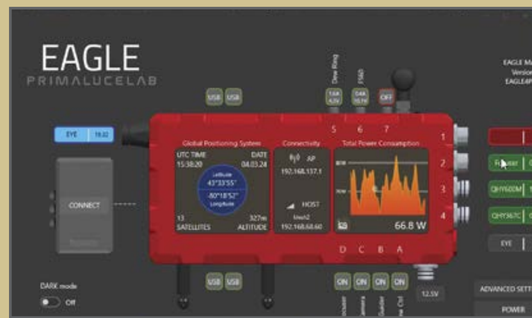
When the startup sequence has completed, I'm ready to image. Here the camera does its work recording the light images. I typically begin a session by having the scope slew to my target, having carefully determined the camera rotation and framing ahead of time in *N.I.N.A.* It then focuses on an adequately bright star in the field. Next, the



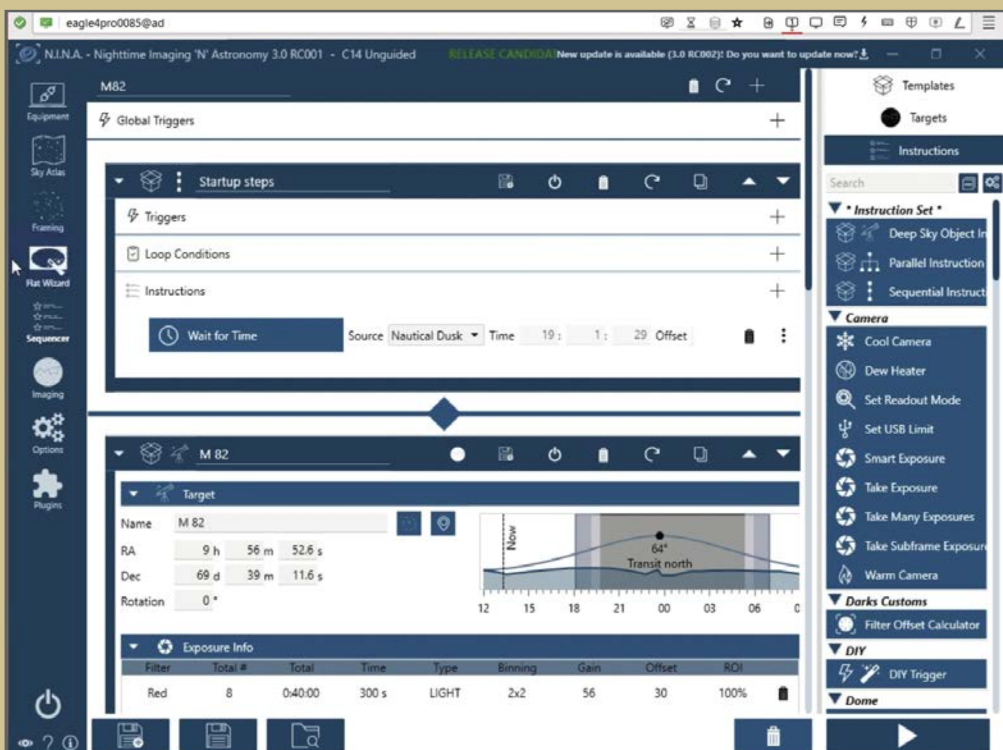
CALIBRATION AID Additional electronically controlled devices can improve any remote-imaging setup. The author employs a PrimaLuceLab GIOTTO Smart Flat Field Generator paired with an ALTO telescope cover motor to ease the task of recording flat-field calibration images and keep dust off his optics when his telescope is not in use.







▲▶ **LOCAL ACCESS** *Microsoft Remote Desktop* is a free program used to connect to your imaging PC if the control device is connected to the same Wi-Fi network, such as when controlling your backyard scopes from within your home.



▲ **LONG-DISTANCE REACH** Remote-desktop programs like *AnyDesk* or *TeamViewer* offer both free and subscription options. The software allows you to connect to your imaging PC online from anywhere in the world.

autoguider kicks into action by finding a guide star and starting its corrections. Once that's set, I'm ready to take the images I've scripted for the evening.

The system is constantly prepared to suspend the imaging session, park the scope, and close the roof if clouds are detected. It also will send a text message, email, or sound an alarm if something goes wrong, such as a piece of equipment losing power.

At the end of the imaging run, the shutdown steps are straightforward. If you need to acquire twilight flat-field images, have your control software do this before parking the telescope and closing the roof. If you're using a flat panel, park the telescope and close the roof first, so that twilight doesn't affect your flats. Finally, disable the camera's cooling and power everything down.

Accessing Data

Astrophotography today generates lots of data. Unless you do all your processing on your imaging PC, you'll need to access your image files from another device. Some imaging PCs like the ZWO ASIAir use removable memory cards to transfer images. But if you don't have that option, there are cloud-based file-storage services like Dropbox (**dropbox.com**) you can use to transfer your images. Other options are available, including Microsoft's OneDrive cloud storage (**https://is.gd/MSonedrive**), Google Drive (**google.com/drive**), and Apple's iCloud Drive (**icloud.com**). Each one offers a free plan, but you may need to pay for the amount of storage you end up requiring for several nights of imaging data.

It's convenient to have the imaging PC save image files in a cloud-based folder that is synced locally on your other devices. That makes it easy to move the files from the shared folder to a local folder for processing.

The ability to easily access one computer with another over a local network or the internet has revolutionized astrophotography. It no longer matters if your telescope is housed in a distant observatory or in your backyard — you'll be able to control and monitor an imaging run from wherever you find yourself on a clear night. Remote access makes imaging more comfortable and more productive. I'm confident that once you try it, you'll be hooked for good!

■ Although his observatory is located in his Guelph, Ontario, backyard, **RON BRECHER** can image the night sky anywhere there's internet access.

FRUITS OF THE LABOR With everything successfully working together, it's possible to obtain results like this detailed shot of NGC 4565 while you relax indoors or observe through another telescope.

Sky-Watcher's 6-inch Astrograph

This fast Newtonian reflector offers generous aperture at an attractive price.

▲ Sky-Watcher's Quattro 150P is a 6-inch f/4 Newtonian reflector that comes with a 6 × 30 finderscope, a photographic coma corrector/focal reducer, 2-inch and 1¼-inch extension adapters, and a 1¼-inch, 22-mm wide-field eyepiece. Also included are the tools needed for collimating the secondary mirror.

Quattro 150P

U.S. Price: $595
skywatcherusa.com

What We Like

Included corrector/reducer

Solid focuser

What We Don't Like

Small knobs rust in humid conditions

Shiny spots in optical path cause scatter

A QUALITY NEWTONIAN reflector is without question the most cost-effective way to get into astrophotography. A Newt produces images inherently free from chromatic aberration and offers a generous aperture in a relatively compact design. I own a 12-inch Sky-Watcher Quattro 300P Newtonian reflector that I've enjoyed using for years, and when I first saw the 6-inch 150P last year at the NEAF trade show, I thought it an adorable baby version of the behemoth I had at home — a scope my wife affectionately calls the "big black garbage can." So, I was looking forward to trying out the 150P on loan from the manufacturer for this review.

The Included Gear

The Quattro 150P is the smallest model in Sky-Watcher's Quattro series. Quattro means "four" in Italian and is a fitting moniker for the company's line of f/4 Newtonian astrographs, which are now available with apertures of 6, 8, 10, and 12 inches (150, 200, 250, and 300 millimeters, respectively). The tube of the 150P is rolled steel with a glossy, metal-flake finish on the outside — just like its larger siblings. The inside is painted flat black, and, unlike in the larger models, there are no ring baffles to reduce scatter in the tube.

The 150P's primary and secondary mirrors are made from borosilicate glass with Sky-Watcher's proprietary Radiant Aluminum Quartz coatings, for which the manufacturer claims 94% reflectivity. Its 2½-inch secondary mirror is designed to illuminate a large field of view. Paired with the included coma corrector, Sky-Watcher states it produces a corrected field ideally matched for APS-C sensors. The instrument's native focal length is 600 mm, though the included coma corrector/focal reducer shortens it to 518 mm, resulting in a photographically fast focal ratio of f/3.45. That's impressively fast — two full f-stops better than an equivalent 150-mm telescope operating at f/7.

▲ The dual-speed Crayford focuser held its position reliably even with heavy cameras and when pointing in any direction. The fine-adjustment knob is adequate for manually focusing even at f/3.45.

The scope has a 2-inch, dual-speed, Crayford-style focuser with 11:1 reduction. It also includes a 2-inch extension tube and a 1¼-inch custom eyepiece adapter, both for visual use. The Quattro 150P comes with a 1¼-inch, 22-mm ultra-wide eyepiece having a 70° apparent field of view that is quite nice. The eye relief isn't listed, but I found it comfortable to use.

A finder shoe is located next to the focuser to accommodate the included 6 × 30 finderscope. Imagers should note this is a great place to mount a small guidescope and autoguider combination.

ALL IMAGES COURTESY OF THE AUTHOR

The scope's front dust cap snaps snugly into place and has a 50-mm off-axis aperture with its own cap that is meant for stopping down the scope to dim the Moon or to install a solar filter. The whole scope with accessories is very light at only 5.7 kilograms (12.6 lbs) and can be used on a small mount that accepts the included Vixen-style dovetail bar. There is also a pair of threaded holes on top of the tube rings for mounting additional accessories.

The center of the 150P's primary mirror is marked with a small ring to aid collimation. The mirror is held in place with three small clips and is collimated by adjusting three pairs of push-pull knobs. The humidity and dew common in Florida where I live quickly rusted the locking knobs. I wish more manufacturers would use stainless-steel hardware to avoid this issue despite the modest additional cost. The overall feel and performance of the 150P is that of a high-quality instrument, so this small detail was disappointing.

▲ The included photographic coma corrector/focal reducer makes the Quattro 150P ideal for narrowband imaging even in moderately light-polluted skies. This image of IC 410 in Auriga was recorded with the telescope paired with a Player One Astronomy Poseidon-M camera equipped with H-alpha and O III filters. Total exposure was 270 minutes using 5-minute sub-exposures.

Visual Performance

I used the Quattro 150P visually my first night out. The finderscope has a nice, wide 7° field of view with cross hairs thick enough to see in a dark sky, which makes centering your target easy enough if you're star hopping or making manual adjustments.

Using the included eyepiece, I centered my first target, Saturn. It looked really awful. The problem turned out to be collimation. I had initially aligned the optics using a laser collimator but had neglected to check the position of the secondary mirror relative to the focuser, and the mirror had arrived slightly off-center. With such a fast focal ratio, even a slight mis-centering can lead to poor views. I carefully centered it and again re-collimated the scope.

Replacing the eyepiece and returning to Saturn produced the view I was expecting — quite good for the seeing conditions. I swung over to Jupiter as well and to a few open clusters. My favorite is the Perseus Double Cluster, NGC 869 and NGC 884, both of which looked lovely. Neither the clusters nor

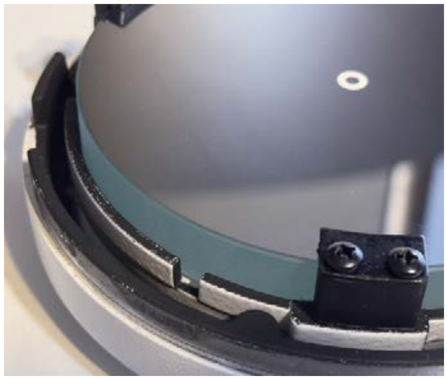
▲ The secondary-mirror assembly uses three hex-head bolts for adjusting its tilt, and the central post is affixed using a Philips-head screw, which lets you shift the position of the secondary back and forth — both important adjustments for any Newtonian. In addition, a white ring marks the center of the primary mirror to aid collimation.

▲ Collimation of the primary mirror is performed with the three large, spring-loaded knobs on the rear of the cell and secured with the three taller knurled knobs. The taller knobs quickly began to rust in the author's humid Florida environment.

▲ For imaging use, the Quattro 150P easily supports an average-size modern CMOS camera or crop-sensor DSLR camera. The shoe for the 6 × 30 finderscope also accepts guidescopes, such as the Evoguide 50DX model seen here (and reviewed in our June 2022 issue, p. 70).

Jupiter, Saturn, or the waxing Moon showed any noticeable false color in the included 22-mm eyepiece, and the views were quite sharp in the middle of the field. I could see a good bit of distortion starting about ¾ of the way from the center to the edge of the field, as would be expected in an f/4 reflector without a coma corrector in place (the corrector included with the 150P is for photographic use only).

I was curious if the Quattro would make a good rich-field telescope. It certainly has a generous field of view and sufficient aperture to provide that "spacewalk" effect. However, it really needs a visual coma corrector such as Tele Vue's Paracorr and a more complex eyepiece to perform as a great rich-field telescope. Alas, this would more than double the cost of the entire system! Still, I used an assortment of eyepieces, and, aside from the coma, I found the views quite satisfactory, with the higher magnification views having progressively less distortion. I did try a Tele Vue Ethos eyepiece, and what a nice, lovely field it would have been had I had a visual coma corrector, but without one only the middle of the field was satisfactorily sharp.



◀ The primary mirror is secured with three clips, each held in place with a pair of black Philips-head screws.

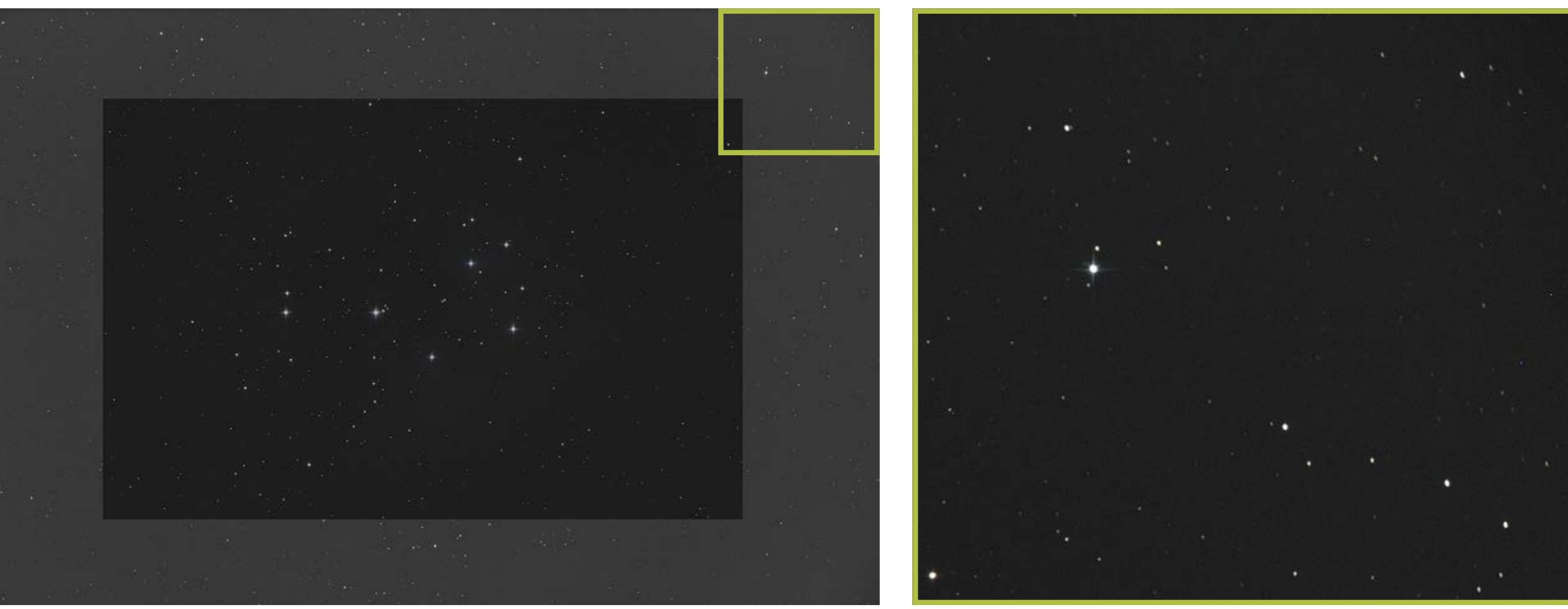
Photographic Performance

While this scope can be used for visual observing, the inclusion of a photographic reducer/corrector is a pretty good indication that its main intention is for use as an astrograph. The corrector connects to your camera via a M48-male-threaded interface and has a 2-inch barrel that slides into the focuser. Its back-focus requirement of 55 mm works perfectly with most modern astronomical cameras or a DSLR/mirrorless camera adapter, though you should note that it will only produce a corrected field large enough for a crop sensor camera. I used the scope with a Player One Poseidon-M (which I reviewed in the December 2023 issue, p. 66), a color Player One Ares-C, and once with a full-frame Canon EOS Ra mirrorless camera in order to assess the size of the corrected field. Taking an exposure of M45 (seen below) shows the corrector can cover an area noticeably larger than the stated APS-C format.

I had some concerns about the fast focal ratio making the scope difficult to keep in collimation. I had to fine-tune my initial collimation slightly using an out-of-focus star with a camera when I transitioned from visual to imaging use, but afterwards I never needed to adjust collimation again, even after driving with it to my dark-sky site over 160 km (100 miles) away. The open back on the primary mirror cell allowed the optics to reach ambient temperature quickly — I was ready to start imaging after about 30 minutes in a typical evening starting around 70°F at sunset.

I'm a bit spoiled by electronic focusers and groaned inwardly about having to focus this scope manually. It turns out that good focus was fairly easy to achieve with the fine-focus knob. The focuser never slipped with heavy

▼ *Left:* The image below is taken with a full-frame camera (EOS Ra), with a rectangle showing the smaller field of an APS-C sensor recommended as the maximum field coverage when using the focal reducer/coma corrector. *Right:* Zooming in on the top right corner shows the image is well-corrected for APS-C detectors and would be acceptable for slightly larger sensors.



cameras attached, even with slewing to multiple targets. What pleasantly surprised me even further was that the focus held even with temperature changes up to 10°F — something I never experience with any of my refractors.

It's natural to make comparisons with similar products, and while my Quattro 300P also shows the same temperature stability, its stock focuser was completely unsuitable for astrophotography, as it would slip very easily despite repeated efforts to adjust it. I asked a representative at Sky-Watcher about this, and he conceded that the Quattro 150P focuser was a better and true Crayford, while the other Quattros utilize a less expensive linear rail model. I'm not sure what the mechanical differences are between the two designs, but I could sure tell the difference in performance.

The 150P is a fun scope to capture images with. Its fast focal ratio makes short work of most deep-sky targets and is an excellent match for one-shot color cameras or narrowband imaging where the additional light is most needed. Although my primary choice in telescopes is a quality refractor, I will confess that I appreciate the diffraction spikes produced by the secondary mirror support in a Newtonian reflector. I took many images of open clusters to capitalize on this feature, and I also like the sparkle they added to my shot of the Triangulum Galaxy, M33.

The brightest stars in some images taken through the scope display minor but noticeable scatter to one side. Not all images showed this flare, but only those with fairly bright stars in the field of view. When I used the scope at home and shot through narrowband filters, the problem disappeared. A possible source is six blackened but reflective screws that secure the clips holding down the primary mirror. Shining a light down the tube while looking into the focuser reveals a glint of light from each screw head. A simple fix is to paint the screws with flat-black paint or cover them with a bit of flocking paper.

▲ The author captured this image of the Double Cluster in Perseus (NGC 869 and NGC 884) with a Player One Astronomy Aries-C CMOS camera. The 150P's fast imaging focal ratio of f/3.45 resulted in a deep image with only 18 minutes of exposure time.

Narrowband imaging with the scope at f/3.45 is quite a luxury. On one night I imaged IC 410 in Auriga, recording 54 five-minute exposures through 3-nanometer hydrogen-alpha and O III filters. To gather the same amount of light with one of my f/7 refractors, I would have had to expose for almost 18½ hours (f/3.45 is 4.1× faster than f/7).

▶ The Quattro 150P also makes a great wide-field visual telescope. Observers should consider adding a third-party coma corrector for visual use.

Final Thoughts

Overall, I found the Quattro 150P to be an affordable and extremely capable Newtonian reflector that was a pleasure to use. Collimation wasn't very difficult, and the scope retains its optical alignment extremely well even after transporting to remote locations. The coma corrector/focal reducer did an excellent job and produces a slightly larger corrected field than advertised. It's easily portable and an ideal scope for budget-minded imagers looking for greater aperture. As an experienced imager, I found it met my needs well.

■ For someone who calls himself a refractor guy, Contributing Editor **RICHARD WRIGHT** often finds his cameras on the business end of reflecting telescopes.

The Newton ad Alto Contrasto Telescope

Refractor performance at a reflector price.

▲ Roy Cerreta's Newton ad Alto Contrasto Telescope provides refractor-like images with a long-focal-ratio primary and minimal secondary mirror.

BACK IN THE 1990S, Italian ATM Roy Cerreta got a wild-hair notion to build a high-contrast Newtonian telescope. He had done some observing with the refractors of Collurania-Teramo and de la Côte d'Azur-Nice observatories, respectively 394 millimeters (15.5 inch) and 500 mm in diameter, and that experience stuck with him. Roy says, "A twenty-year-old visual observer is willing to do anything to increase resolution and contrast, even thinking of a mirror instrument up to focal ratios typical of a lens instrument." Since he couldn't count on continued access to those professional scopes, he decided to build his own telescope that would come as close as possible to their performance, at least in terms of sharpness and contrast.

Reading J. B. Sidgwick's *Amateur Astronomer's Handbook*, Roy learned that when the focal ratio reaches double digits, aberrations become negligible, alignment is much less critical, and magnification is easier to achieve with modest eyepieces. Roy decided to make a 254-mm f/12 system, and thus was born the NAC, the "Newton ad Alto Contrasto" or "High Contrast Newtonian."

Roy purchased a Duran 50 Schott blank and commissioned master mirror maker Lorenzo Quintili in the town of Cupra Marittima to grind it, resulting in a mirror with a precision of an astonishing 1⁄30 wave.

To house this mirror, Roy built a three-part OTA out of marine plywood, each section of decreasing dimensions. The primary housing was the widest, then a long central box of 400 mm external dimension, then a "door box" secondary housing measuring 300 mm externally. Roy wanted to make it wide to keep any tube currents well out of the optical path. Vents allowed the rising warm air to exit the tube partway up, further reducing its effect.

The mirror was 40 mm thick, but Roy set it on a 9-point cell just to make sure there would be no cell-induced astigmatism. He mounted a 20-mm secondary mirror on a three-vane spider and had a local artisan machine a low-profile, bronze helical focuser. With a secondary obstruction of only 8%, the secondary shadow was almost invisible in a star test.

◀ The yoke-mounted version of the scope was an engineering marvel but not very portable.

Part of the impetus for building the scope was a bet with another amateur astronomer whom Roy often met while volunteering at the Colle Leone Astronomical Observatory – Mosciano Sant'Angelo. One condition of that bet was that the scope be yoke-mounted, so Roy did just that, building a huge, ungainly framework to hold the yoke. That worked well enough, but it was so difficult to transport that the scope saw little use in the next few years.

Roy soon realized that he needed a more portable setup, so he built an altazimuth mount for it. That made a huge difference, with Roy reporting, "The altazimuth NAC immediately revealed itself to be a very manageable instrument, despite its weight of 200 kg (440 pounds) or more. I could move it myself and, by tilting the tube, pull it inside to store it in a small corridor."

Outside, standing upright, the scope was a veritable tower. Roy says, "Indeed, when I finished painting it white, looking at it from below it had a bit of a Saturn V effect."

Of course, such a tall telescope requires a ladder. At the zenith, the eyepiece reached about 3.5 meters (11½ feet) in height, and Roy conquered it

ALL IMAGES COURTESY OF ROY CERRETA

▲ Such a long scope bounced up and down vertically, so Roy added a stabilizing arc bolted to the mount, with a spring-loaded, braked ball bearing attached to the scope and pushing on the arc. That stabilized it nicely.

only by climbing up to the eighth or ninth rung. Eventually he got a double-access ladder that allowed the operator and the observer to climb up together, a necessity with the small field of view when operating the scope at high magnifications.

That, of course, led Roy to motorize the scope, using a sector gear for the altitude axis and another for azimuth.

How did all this effort work out? Roy reports, "This telescope gave me some of the best views of planets I've ever experienced."

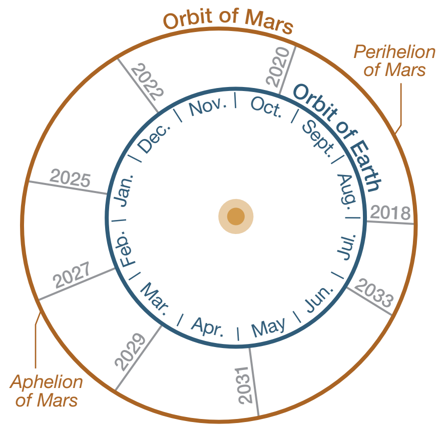
Unfortunately, the scope met with a wind gust a few years ago, which damaged the OTA but not the optics, so Roy plans to rebuild it, this time in a more traditional (and lighter) Dobsonian style. As he says, "Time elapses, and I am not so young to easily move 200 kilos anymore."

So the NAC 2512 is still a work in progress. I can't wait to see what its new incarnation looks like.

For more on the NAC, contact Roy at **rcimago@gmail.com**.

■ Contributing Editor **JERRY OLTION** has a few works in progress as well, but none quite so large as this.

When Is the Best Time to Observe Mars?



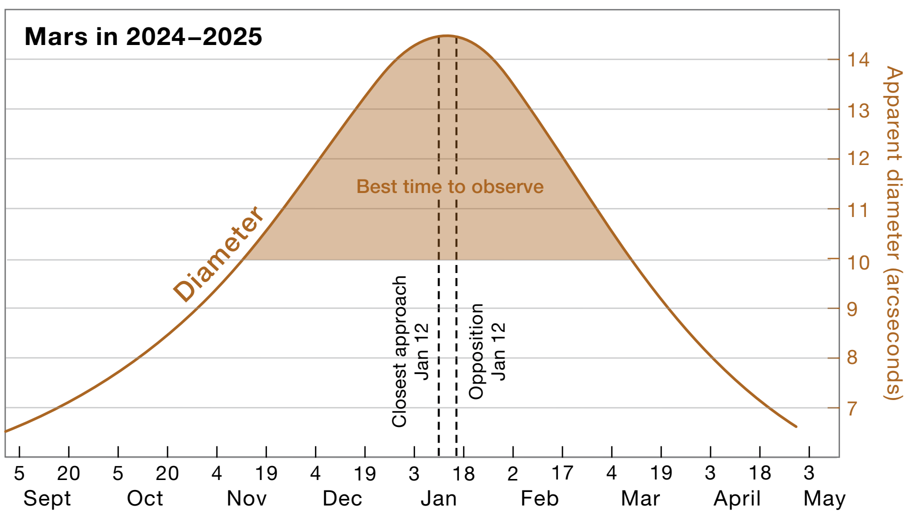
▲ **THE CYCLE OF MARS** Due to the elliptical nature of the planets' orbits, Mars comes closer to Earth in some years than in others in a period that repeats over 15 years. This diagram shows the position of Mars and Earth at opposition between 2018 and 2033.

MARS IS A UNIQUE PLANET in many ways. It's the only planet in the solar system whose surface can be viewed directly in a telescope. And unlike the other outer planets, which reach opposition every year, Mars does so once every two years.

Because of its reputation and brightness, Mars is a tempting target for new observers and their telescopes. Unfortunately, the planet frequently disappoints, because it only appears big enough to impress in telescopes for a few months every two years. So, when is the best time to cast your gaze toward the famed Red Planet?

As discussed in this column in the March 2023 issue (page 72), the outer planets look biggest and brightest when appearing opposite to the Sun in our sky, a period known as *opposition*. But because Jupiter, Saturn, Uranus, and Neptune are so distant, the difference is relatively insignificant in the telescope. Because Mars is comparatively nearby, the planet's disk dramatically grows in size as opposition nears. The apparent size of Mars varies between a minuscule 3.5 arcseconds at its farthest distance to a maximum of 25.6″ at its nearest apparitions. Also important is the date of closest approach, which often occurs a few days before or after opposition. This time, closest approach is January 12, 2025, four days before its January 16th opposition.

During the lead-up to closest approach, it's generally accepted that good views of the planet typically come when the planet's apparent diameter reaches 10″ and greater. At that point, most any telescope will resolve the largest dark surface markings, such as Syrtis Major, Sinus Meridiani, Mare Cimmerium, and others. The bright white polar caps will also be clearly visible, as will ice clouds and, if you're lucky, the occasional yellowish dust storms. That luck might not be considered good if the storm spreads across the entire globe.



▲ **OBSERVING SEASON** This graph shows the angular size and magnitude of the Red Planet throughout this coming apparition. Mars should yield satisfying telescopic views on steady nights between November 12, 2024, and March 10, 2025.

Each apparition of Mars is different due to the elliptical nature of its orbit. That's why some approaches are closer than others. For example, the closest approach next January is a distant or *aphelic* opposition, in which the planet will only reach 14.6″. Compared to the most recent closest or *perihelic* apparition, which occurred on July 27, 2018, when the planet achieved an angular size of 24.3″, it will appear a bit more than half that size this time around.

But just because Mars won't be as big as it can get during the next apparition, you shouldn't ignore it — especially if you observe from northerly latitudes. The planet will be at its best at the same time it's favorably positioned in the most northerly extent of the ecliptic, placing the planet high in the sky when it climbs to the meridian.

So, when exactly does Mars reach that 10″ apparent diameter threshold? That occurs this year on November 12th, a date that marks the start of a four-month observing season that ends on March 10, 2025, when its disk once again shrinks to below 10″.

So, get ready for Mars season. The more often you look, the more you'll see. And keep an eye on upcoming issues for more information about Mars's 2024–25 apparition. ■

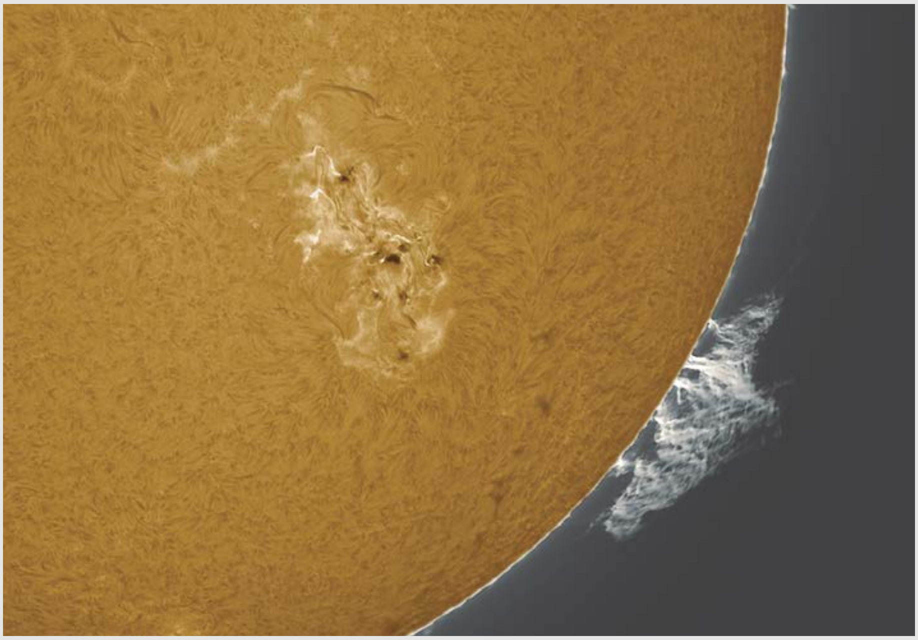
APPARITION GRAPH: BEATRIZ INGLESSIS / *S&T*; ORBIT: ROY BISHOP / RASC *OBSERVER'S HANDBOOK*

DAZZLING DISPLAY

Philippe Moussette

On the night of May 10th and lasting through the morning hours on the 11th, a massive geomagnetic storm produced this bright aurora display. Here folks gathered to watch the spectacle above the trees of Laurentides Wildlife Reserve in Québec, Canada.

DETAILS: *Canon EOS R3 camera and EF 8-to-15mm fisheye lens. Total exposure: 15 seconds at 15 mm, ISO 3200.*

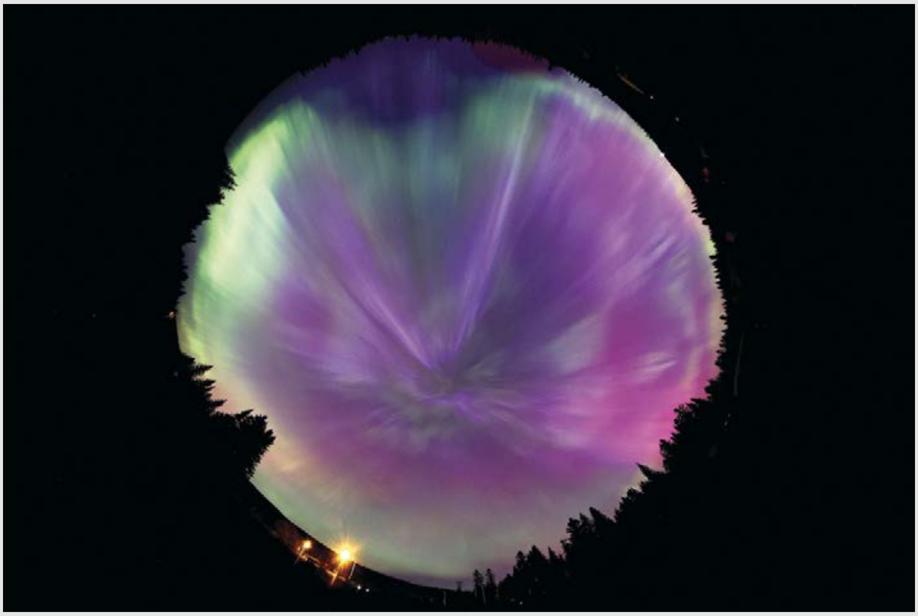


△ HOT SPOTS

Behyar Bakhshandeh

Active regions 3664 and 3668 seen above are the largest sunspot groups to appear in two decades. On several days in early May, the merging groups produced five coronal mass ejections, resulting in aurorae visible as far south as Puerto Rico.

DETAILS: *Coronado SolarMax II 60-mm refractor and ZWO ASI174MM camera. Stack of multiple frames captured on May 9th.*



△ GEOMAGNETIC LIGHTSHOW

Philippe Moussette

This additional view by Philippe Moussette of the massive auroral display seen in the morning hours of May 11th shows rapidly changing streamers in hues of greens, pinks, and purples visible all the way to the zenith.

DETAILS: *Canon EOS R3 camera and EF 8-to-15-mm fisheye lens. Total exposure: 15 seconds at 8 mm, ISO 3200.*

△ HERON AND FRIENDS

Kfir Simon

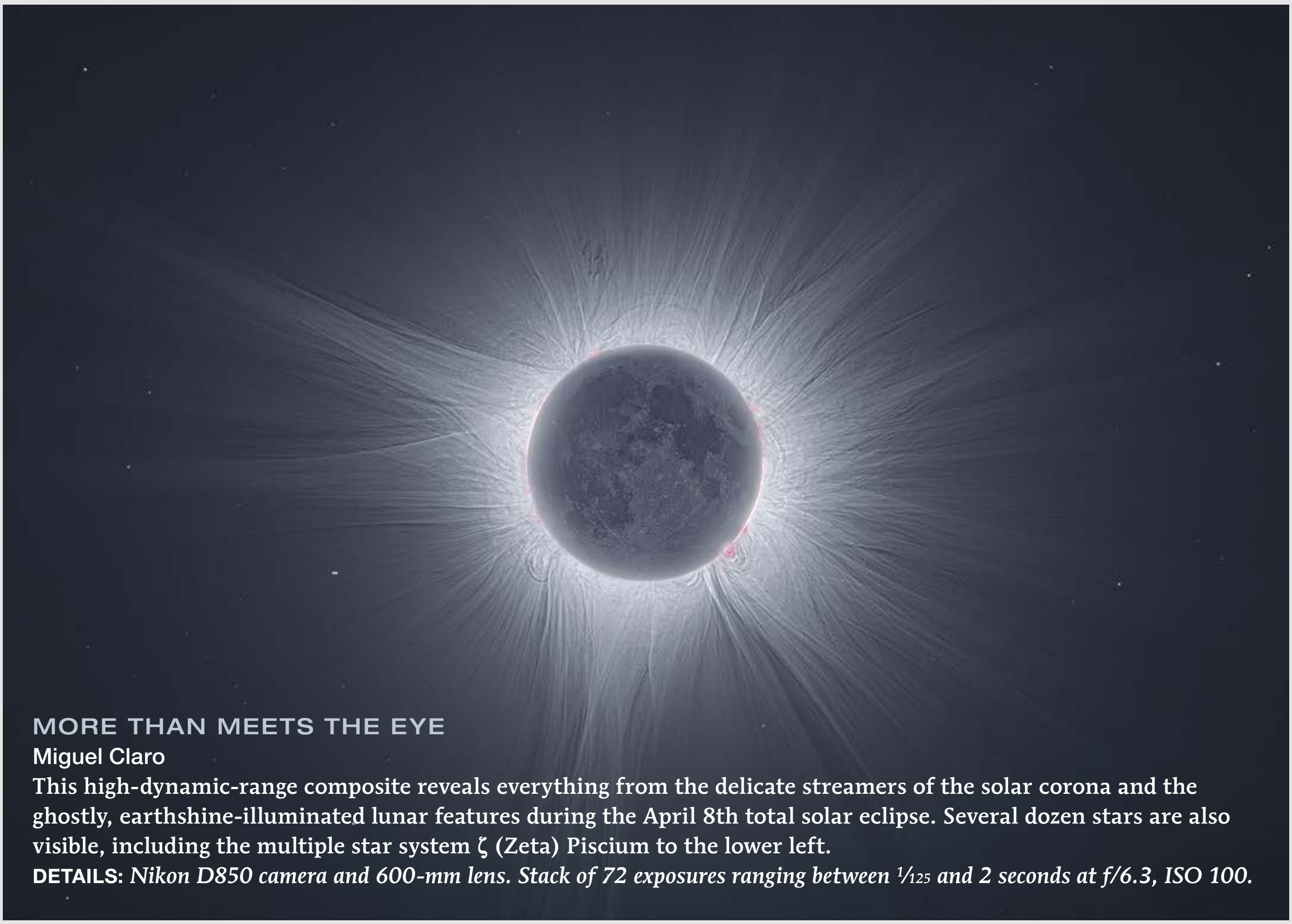
NGC 5395 and 5394 (left) in Canes Venatici are interacting spiral galaxies that appear to have collided in the recent past. Other visible galaxies include NGC 5380 (lower right) and NGC 5378 (far right) as well as several distant galaxies.

DETAILS: *AstroSysteme Austria 600-mm Ritchey-Chrétien telescope and Moravian Instruments C3-61000 Pro camera. Total exposure: 4½ hours through LRGB and Hα filters.*

GLITTERING DIAMOND
Cameron Mertz
The first rays of sunlight flood out from behind the Moon, marking the end of totality on April 8th. Three prominences are visible along the Moon's eastern limb.
DETAILS: *Canon EOS Rebel SL2 camera and 70-to-300-mm zoom lens. Total exposure: 1/250 second at f/7.1, ISO 200.*

ANNULARITY
Chirag Upreti
Nearly every phase of the annular eclipse of October 14, 2023, is seen in this image taken at the ruins of Pueblo Bonito in Chaco Culture National Historical Park in northern New Mexico.
DETAILS: *Sony α7R III camera and 24-to-70-mm lens. Stack of 54 frames, each less than a second at f/8, ISO 100.*

◁ **ECLIPSED SOLARGRAPH**
David Kazdan
By placing photographically sensitive paper inside a soda can with a small hole in the side, the photographer captured this cyanotype of the April 8th total solar eclipse from Cleveland Heights, Ohio. On the left, the tapered gap in the blue line of the Sun records the entire sequence of the event. The gap in the path at top left is due to the Sun passing behind a light post.
DETAILS: *Soda-can pinhole camera and cyanotype paper. Total exposure: 13 hours.*



MORE THAN MEETS THE EYE
Miguel Claro
This high-dynamic-range composite reveals everything from the delicate streamers of the solar corona and the ghostly, earthshine-illuminated lunar features during the April 8th total solar eclipse. Several dozen stars are also visible, including the multiple star system ζ (Zeta) Piscium to the lower left.
DETAILS: *Nikon D850 camera and 600-mm lens. Stack of 72 exposures ranging between 1/125 and 2 seconds at f/6.3, ISO 100.*

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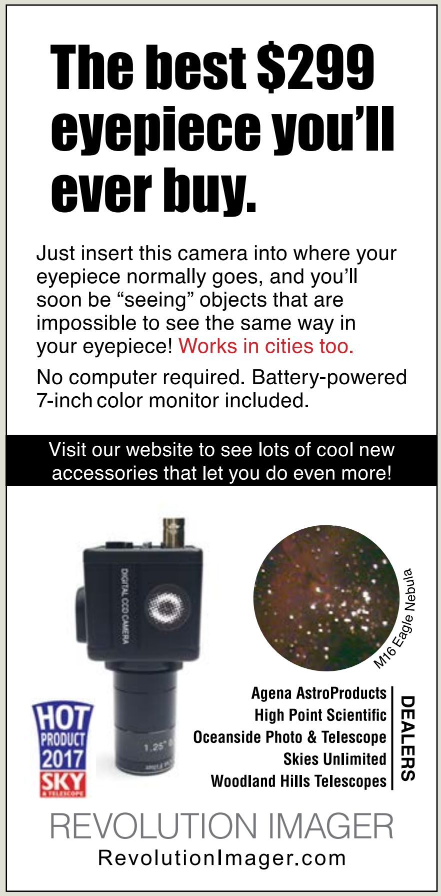

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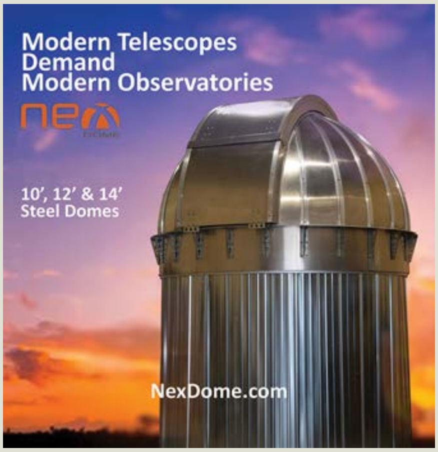

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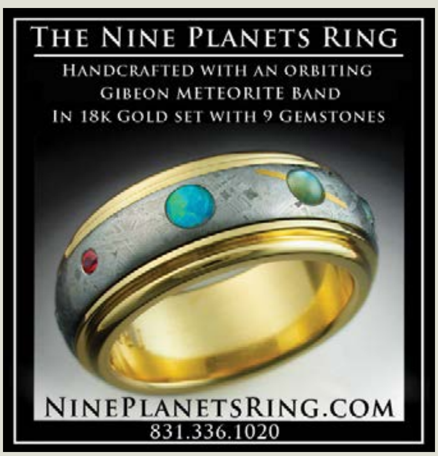

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Event Calendar

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

July 28–August 2
NEBRASKA STAR PARTY
Valentine, NE
nebraskastarparty.org

July 30–August 3
TABLE MOUNTAIN STAR PARTY
Oroville, WA
tmspa.com

July 30–August 4
OREGON STAR PARTY
Indian Trail Spring, OR
oregonstarparty.org

August 1–4
STELLAFANE CONVENTION
Springfield, VT
stellafane.org/convention

August 2–4
NORTHWOODS STARFEST
Fall Creek, WI
cvastro.org/northwoods-starfest

August 3–11
MOUNT KOBAU STAR PARTY
Osoyoos, BC
mksp.ca

August 8–11
STARFEST
Ayton, ON
nyaa.ca/starfest.html

August 28–September 2
NORTHERN NIGHTS STAR FEST
Palisade, MN
mnastro.org/events/northern-nights

August 30–September 3
ALMOST HEAVEN STAR PARTY
Spruce Knob, WV
ahsp.org

September 2–8
MAINE ASTRONOMY RETREAT
Washington, ME
astronomyretreat.com

September 5–8
BOOTLEG FALL STAR PARTY
Harmon, IL
bootlegastronomy.com

September 6–7
ALBERTA STAR PARTY
Starland County, AB
calgary.rasc.ca/asp.htm

September 6–7
IDAHO STAR PARTY
Bruneau Dunes State Park, ID
boiseastro.org/event-5617011

September 6–8
BLACK FOREST STAR PARTY
Cherry Springs State Park, PA
bfsp.org

September 6–8
CONNECTICUT STAR PARTY
Goshen, CT
asnh.org

September 14
OBSERVE THE MOON NIGHT
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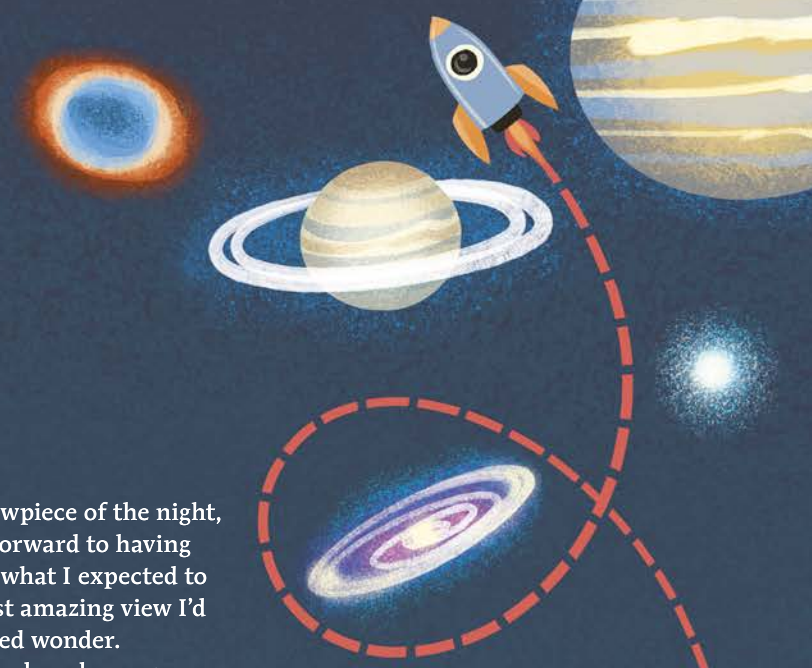
• For a more complete listing, visit https://is.gd/star_parties.



My Rocket to the Stars

A long-awaited view through a legendary telescope gave the author an unexpected surprise.

A PUBLIC OUTREACH night is always fun for amateur astronomers, and to have a famous observatory as the centerpiece makes it even more special.

On a warm summer night a number of years ago, I joined a small crowd on the stately grounds of the David Dunlap Observatory. The DDO lies in Toronto's Richmond Hill area, and that night the Royal Astronomical Society of Toronto was hosting a public observing evening. As a member, I'd brought my own 8-inch Schmidt-Cassegrain, but it was a tiny cousin to the 74-inch reflector housed under the DDO's giant copper dome.

The 74-inch might be a relative pipsqueak compared to modern instruments, but in 1935 when it began operations it was a titan, second only to the 100-inch Hooker Telescope on California's Mount Wilson. Astronomers using the 74-inch made important discoveries, including the first observations that led to the conclusion that the X-ray source known as Cygnus X-1 is actually a black hole.

That evening wasn't my first visit to the DDO, but it was the first chance I'd had to look through such a large instrument. I still remember the incredibly deep rumble of the dome as the slit opened to the evening sky; the memory gives me chills to this day. Saturn was the showpiece of the night, and I was looking forward to having my mind blown by what I expected to be perhaps the most amazing view I'd ever get of the ringed wonder.

I left my scope and made my way into the dome, where a line of people snaked away from the 74-inch, waiting for their turn at the eyepiece. I made small talk and fidgeted like a kid about to climb onto a carnival ride. I had butterflies of excitement spinning Saturn-like rings through my stomach. *This is going to be great*, I thought.

Finally, my turn arrived. I climbed the ladder and put my eye to the eyepiece. And there it was, the King of Rings swimming before my eye. A good view, yes. Colorful, for sure. But something just wasn't right.

I took my allotted time and then surrendered my position to the next in line. I thanked the person minding the telescope and went back to my own scope. I pointed it at Saturn and took a look. There it was, smaller and not as colorful, but . . . better.

Over the years, I've pondered the meaning of this experience. The explanation could be technical — the difference in aperture and churning of the air above, resulting in Saturn being sharper in my scope. Or maybe psychological — feeling a little out of place as a celestial tourist at the eyepiece of such a venerable instrument.

But I think it's closer to the truth to say that, while my telescope is smaller, it's also mine. It's my personal spaceship that carries me to the planets and the stars whenever I want. And no matter how often I see Saturn or Jupiter or M57 or any of a thousand other celestial sights, it's always like the first time. I'm good with that.

■ **ANDREW WAREING** enjoys his small but mighty telescope in Sudbury, Ontario, Canada.

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