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PAGE 74

SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

SEPTEMBER 2022

Cosmic Triplets

Good Things Come in Threes Page 20

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THE ESSENTIAL GUIDE TO ASTRONOMY

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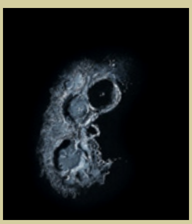
RON BRECHER

ON THE COVER



Drawing of lunar craters Theophilus, Cyrillus, and Catharina
CINDY KRACH

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Beginner's Space

WITH THIS ISSUE, we're launching a new monthly department aimed at those new to astronomy. We've long wanted to do this, to show beginners that there's something specifically designed for them in every issue of *Sky & Telescope*.

To many new to our hobby, *S&T* can appear daunting. Even if their new-found interest is strong, they might find it challenging to know where or how to "break in" to an issue. We offer this new spread (see pages 74–75) as an open door with a welcoming sign that essentially says, "Come on in!"

In a way, we're emulating *S&T*'s founding editor, Charles Federer, who threw open just such a door for novices starting with our very first issue. Introduced in November 1941, Beginner's Page ran several dozen times into the mid-1940s. We'd like to have titled our new iteration the same, in a nod to Charlie and the two authors of those early pieces — George Plachy and Percy Witherell. But ours will be two pages every month, so we're calling it Beginner's Space.

M. O'NEILL / NPS

But like the 1940s version, this one will cover basic concepts of interest to newcomers. What is the ecliptic? Why do we use Greek letters in astronomy? How does an equatorial mount differ from an altazimuth mount? What is a Dobsonian? In coming issues, we'll cover these and other questions across all areas of our hobby — observing, tools and techniques, and science.

As Consulting Editor Gary Seronik likes to say, amateur astronomers aren't born, they're made. "We all started from zero," he says. "I know the 12-year-old Gary who got his first *S&T* would have loved seeing something like this."

Of course, each issue already provides much of appeal to beginners. Our Observing section opens on page 41 with basic stargazing tips, then progresses through content of interest to skywatchers at any level: the monthly sky chart and Binocular Highlight (pages 42–43), naked-eye stargazing (page 45), things to watch for in the sky this month (pages 46–51), and much more besides.

But titled as it is, Beginner's Space will be clear as day whom it's principally meant for. I say "principally," because we hope more advanced hobbyists will want to read it, too — if only to remind themselves of how far they've come. We also hope that long-time readers will want to share Beginner's Space with a young relative who's just felt the spark, or with other beginners of any age. After all, getting novices excited about our hobby is the key to ensuring it thrives.

For now, four *S&T* editors will divvy up writing this new offering: Observing Editor Diana Hannikainen, Associate Editor Sean Walker, Gary, and myself. We welcome beginner questions for us to consider answering.
Send them to **editors@skyandtelescope.org**.

Peter
Editor in Chief

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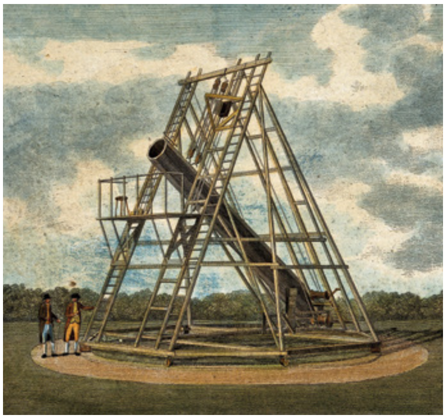


Found in Fornax

In Scott Harrington's excellent tour of "Springtime's Neglected Binocular Galaxies" (*S&T:* May 2022, p. 26), he mentions that NGC 3621 in Hydra is the most southerly object William Herschel discovered. While this galaxy is presently the farthest south, that actually wasn't true in 1790 when Herschel identified it. By precessing the J2000.0 coordinates back, I found that his farthest southern discovery came later that year when he chanced upon the galaxy NGC 1366 in Fornax (0.2° lower). It was a remarkable achievement considering that from the latitude of his home in Slough, England (+51.5°), this horizon-hugger only reached an elevation of 6.6°.

◀ A colored etching of William Herschel's impressive 20-foot telescope

Steve Gottlieb
Albany, California

The Averaging of Image Stacking

Since many astrophotographers misunderstand image stacking, I was pleased to see Richard Wright's article "Image Stacking Demystified" (*S&T:* Apr. 2022, p. 54).

While it was a good article, the author didn't delve into one of the most salient aspects of image stacking: that it works because it is an averaging process. It counts on the fact that the pixel-to-pixel graininess (noise) in a relatively uniform portion of an acquired image (like the background) is spatially distributed in a random manner. Each acquired image has its own unique pixel-to-pixel distribution of noise. So when we stack a set of images, the resulting sample average for each pixel tends toward the population (true) average.

Statistical theory tells us that the more samples we use, the closer the sample average will approach the population average. This explains why averaging more subexposures is better, but also why the beneficial effect of stacking decreases with increasingly large numbers of subexposures — at some point, we've averaged out most of the random noise. This also explains why we can't simply take one image, copy it many times, and stack the duplicates to reduce the noise — because the spatial distribution of noise in those copies is identical and not random. It also explains why stacking images does not increase the overall brightness of the target in the imagery. I applaud Richard Wright's efforts in his article, and I would like to see more on this topic.

Steve Maas
Ransom Canyon, Texas

Solid Catadioptric Lens

I read, with pleasure, Jerry Oltion's "A Solid-Glass Schmidt-Cassegrain Aims High" (*S&T:* May 2022, p. 74). It reminded me of the Vivitar Series 1 solid catadioptric telephoto lenses from the 1970s. They had huge central obstructions, but it's good to see that the concept hasn't been forgotten.

Fred Veretto
Oceanside, California

Congratulations on "A Solid-Glass Schmidt-Cassegrain Aims High" by Jerry Oltion in the May 2022 issue of *Sky & Telescope*. I have been a subscriber since 1947 and always enjoy my monthly edition. *S&T* was responsible for my telescope beginnings and has always been a source of reading pleasure ever since that significant year of my *formal* entry into the fields of astronomy and optical sciences.

The article reminded me of my first boss, Juan Rayces, who was a pioneer in the field of lens design at PerkinElmer when I joined the company in June 1961. Rayces was one of the most remarkable individuals that I have ever known: generous, patient, kind, and brilliant. I was most fortunate to begin my career in optics under his wing, where I learned to think outside the box.

I hope you will enjoy this interview by friends Rich Donnelly and Tim Lamkins — **https://is.gd/OutofThisWorld** — especially the parts with Rayces' reminiscences of the "solid cat" and other amazing optical design projects.

Keep up the great work you are doing and please continue writing about astronomical telescopes.

Joe Houston
Saratoga, California

Not All Problematic

I read Jerry Oltion's "To Build or Buy?" (*S&T:* Nov. 2021, p. 66) and Alan Raycraft's response "Problematic Mirrors" (*S&T:* May 2022, p. 7). My experience is contrary to the low quality they express.

My 12.5-inch (31.75-cm) f/15 Dall-Kirkham mirror set was purchased in 1975. A machinist friend made a telescope with them and later sold it to me. Other observers have commented on its good image quality, and they were not saying this just to make me feel good. Its image quality is just as good as my 16-inch Meade LX200R.

Other factors may explain this image quality, though, instead of my friend lucking out in a "hit-and-miss" process. One is that Coulter may have produced better optics in 1975, when it was still making a name for itself. Or maybe it produced better mirrors for the more expensive Dall-Kirkham, as opposed to those for the Dobsonian. The popularity of the Dobsonian was not due to image quality, but to the ease of set-up and the inexpensive construction.

However, others have not had the favorable experience with their Dall-Kirkhams that I've had. Alignment between the secondary and primary mirrors is critical, which may explain some of this. The mirrors in my Dall-Kirkham are rigidly held in place in a $\frac{3}{16}$-inch-thick fiberglass tube that my machinist friend made with layers of cloth fiberglass.

Stanley Gorodenski
Dewey, Arizona

DIY Spectroscopy

I just finished reading Diana Hannikainen's exciting article on "Decoding Light" (*S&T:* May 2022, p. 57). I've been capturing the spectra of stars with my 6-inch refractor and a Star Analyser and RSpec for about 10 years. When I show my astronomy friends how much science I can do with a few hundred dollars' worth of equipment, they're always surprised. Hannikainen's article helps dispel the myth that spectroscopy is expensive or hard to do. She quotes respected professional astronomer Steven Shore regarding the care required to capture research-quality spectra. My experience is that after one or two sessions with my telescope, I was able to capture spectra that contained all sorts of useful scientific data. I think it's important that we not let perfection get in the way.

Spectroscopy isn't only for PhDs who have access to professional telescopes. Anyone who has captured astronomical images can spend years capturing exciting star spectra that they can submit to the AAVSO spectroscopy database.

Rick Hiestand
Milton, Florida

The Galilean Moons

I enjoyed Benjamin Skuse's article "Ocean Underworlds" (*S&T:* Apr. 2022, p. 14) on the subterranean oceans on the Galilean moons. Are the ages and origin of the moons known?

Benjamin Skuse didn't address it in the article, and when it comes to what type of organisms might be discovered, it's important.

Steve Bernstein
Jackson, New Jersey

Camille M. Carlisle replies: *Planetary scientists think that the Galilean moons are primordial — that is, that they formed with or soon after Jupiter some 4½ billion years ago. There's a good overview of recent work on this at* ***https://is.gd/galileanmoonsformed****.*

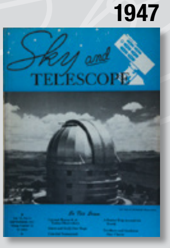
FOR THE RECORD

• In "A Star Where It Shouldn't Be" (*S&T:* June 2022, p. 10), the peculiar properties of HD 93521 were identified in the 1980s, rather than in 1993.

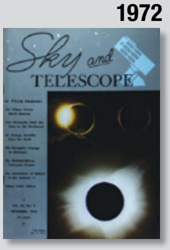
SUBMISSIONS: Write to *Sky & Telescope*, One Alewife Center, Suite 300B, Cambridge, MA 02140, USA or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1947



1972



1997

◖ September 1947

Meteorite Ages "Assuming that the helium contents of meteorites are affected only by the radioactive decay of uranium and thorium, the relative abundances of these elements have in the past been used for estimating the ages of meteorites. . . . Carl A. Bauer, of Harvard College Observatory, questions the infallibility of such estimates . . .

"Pointing out that cosmic rays produce nuclear disruptions in which alpha particles (helium nuclei) are among the disintegration products, Mr. Bauer [notes that] 'the largest observed helium content can be produced in a small meteoroid by cosmic radiation in a time less than the present assigned age.'"

Fortunately, other forms of radioactive decay not involving helium can also be used for dating meteorites. Most meteorites have the same age as the solar system, 4.5 billion years.

◖ September 1972

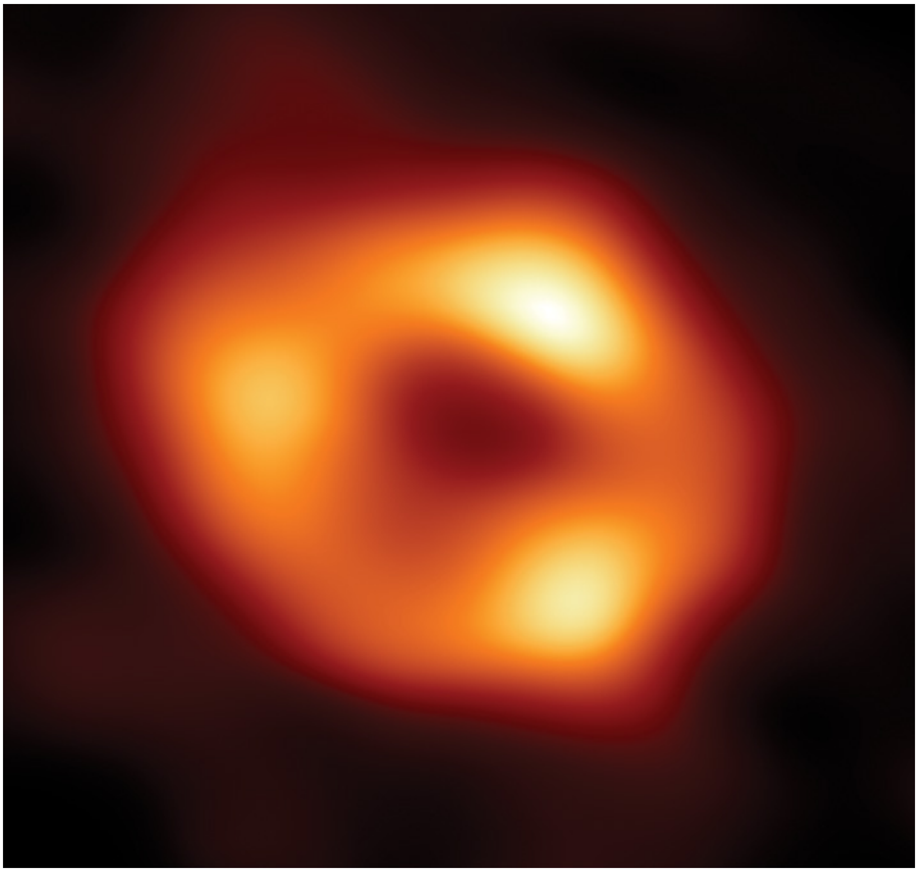
Aperture Fever "Last year at the Hale Observatories in California, the English astronomer R. F. Griffin spent several nights measuring the radial velocities of stars in star clusters. . . . 'You would have to be a very hard-boiled astronomer indeed not to be impressed at the sight of M13 in the [200-inch] telescope. The dense central part is several field diameters wide, and you can see the colours of the stars down to about the fifteenth magnitude. In addition to the densely packed mass of individually resolved stars, in good seeing the whole cluster shows a granular background — it's rather like looking into a bowl of sugar! . . . There must be perhaps 200 [red giant stars] . . . and you can pick them out at sight, even in the very middle of the cluster.'"

◖ September 1997

Hungry Galaxy "For several years now, astronomers have used small satellite galaxies — our Milky Way's Magellanic Clouds being a prime example — to 'weigh' the much larger spirals they orbit. . . . Claude Carignan (University of Montreal) and his collaborators have measured the line-of-sight velocities of *eight* dwarf galaxies that appear to orbit NGC 5084.

"[They] ascribe a total mass of 6 to 10 *trillion* Suns to NGC 5084 — making it the 'heaviest' disk galaxy known. In addition they noted whether each satellite was moving away from Earth at a faster or slower speed than NGC 5084 itself. This showed an intriguing trend — nearly all the dwarfs follow retrograde orbits. (That is, they appear to circle NGC 5084's center in the opposite way than do the galaxy's own stars and gas.)

"Computer models have shown that dwarf galaxies in prograde orbits are much more likely than retrograde orbiters to be consumed by tidal interactions with the parent spiral. Thus, NGC 5084 presumably once had a larger population of satellite galaxies but has absorbed many of them."



▲ This is the first image of Sgr A*, the supermassive black hole at the center of our galaxy.

SUPERMASSIVE BLACK HOLES

Astronomers Unveil Image of the Milky Way's Central Black Hole

SCIENTISTS WITH THE Event Horizon Telescope project have unveiled the first image of the black hole at the heart of our galaxy.

Sagittarius A* (Sgr A*) packs the mass of about 4 million Suns into a region smaller than Mercury's orbit. It's a "gentle giant" among black holes, grazing on a thin trickle of gas and putting out only about 100 times as much energy as the Sun does. At 26,000 light-years away, Sgr A* is also the closest supermassive black hole to Earth and thus an irresistible target.

More than 300 people, working at 80 institutions in various countries, helped make the new image a reality. It's a painstaking reconstruction from data taken in April 2017 by eight radio telescopes that operated together as a single, planet-size virtual telescope. (The same observing run brought us the M87* image; *S&T:* Sept. 2019, p. 18).

The new image shows Sgr A* in silhouette, a dark center encircled by a fuzzy ring of light. That light is radio emission that comes from electrons in the gas swirling around the black hole; the dark center is where light plunges past the event horizon, leaving a "shadow" where the black hole is.

The ring caused the imaging team members grief. Unlike initial reconstructions of M87*, those of Sgr A* didn't agree — many showed a ring, but not all. Team members doubted their results until they created mock data to test how their algorithms reacted to different situations, ultimately convincing themselves that the ring was real.

The ring is about 50 microarcseconds wide on the sky, exactly as Einstein's theory of gravity predicts given the black hole's mass and distance.

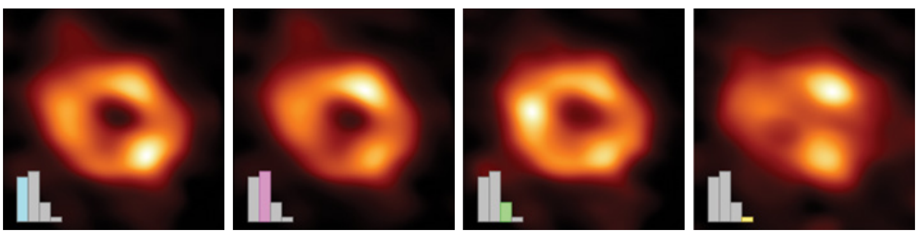
What the reconstructed images still don't agree on is the bright knots that dot the ring. The knots move depending on the reconstruction used, and they tend to line up along directions observed with more telescopes, warns Feryal Özel (University of Arizona). "We don't trust the knots that much," she says.

Gas whips around Sgr A* in only a few minutes, so its image is constantly changing — much faster than the hours-long observing sessions undertaken. Yet over five nights of EHT observations, the gas flow remained surprisingly calm. "To my mind, that is one of the most interesting things that we learned," says theorist Dimitrios Psaltis (University of Arizona). "We predicted the storm, and we got a beautiful sunny day." The magnetic fields in the gas might not be as tangled as expected, he speculated, although whether this condition is temporary is unclear.

A second notable result is that the team determined we're essentially looking down on Sgr A*'s head — the angle between our line of sight and the black hole's rotation axis is less than 30°.

■ CAMILLE M. CARLISLE

Read the full story at https://is.gd/EHTSgrA. A deeper analysis of the image will appear in a future issue.



▲ Computational methods resulted in thousands of images that all accurately fit the data. These images cluster into four groups; the bar graphs show how many images belong to each cluster.

EHT COLLABORATION (2)

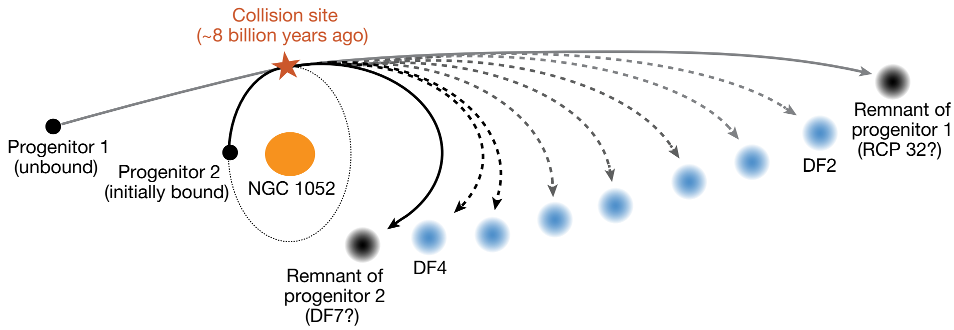
GALAXIES

Did a Cosmic Collision Rob Two Dwarfs of Dark Matter?

WHEN TWO DWARF galaxies were found apparently devoid of dark matter, they made headlines (*S&T:* July 2019, p. 11). Dark matter is key to galactic formation, so how had these galaxies come to be without it?

In the May 19th *Nature*, Pieter van Dokkum (Yale) and team propose an answer: The two dwarfs, dubbed DF2 and DF4, were born sans dark matter as a result of a long-ago collision near the bright elliptical galaxy NGC 1052.

Using the dwarfs' present-day positions and velocities and DF2's estimated age, the team traced their motions back in time to a common origin. The team hypothesizes that some 8 billion years ago, a satellite of NGC 1052 collided with an unbound galaxy. While the galaxies' stars and dark matter slipped past one another, interacting only weakly through gravity, the high-speed crash slowed down the galaxies' gas.



▲ In the collision scenario, an infalling, unbound galaxy (progenitor 1) crashed into a satellite galaxy of NGC 1052 (progenitor 2), leaving two dark remnants (RCP 32 and DF7) and several dark-matter-free galaxies, including DF2 and DF4. The latter two lie roughly 7 million light-years apart.

That gas was then free to form new galaxies. "The gas got strung out into a whole bunch of clumps that then, under their own gravity, collapsed and formed new galaxies without dark matter," van Dokkum explains. These dark matter–deficient galaxies would now line up like a string of pearls. Indeed, when the team searched for galaxies around NGC 1052, they found 11, including DF2 and DF4, lying in a row. At the far ends, beyond DF2 and DF4, are two peculiar galaxies, RCP 32 and DF7 — perhaps the remains of the original collision.

"For me, it comes across as a nice idea, but with a number of significant issues," says Michelle Collins (University of Surrey, UK), who wasn't involved in the study. The team will need more data, she adds, to demonstrate that the galactic string they've found isn't just a chance alignment on the sky.

Van Dokkum agrees: His team is already planning to point an army of ground- and space-based telescopes at the string-of-pearl galaxies to settle their origin.

■ BENJAMIN SKUSE

STARS

X-ray Flash from White Dwarf Fireball Observed

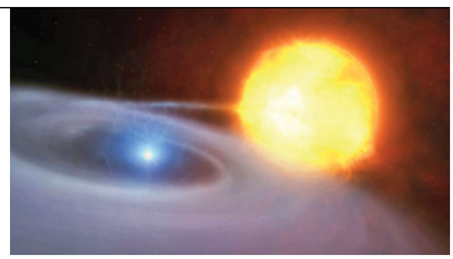
FOR THE FIRST TIME, astronomers have spotted the X-ray flash that precedes a nova, as reported in the May 12th *Nature*. The flare was the first sign that a white dwarf's entire surface had ignited in a colossal, expanding fireball.

Astronomer Robert McNaught noticed the "new star" on July 15, 2020: The nova, YZ Reticuli, ultimately brightened thousands-fold to magnitude 3.7 before fading back into obscurity.

Further observations revealed the system consists of a white dwarf whipping around a companion star every three hours, so close that the white dwarf steals its companion's outer layers. The gas piles up on the white dwarf's surface until, once the pressure has reached the tipping point, the entire top layer of hydrogen goes aflame in a runaway thermonuclear reaction.

The fusion created the visible light that astronomers monitored as the second-brightest nova of the decade. But even before the visible light spiked, theory said the conflagration ought to emit a brief flash of X-rays. Such a flash had never been recorded, but in this case the space telescope EROSITA happened to be imaging in the right direction at the right time to catch 35.8 seconds of the flare. Ole König (Friedrich-Alexander University Erlangen-Nürnberg, Germany) and team recognized the "now-you-see-it, now-you-don't" X-ray source as the nova's incendiary flash.

The X-rays indicated that the white dwarf's fireball had expanded quickly, becoming much bigger than the white dwarf itself. By the time EROSITA observed it, the layer of fusing hydrogen had already mushroomed to more than five times Earth's diameter. "The fact that we caught the event when it was still so close to the white dwarf was quite lucky," König says.



▲ In this artist's view, a white dwarf (*left*) robs gas from its companion star, material that ultimately ignites in a thermonuclear blast.

The observation validates long-established predictions for what occurs when novae start burning. "This is a spectacular result!" says Simone Scaringi (Durham University, UK), who wasn't involved in the study. "The detection of the X-ray flash will clearly aid in testing and refining the physical models yielding thermonuclear explosions."

■ MONICA YOUNG

COLLISION SCENARIO: P. VAN DOKKUM (YALE UNIVERSITY); WHITE DWARF AND COMPANION: ESO / M. KORNMESSER

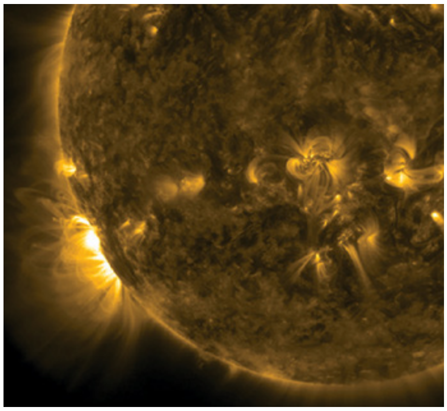
SUN

The Solar Cycle Restarts

THE SUN IS WAKING UP: After years of solar quiescence, recent months have seen numerous X-class flares, large sunspot groups, and coronal mass ejections.

The uptick isn't surprising: The Sun goes through 11-year cycles of magnetically instigated activity. But while such action last peaked between 2011 and 2014, that meager maximum marked the quietest cycle in 100 years (*S&T:* Nov. 2013, p. 10). The more recent revival, on the other hand, marks a change in the Sun's behavior. Even though it's still a weak cycle, Lisa Upton (Space Systems Research Corporation), co-chair of the Solar Cycle 25 Prediction Panel, says that for the first time in 50 years, this solar cycle may be stronger than the one before it.

In 2019, the prediction panel reviewed available models and found that physics-based scenarios resulted in the most successful forecasts. Using these models, the panel predicted that the new solar cycle had started within six months of December 2019, and that activity would peak in 2025 with a maximum sunspot number between 105 and 125. (The wiggle room in these predictions reflects that even the various physics-based models are not 100% in agreement.)



▲ The Sun fired off a powerful solar flare (lower left) on May 3, 2022.

Now, with more than two years of the cycle under our collective belt, the predictions are holding up well, albeit with numbers veering toward the earlier and higher end of the forecast. But that doesn't mean there isn't room for disagreement. Scott McIntosh (National Center for Atmospheric Research), for one, has gone against the consensus in predicting that this cycle will be one of the strongest on record. By 2023, if not before, it should become clear which prediction is correct.

The cycle's earlier and more active start has some practical consequences: An earlier minimum means an earlier maximum, which brings the peak of the solar cycle closer to the 2024 total solar eclipse. When totality reveals the Sun's *corona*, the white wisps could take on different shapes depending on solar activity. "We should have a very interesting Sun to see during the 2024 Great American Eclipse," Upton says.

■ **MONICA YOUNG**

METEORITES

DNA Building Blocks Found in Meteorites

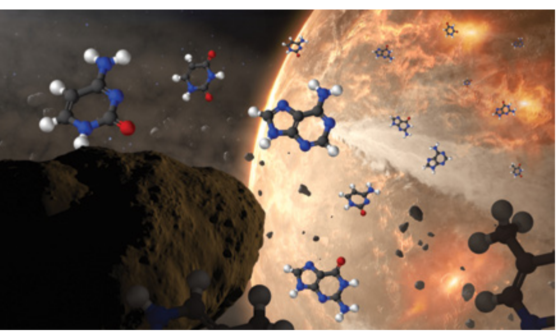
A NEW METHOD has revealed the presence of the full DNA and RNA "alphabet" within meteorites. These prebiotic molecules might have evolved even before Earth existed.

Scientists have previously found evidence of prebiotic molecules in meteorites, including the nucleobases guanine, adenine, and uracil that are among the building blocks of DNA and RNA. These discoveries established that organic chemistry occurred on asteroids.

Now, Yasuhiro Oba (Hokkaido University, Japan) and colleagues have reported on April 26th in *Nature Communications* the detection of the "missing" pyrimidine nucleobases, cytosine and thymine, which make up the rest of our genetic code.

The team developed a milder and more sensitive extraction method, which involved mixing a small amount of meteorite powder with water and then sending intense ultrasound waves through the medium. The resulting pressure waves "sorted" molecules within samples from three ancient meteorites, revealing a small amount of pyrimidine nucleobases.

To determine whether the newfound molecules were truly extraterrestrial, Oba's group compared soil at the impact site of one of the meteorites (dubbed "Murchison" for the location of the strewn field in Australia) with the meteorite itself. "Although some nucleobases were identified in the soil sample," Oba says, "the concentration and molecular distribution are clearly different from those detected in the Murchison meteorite."



◀ This conceptual image shows meteoroids delivering nucleobases to ancient Earth.

At 7 billion years old, the Murchison meteorite formed while the Sun was still a protostar. If the nucleobases are original to the space rock, then they support an extraterrestrial origin for life on Earth.

However, Michael Callahan (now at Boise State University), who performed an earlier study of the meteorite, cautions that the pyrimidines are found in such low concentrations that they can't explain the emergence of genetic material on their own. These molecules must have emerged on Earth, too.

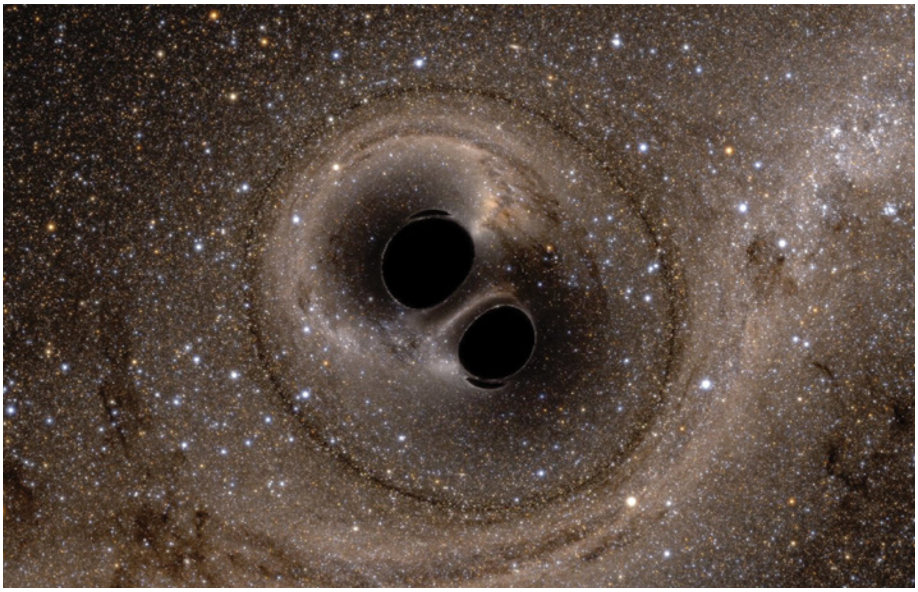
Sample-return missions from the asteroids Ryugu and Bennu will help us better understand the evolution of extraterrestrial organic molecules. The methods pioneered by Oba's group could help determine the true composition of these pristine asteroids, as well as the origin of complex organic molecules in interstellar space.

■ **ARWEN RIMMER**

SUN: NASA / SDO; ASTEROIDS DELIVERING ORGANIC MOLECULES: NASA GODDARD / CI LAB / DAN GALLAGHER

GRAVITATIONAL WAVES

10 New Black Hole Mergers Found in LIGO Data



▲ A simulated image of the merger of a black-hole binary

SXS LENSING

THE LIGO, VIRGO, AND KAGRA (LVK) collaboration has so far tallied 90 gravitational-wave events, almost all of which were mergers of two black holes. But LVK researchers aren't the only ones trawling the data.

One team that applies its own analysis techniques has its hub at the Institute for Advanced Studies (IAS). These researchers have now taken their own look at the first half of the third observing run and turned up 10 new candidate mergers. They also recovered one that LVK collaborators had found and dismissed, Seth Olsen (Princeton) reported at the April meeting of the American Physical Society.

But we can't simply add these 11 events to the total. To tease out minuscule signals from all the noise, researchers use *pipelines*, chains of computing processes that clean and assess data. Choices made in these pipelines determine which of the signals will pop out of the background. The IAS team's pipeline improves on computing efficiency but also ignores some of the loudest (and most likely) events in order to be more sensitive to quieter, and potentially more exotic, ones.

Thanks to these choices, the IAS pipeline "lost" six events from the observing run but gained 11 new ones. Statistically speaking, however, three of the new detections are likely to be flukes rather than real events.

The new candidates include several mergers of black holes with masses both above and below the expected ranges: One involved a monster 80-solar-mass black hole, while another involved a tiny object (a black hole or a massive neutron star) of 2.1 to 4.4 solar masses.

The LVK collaboration keeps track of events that independent teams find and compares those analyses to its own. "We are delighted that people look at the data from new perspectives and with new tools," says LIGO spokesperson Patrick Brady (University of Wisconsin, Milwaukee). Some events are added to the LVK catalog if the collaboration can confirm them using its own methods. Such additions must be done carefully to enable clean analyses of the merger population.

LVK researchers are now turning their attention to the fourth observing run, set to begin in December. With upgrades to sensitivity, they expect to detect a merger every few days. As the events stack up, oddballs and subclasses will become more explorable.

■ CAMILLE M. CARLISLE

IN BRIEF

Insight at Mars: Monster Quake, Powering Down

NASA's Insight Mars lander witnessed the biggest quake yet in the nick of time — just before the craft began to run low on power. The record-breaker wasn't strong by Earth standards, but it was the strongest temblor recorded on another planet. The Seismic Experiment for Interior Structure aboard Insight noted the 5th-magnitude marsquake on May 4, 2022. Three days later, increasing dust in the air and on the solar panels caused the lander's power levels to drop. The mission entered a preemptive safe mode on May 7th but is back to collecting seismic data as of press time. NASA has approved an extended mission through December 2022, with most power being prioritized for the seismometer. To date, Insight has detected more than 1,313 marsquakes and has achieved the top science goals for its two-year primary mission. The quakes have enabled scientists to probe the Martian interior: So far, researchers have put the radius of the planet's core at 1,830 km (1,137 miles), and they've estimated that the crust could extend as deep as 37 km (*S&T:* Nov. 2021, p. 8). Analysis of new temblors could reveal additional details about the structure of Mars's crust, mantle, and core.

■ DAVID DICKINSON

Tau Herculids: A New Meteor Shower

In the fall of 1995, Comet 73P/Schwassmann-Wachmann 3 fractured into several pieces and left a trail of fragments in its wake. In the May issue of *Sky & Telescope*, I reported that Earth might encounter this stream of debris during the overnight hours of May 30–31. The possible scenarios included a brief outburst of meteors ranking with some of our richest annual displays (Geminids and Perseids), perhaps even amounting to a meteor storm. On the flip side, the uncertainties inherent in such calculations meant that we might only encounter very few comet particles — or none at all. The reality, as so often happens, was something in between. Observers at clear and dark sites reported seeing dozens of meteors per hour, with many bright, slow-moving shower members, some of them leaving a smoky train. Unfortunately for those who were hoping for a major outburst, or even a meteor storm, it was not to be.

■ JOE RAO

Crash as Trash

When should we start thinking about cleaning up our space junk on Mars?

▲ The Perseverance rover's "backshell" lies where it fell in early 2021 on the surface of Mars's Jezero Crater.

NASA / JPL-CALTECH

SHARDS OF ALIEN METAL lie strewn about the crash site of a derelict contraption from another planet, the remains of an intricately machined saucer sent by a strange and distant civilization. . . .

Ours.

In April, NASA's Ingenuity helicopter, which is tagging along with the Perseverance rover, returned hauntingly surreal photographs of the rover's own discarded "backshell," the cover of its entry vehicle. As the rover descended to the Martian surface on February 18th of last year, the backshell was jettisoned and came to rest, largely intact but smashed around the edges, atop the shifting red sands.

My first thought on seeing the image above was "Cool!" It's still very hard to fly something to Mars, and now to finally fly something *on* Mars, not to mention use it to survey our own wreckage from the air — that is next-level cool. It's also useful: The forensics of the crash can help us improve future landing craft.

My second thought was "Beautiful!" If Mars has never had life (open question) or, as seems likely, any of its own cultures to create art or technology, then arguably there's something wonderful about finally bringing these to the planet.

But my third thought was to wonder when we will start picking up after ourselves. Some readers will consider it ridiculous to ask. Others will consider it ridiculous not to ask. They're both right. It's just a question of time scale and perspective.

To worry about this right now seems silly. It's like asking the first sea creatures that wriggled onto a shoreline of Earth's barren continents billions of years ago to erase their tracks. Mars is so vast, unexplored, and utterly empty of artifacts, and our efforts are so tentative and puny. But a few thousand years ago, our own planet seemed so huge compared to any of our creations or influences that it would have seemed silly then to think we could meaningfully perturb or pollute it.

In a later era that I've called the "immature Anthropocene," we started to significantly alter our planet but remained ignorant of the fact that we could. Finally, as our numbers and influence grew, we learned that there was no throwing things "away," that we inhabit a finite and mutable world.

Our maturity as a species is tied to our recognition that we are a *planet-changing* species and must learn to act accordingly. Integrating this realization into our global-scale activities will be at least as essential to our long-term survival as becoming a multi-planet species might someday be.

We are obviously a long way from filling up Martian craters with our debris, bacteria, and effluence. I bet it will be many generations before humans live on the Red Planet in sufficient numbers to have a self-sustaining presence and make our mark to any significant degree.

But at what point in the future should we concern ourselves with this? If we imagine that someday we'll build cities and civilizations there, then clearly "never" is the wrong answer.

Mars is not an escape hatch for a ruined Earth. It could, however, serve as a model for how we engage with a planet from the beginning, with a long-term plan and ourselves in the picture. Perhaps interacting thoughtfully with Mars, as opposed to inadvertently and haphazardly, can even help us care for our home world both before and after some of us do eventually leave our comfortable blue-and-green Earth for the challenging lands beyond.

Ad astra cum conscientia.

■ Astrobiologist **DAVID GRINSPOON** is author of *Earth in Human Hands: Shaping Our Planet's Future.*

SMASH and Nu

This year, the DART mission will make humanity's first perceptible impact on the motion of a celestial body. The result might help us someday avert our potential annihilation by asteroid.

For all its destructiveness, smashing stuff together tells us a great deal about the universe. Colliding suspended balls demonstrated conservation of momentum and energy in the 17th century and led to every 1980s executive's favorite desk decoration, Newton's cradle. Atom smashers like the Large Hadron Collider have revealed the tiniest constituents of reality. And observing two distant black holes violently merge has offered us a new window into extreme gravity at work in the cosmos.

Our exploration of the solar system has been no different. Sending multi-million-dollar probes into fatal nose-dives has a rich past. After the USSR's Luna 2 made history with the first impact on another world in 1959, the NASA Ranger 7–9 probes followed, smashing into the Moon's surface in 1964 and 1965 in order to take detailed images that would inform the design of Apollo. More recently, NASA's Deep Impact shot a projectile into Comet Tempel 1 at the end of its primary mission in 2005, revealing surprising details about the comet's composition.

Most impactor missions in the last couple of decades have been designed to expose the makeup of the body into which they collide. But the latest project has a different aim. NASA's Double Asteroid Redirection Test (DART) mission is traveling to Dimorphos, a companion moonlet of asteroid 65803 Didymos, in order to bump it off course in its orbit.

NASA is not doing this because the binary asteroid is a threat to us: "It's always good to state clearly that we are not in danger — we are not doing this because we have to. It's a test," emphasizes DART program scientist Tom Statler (NASA). Moreover, the change won't push the asteroids onto a dangerous path toward Earth — Dimorphos won't leave its orbit around Didymos, and the asteroids will continue on their current trajectory around the Sun.

Instead, scientists hope that DART will show us whether crashing a probe into an asteroid actually changes its motion, knowledge we must have in case we ever need to nudge an asteroid away from Earth to avert annihilation.

Don't Look Up

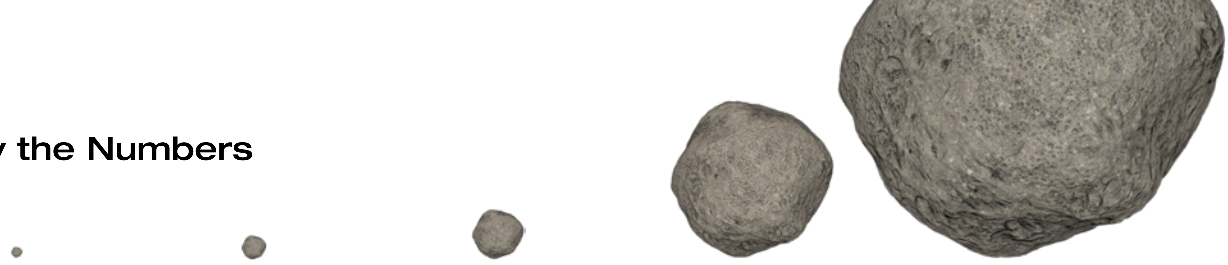
Planetary defense against asteroid impacts can be boiled down to two tasks: finding threats and removing them. Responsibility for the former rests on the International Astronomical Union's Minor Planet Center (MPC) and the Jet Propulsion Laboratory's Center for Near-Earth Object Studies (CNEOS).

The MPC is the internationally recognized clearinghouse for small-body position measurements, including near-Earth objects. Data fed into the MPC come from observatories around the world and include valuable contributions from amateur astronomers. CNEOS in turn plugs MPC data into its recently updated Sentry-II impact-monitoring system, which continuously performs long-term analyses of the

◀ **INCOMING** The DART spacecraft will slam into Didymos' moon, Dimorphos, in an attempt to change the size of the moon's orbit around the larger asteroid.

NASA / JHU APL

The Hazard by the Numbers



Asteroid Size	4 meters	25 meters	140 meters	1 kilometer	10 kilometers
Impact Frequency	~1 per year	~1 per 100 years	~1 per 20,000 years	~1 per 500,000 years	~1 per 100–200 million years
Effects	Bright flash, no ground damage, possible meteorites	Airburst explosion, could cause widespread injuries if over populated area	Crater 1 to 2 km wide, deadly over metro or state-size areas, mass casualties	10-km-wide crater, global devastation, possible civilization collapse	100-km-wide crater, global devastation, mass extinctions
Est. Number of Objects	~500 million	~5 million	~25,000	~900	4
% Discovered	<0.1%	0.4%	39%	>95%	100%

▲ **NEAR-EARTH OBJECTS** Scientists have found nearly all of the nearby asteroids that could cause global devastation, but they have a far more incomplete tally of smaller, regionally dangerous objects. A given object's effect depends on many factors, including composition, speed, and incoming angle, not just its size.

orbits of potentially hazardous objects.

Up to now, results from CNEOS have been comforting. There's virtually no chance a known hazardous object will impact Earth in the next 100 years. Even 101955 Bennu, one of the most likely asteroids to hit Earth, only has a 1-in-1,800 chance of a future collision over the next three centuries.

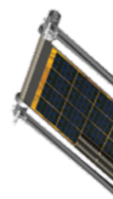
But this doesn't mean we should sit back and relax. There are still unknown objects flying through the solar system that could suddenly pose a threat to Earth at any given moment. At the time of writing, observers had discovered 28,539 near-Earth asteroids. Of these, 10,030 appear to be at least 140 meters (460 ft) wide, and 881 are thought to be more than 1 kilometer wide. Objects of these sizes would have impacts ranging from significant regional damage to worldwide extinction if they hit Earth. (For a gauge of what "significant regional damage" means, think the devastation of an entire U.S. state.)

According to NASA, only about 40% of asteroids larger than 140 meters have been found. And to add to the uncertainty, only about 2,000 of these objects have been properly characterized by the only instrument suitable for the task: NEOWISE, an old, partially broken down, and repurposed space-based infrared telescope.

Amy Mainzer (University of Arizona) is principal investigator on both NEOWISE and its purpose-built successor, NEO Surveyor, scheduled to launch in 2026. With Surveyor, she says, our knowledge of near-Earth objects (NEOs) will expand dramatically; over its lifespan, the space telescope could add a few hundred thousand objects to our roster.

Of these, there is no telling if any will be racing towards Earth in the near future. But if one does, Surveyor's infrared data should enable scientists to accurately estimate its size and probable shape and, when combined with visible-light observations, the object's albedo and hints of its composition. Having that knowledge well in advance of any potential asteroid rendezvous with Earth is essential to planetary defense. "We really want to try to give people time, because that's the best weapon in this business," says Mainzer.

But time is not the only weapon humanity would need. There's little point in finding and characterizing threats if we have no way of removing them. This is why DART is on a collision course with Dimorphos now — so that scientists can test mitigation measures, just in case they have to use them.



DARTing into Didymos

Since its launch on November 24, 2021, DART has raced through space to reach the Didymos system. Didymos and Dimorphos are approximately 780 meters and 160 meters wide, respectively. They take 770 days to orbit the Sun at a distance that varies from 1.0 to 2.3 astronomical units (a.u.), and they orbit each other at a distance of about 1 kilometer. They will make their "close" approach to Earth on October 4, 2022, at 10.7 million km — nearly 30 times farther away than the Moon.

Sometime between September 26th and October 1st, just before the asteroid's perigee, the 550-kilogram spacecraft will zoom towards Dimorphos at 6.7 kilometers per second (15,000 mph). As the moonlet comes around from the backside of Didymos on its 11.92-hour orbit, DART will collide with it head-on.

TERRI DUBÉ / S&T, SOURCE: NASA

DART will have two witnesses to this manufactured cosmic event: the impactor's own high-resolution imager, named Didymos Reconnaissance and Asteroid Camera for Optical navigation (DRACO), and a small Italian CubeSat called the Light Italian CubeSat for Imaging of Asteroids (LICIACube) that will piggyback the DART spacecraft.

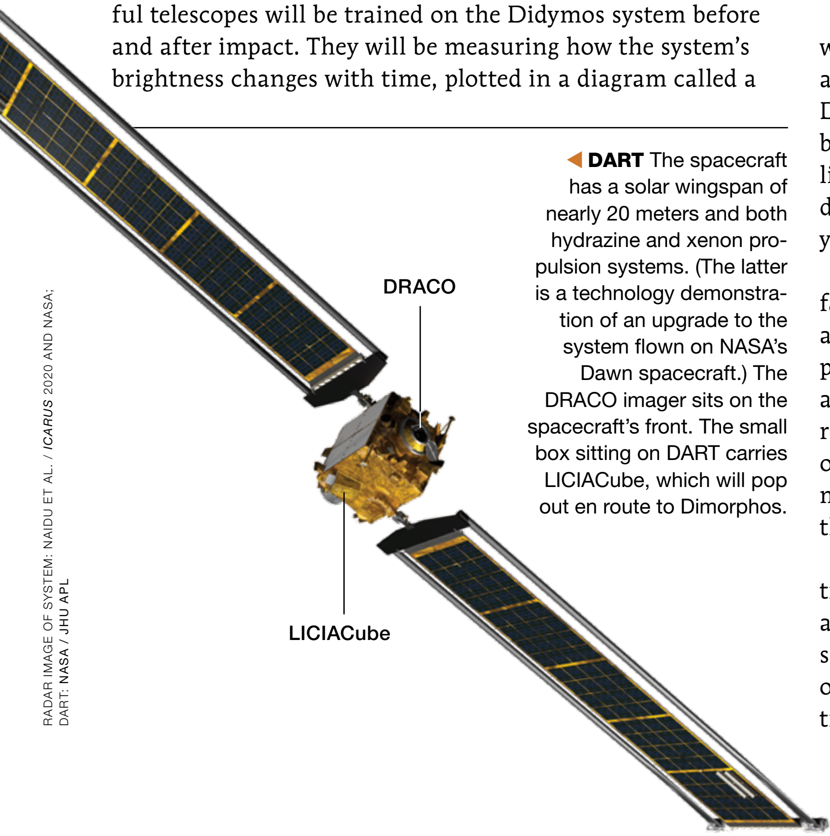
DRACO performs two roles, supporting the autonomous guidance system to ensure DART hits its target and providing essential data for the analysis and interpretation of the results. It will snap images of Didymos and Dimorphos on approach to measure their size and shape, as well as images of Dimorphos' surface in order to characterize the impact site just before the probe's annihilation.

Meanwhile, LICIACube will have detached from DART 10 days prior to impact and altered its trajectory to lag just under 3 minutes behind the main spacecraft, so as to fly safely past the target. As the CubeSat sweeps past the Didymos system, just 55 km away at its closest approach, its two optical cameras — dubbed LICIACube Unit Key Explorer (LUKE) and LICIACube Explorer Imaging for Asteroid (LEIA) — will witness the impact itself, the initial ejecta plume and beginnings of the impact crater, and finally the backside of both Didymos and Dimorphos as it speeds away. With no way to slow down, the sole survivor of the DART impact will continue travelling through the celestial abyss, doomed to purposelessly circle the Sun.

But back on Earth, the DART team's excitement will only now be reaching its zenith. Some of the world's most powerful telescopes will be trained on the Didymos system before and after impact. They will be measuring how the system's brightness changes with time, plotted in a diagram called a *light curve*. Dips in the light curve indicate when the smaller moonlet passes in front of (or is hidden behind) Didymos from Earth's point of view, giving a precise gauge of the orbital period.

◀ **DIDYMOS SYSTEM** Captured by the Arecibo Observatory in 2003, these radar images are the best views we have of Didymos and its moon, Dimorphos.

"When we see the binary orbit start going off schedule in the data, that's when we know we have, in fact, changed the motion of a celestial body in space for the first time," says Statler. "That's the goosebumps moment for me." With initial estimates of how much DART changed Dimorphos' orbit expected around two weeks after impact, the NASA mission will be complete.



◀ **DART** The spacecraft has a solar wingspan of nearly 20 meters and both hydrazine and xenon propulsion systems. (The latter is a technology demonstration of an upgrade to the system flown on NASA's Dawn spacecraft.) The DRACO imager sits on the spacecraft's front. The small box sitting on DART carries LICIACube, which will pop out en route to Dimorphos.

RADAR IMAGE OF SYSTEM: NAIDU ET AL. / *ICARUS* 2020 AND NASA; DART: NASA / JHU APL

Uncertain Beta

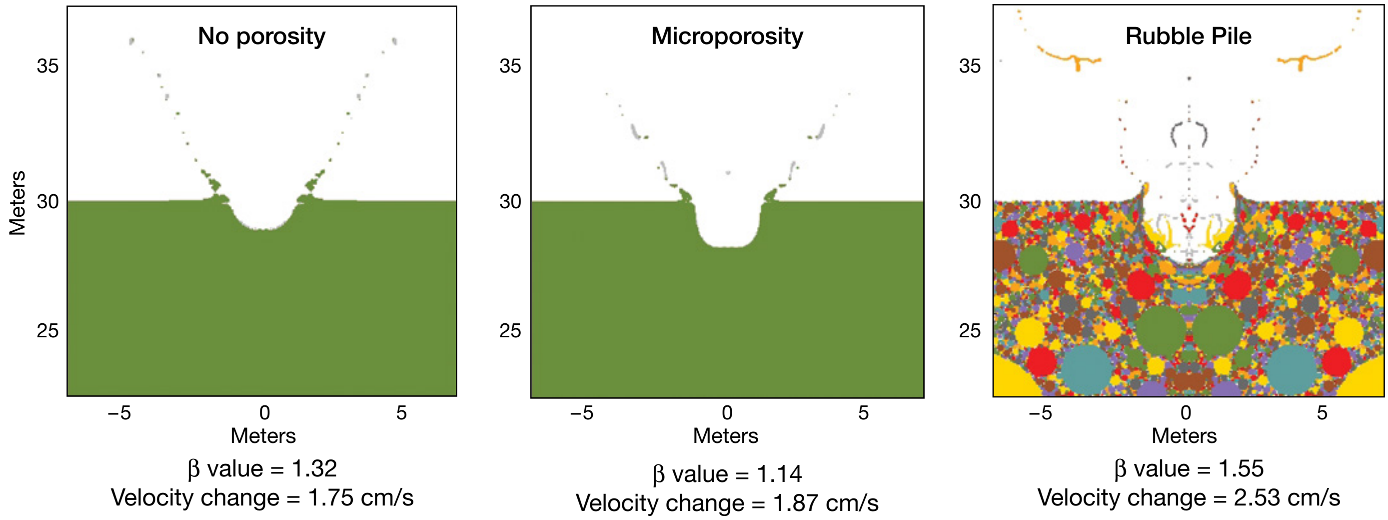
The collision should slow the moonlet down and kick it into a slightly lower orbit with a shorter period. Although the deflection will be declared a success if DART shoves Dimorphos' orbit off schedule by the minimum amount deemed detectable from Earth — a measly 73 seconds — Statler is more optimistic: "We're expecting a change in period in the vicinity of 10-ish minutes," equivalent to bringing the asteroids' nearest approach 22 meters closer. "But this is why we have to do the test, because we don't know."

Uncertainty can be boiled down to a single figure, *beta* (β). Beta is a number that compares the momentum of Dimorphos before and after the collision. More specifically, it is a measure of how much additional momentum *beyond* what's carried by the spacecraft itself is transferred to the asteroid.

If beta equals 1, DART will have a perfect *inelastic collision* with Dimorphos, adding all of DART's momentum to the asteroid. But what mission scientists are hoping for is that DART's momentum gets a boost from a huge plume of ejecta blasted off the surface. "It works like an extra, instantaneous little rocket engine that pushes the asteroid in the other direction," explains Statler. "By having this ejecta help you, you get beta greater than 1."

But calculating beta is no simple task. It consists of many factors linked to the properties of both the impactor and asteroid in question. And right now, most of Dimorphos' properties are completely unknown. Is it shaped like a potato, a donut, a die, or some other wacky configuration? Is it solid rock? Basalt? Is it porous or dense, cracked or solid, strong or weak, tough or brittle? What happens if the probe hits the moonlet at a different location or angle than simulated? All these factors play a part in determining the beta value.

Depending on the best guesses physicists choose, simulations suggest the beta of the DART collision could range from a little extra push ($\beta = 1.5$) to a huge shove ($\beta = 5$), Statler says. And this is a problem. If ever we need to deflect an asteroid from Earth's path, we will require more precise simulations, to tell us if our efforts are likely to succeed or fail.



▲ **BETA** An asteroid's porosity affects how it responds to being hit by a projectile, as shown in these simulated collisions. As microporosity increases, β decreases but the imparted velocity increases, because the asteroid is less massive and thus easier to deflect. However, a rubble-pile asteroid forms a larger crater and far more ejecta, increasing both β and the change in velocity. These snapshots are for 5 milliseconds after the impact.

Europe Follows Up

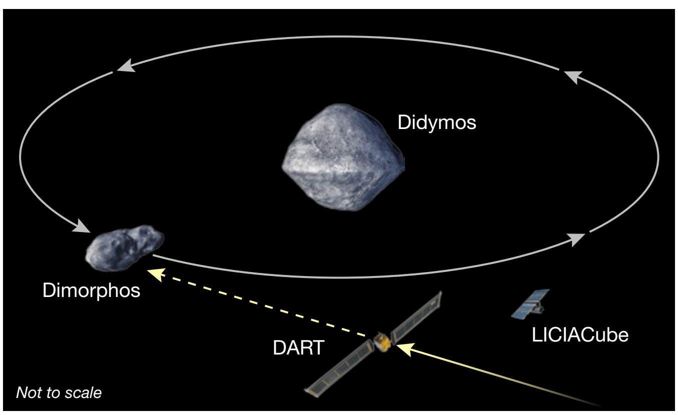
DRACO's head-on view, LICIACube's sweeping perspective, and distant observations from Earth will bring most of the unknowns in calculating beta into focus. But some will remain a little hazy. This is why, long after Dimorphos' dust settles, the moonlet will receive another visitor.

The European Space Agency's Hera is scheduled to arrive at the Didymos system in December 2026. Like a crime scene investigator, Hera will be tooled up with various instruments to pick apart precisely what happened when DART smashed into Dimorphos. "We want a fully documented impact experiment," explains Hera principal investigator Patrick Michel (Côte d'Azur Observatory, France). "DART will provide the initial conditions, but we need two other things: the outcome of the impact and the physical properties of the target."

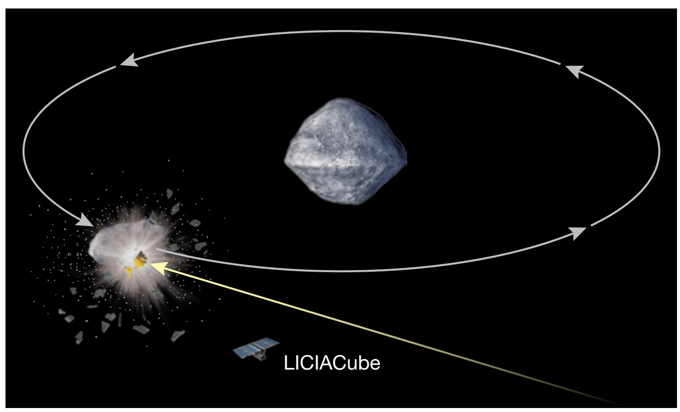
One key property that the investigation will uncover is Dimorphos' mass. DART will measure this indirectly, using DRACO and LICIACube imaging to constrain the asteroid's shape and volume and assuming an appropriate density. Hera will take a more accurate mass measurement by determining the "wobble" the moonlet causes in Didymos' position, relative to the system's common center of gravity. This should lead to a value with an uncertainty of less than 10%.

Hera will also map the shape of DART's impact crater in detail, which has a bearing on the accuracy of impact simulations as well. After DART's obliteration, LICIACube will only witness the immediate impact aftermath from close range. From previous experience, this might not be long enough to see the full extent of DART's effect.

NASA's OSIRIS-REX spacecraft touched down on asteroid Bennu on October 20, 2020. The mission team was hoping to collect at least 60 grams of material from the surface in a "touch-and-go" maneuver. But the spacecraft's grabber penetrated much deeper into the asteroid than anticipated, scoop-



1. DART and LICIACube bear down on Dimorphos in late 2022.



2. DART hits Dimorphos, creating a blast of debris that helps slow the moonlet down.

BETA EXAMPLES: ANGELA STICKLE / JOHNS HOPKINS APL; MISSION STEPS: GREGG DINDERMAN / S&T, SOURCE: NASA / JHU APL ing up at least 10 times as much. Digging into Bennu was more like dipping a hand in water than penetrating solid rock. "This material just doesn't seem to dissipate energy," explains Statler. "It's friction-free. It's strength-free. It doesn't cohere."

This should perhaps have been less surprising than it was. When a 2-kilogram copper impactor from JAXA's Hayabusa 2 crashed into asteroid Ryugu at 2 km/s more than a year earlier, over 8 minutes passed before the crater finished forming. "You would think this would all just settle down and stop within a few seconds, because you surely lose a lot of energy just in the friction," explains Statler. "But instead, these little bits of rock kept pushing on each other little piece even when it got down to less than walking speed motion — it's just totally counterintuitive."

15%

Fraction of near-Earth asteroids that are binaries

Both Bennu and Ryugu are rubble-pile asteroids consisting of a hodge-podge of large rocks and gravel, held together by the asteroid's weak gravity rather than material strength. If Dimorphos turns out to be similar, reconstructing DART's collision becomes a challenge for theorists. Researchers traditionally base impact simulations on known shock physics and verify them through laboratory-based experiments here on Earth. The codes are not built to handle this liquid-like, friction-free material moving in slow motion, Michel explains.

As a result, experts have been developing simulations that incorporate granular physics, accounting for the strange, cohesionless material encountered on Bennu and Ryugu. "It becomes very complex code, and therefore we need to make sure we do it correctly, which is why DART and Hera are so important," he says.

With the real-world data that DART and Hera will offer, physicists should finally have everything they need to confirm the impact's beta value and reproduce exactly what happened on Dimorphos. And if they can simulate the DART impact accurately, then they can apply the same physics in simulations of other asteroids and impacts, taking a lot of the guesswork out of planning a real deflection mission.

What If . . . ?

A concern on many people's minds is that Dimorphos will follow Bennu and Ryugu's lead and throw a curveball. What if DART's crash produces a beta value models cannot explain? In this case, asteroid impact science will need to go back to the drawing board. "As a scientist, I would like to be surprised by DART," says Statler. "As a planetary defender, I really don't."

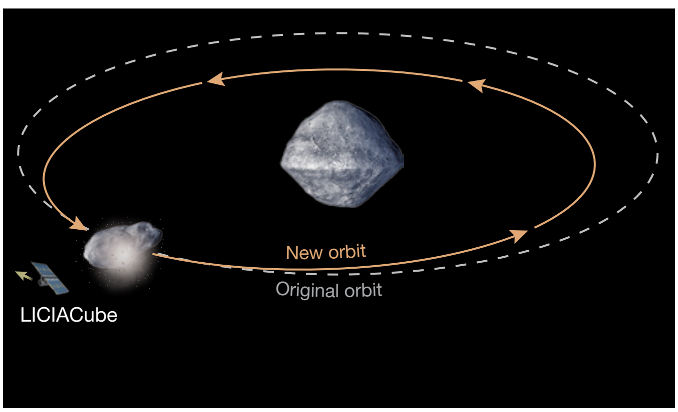
Another worry is that the DART impact simply won't provide enough data. Crashing into Dimorphos represents just one real-world data point to verify a vast range of impact scenarios. How can one test validate an entire field of research?

In reality, it can't. All DART and Hera can really do is tell us whether physicists' current understanding and simulations are heading in the right direction. We'll need more missions to other asteroids before any planetary defender can say with confidence that we could successfully deflect a dangerous asteroid headed for Earth.

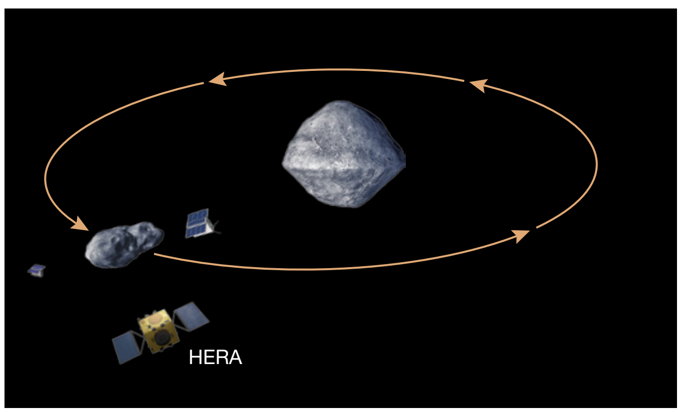
Some people might see DART and Hera, and planetary defense more generally, as a frivolous waste of money when the chances of a large asteroid impacting Earth in the near future are vanishingly small. But recent world events have taught us that low-probability situations can and do have huge, global consequences — and preparedness is key to mitigating their impact. Michel feels it would be foolish to put off planning for the worst: "We have the means and time to prepare for what's necessary to offer security for future generations," he says. As the proverb goes: "Failing to plan is planning to fail."

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

Explore Sentry's list of potential hazardous objects: cneos.jpl.nasa.gov/sentry. Find a list of observable asteroids and comets (hazardous or not) at https://is.gd/ssd_observe.



3. A few minutes later, LICIACube flies safely by, observing the wreckage. The smack robs Dimorphos of orbital energy, slightly shrinking its circuit around Didymos (size change and elongation exaggerated for clarity).



4. In 2026, Hera and its two tagalong CubeSats arrive to investigate.

COSMIC TRIOS by Jerry Oltion

Seeing Triple

Good things come in threes. Feast your eyes on these celestial triplets.

People seem to have an affinity for the number three. Comedians and fiction writers have a guideline we call the "rule of threes": When you're telling a joke or a story, you set things up with a situation, then you repeat it with a subtle variation, then you give it a twist for the grand finale. That somehow seems to speak to a part of the human psyche that finds completion in triplets. Two of something leaves us feeling unfulfilled, and four of something seems too busy. Three is just right. (How many chairs, bowls of porridge, and beds did Goldilocks sample? That's right: three of each.)

While thinking about the rule of threes one day, I realized that I really enjoy seeing triplets in the sky, too. Triple stars are way more exciting than double stars. Galaxy triplets are more interesting than single or even double galaxies. The Trifid Nebula is sublime. And so on. So I decided to highlight some of the neatest triplets in the sky. These are organized by type rather than by time, and they're scattered all over the sky, so you'll want to keep this article handy for the entire year.

Lunar Triads

Let's start nearby, on the Moon. Earth's nearest celestial neighbor is covered in craters, so it's not surprising that you can find groups of three — but there are two such groups that stand out like no others. The first is best seen a few days shy of first quarter and is composed of three craters of nearly equal size: **Theophilus**, **Cyrillus**, and **Catharina**. Theophilus and Cyrillus overlap, with Theophilus's wall pushing slightly into Cyrillus, while Catharina stands off about half a diameter south of Cyrillus. All three craters are ruggedly complex; when the terminator runs across this grouping, they're the first things you'll notice — and they're full of interesting terrain.

Just two or three days later, close to first quarter, the terminator moves on to three more craters with nearly the same north-south orientation. But **Ptolemaeus**, **Alphonsus**,

▲ **ENTER THE DRAGON** NGC 5981, NGC 5982, and NGC 5985 form the Draco Triplet, a delightful cosmic sampler. Savor this sight in late spring and early summer. North is at seven o'clock in this image.

BRANDT SCHRAM

and **Arzachel** are different sizes. Ptolemaeus is the northernmost and the largest, with a flat, lava-flooded floor broken by a single craterlet (Ammonius). Just below it (and sharing an overlapping rim), Alphonsus is a bit smaller and is also mostly flooded, but its central peak still stands just a smidgen above the lava. Arzachel is off by itself half a diameter to the south and has a distinct central peak and slumped walls. It's great to study these three siblings, each with its own unique features.

The rule of threes says the Moon should provide a third triplet, but nature doesn't really care about that sort of thing. It has given us two really good ones (and a bunch of lesser ones), so let's move on to deeper sky.

Stellar Triplets

How about triple stars? There are dozens of them, way too many to describe here, so I'll just talk about my favorites. Observers often consider **Iota (ι) Cassiopeiae** the most colorful triple, in that it has a 4.6-magnitude white primary with 6.9-magnitude yellow and 9.0-magnitude blue companions. The separations between the primary and its companions are only 3.0″ and 6.7″, respectively, so you'll need plenty of magnification and steady seeing to split all three, but when you do it's a beautiful sight. To find it, extend the line between Delta (δ) Cassiopeiae and Epsilon (ε) Cassiopeiae to the northeast the same distance again.

There's another beautiful triplet in the middle of the Pleiades. Alcyone is the notorious central Pleiad, but right next to it on its northwest edge is my main reason for looking at the Seven Sisters on any given night. A delightful triangle of stars comprising **24 Tauri**, **HD 23607**, and **HD 23608** (magnitudes 6.3, 8.3, and 8.7, respectively) form a pleasing trio that stands out well even at medium-low power.

As long as we're digging into the Henry Draper catalog, I also think **HD 51502** in Gemini is pretty special. It's the lucida of a triplet of 7th- and 8th-magnitude stars with enough separation (81″, 107″, and 124″) to just be splittable in binoculars if you steady them on something solid. It's nice in a telescope at low power, too. Look for them about 3½° northeast of Xi (ξ) Geminorum. They make a nearly equilateral triangle, which I always find pleasing in triple stars, and they have subtle color differences of white, yellow, and blue. The stars aren't a true triple, since they lie at different distances, but it's a neat little asterism.

HD 46867, about 1° east-northeast of the center of the Rosette Nebula in Monoceros, is the anchor of another nice, nearly equilateral triangle. These three 8th- and 9th-magnitude stars split at 30″, 34″, and 40″, so they're pretty tight in binoculars but easy in a telescope.

What about more intricate triangles? Are there any made up of more than just three stars? Indeed, there are. One of

▶ **COPIOUS CRATERS** (Top) Theophilus, Cyrillus, and Catharina make a distinctive triplet on the Moon in more ways than one: Catharina is one of only a handful of lunar features named after a woman. (Bottom) Ptolemaeus, Alphonsus, and Arzachel stand out beautifully near first quarter. The fields of view (FOV) of the two images are 2.5′ and 3′, respectively.

SKETCHES: CINDY KRACH (2)

▲ **TRIANGLE IN THE SEVEN SISTERS** The triangle of stars next to Alcyone, the middle star of the Pleiades, is easy to locate and a fine winter sight in small telescopes. FOV = 1° 20′.

▲ **TRIANGLE OF DOUBLES** Another delightful wintertime sight, the Yield Sign is just part of the Hyades cluster, but it's the coolest part. The bright star on the left is Aldebaran. FOV = 7°.

my favorites is near M11 in Scutum. Scan south of the open cluster by 1½° and you'll come to an obvious asterism of 7th- to 9th-magnitude stars that make up a triangle with three stars defining each side. Actually, the southwestern side has four stars, and the most westerly star of all — making up the western point of the triangle — is a deep-red carbon star, 6.8-magnitude **S Scuti**. I always drop down for a peek after I've looked at M11.

How about a real Arabic numeral 3? If you don't mind a tag-along 7 right next to it, **NGC 2169**, nicknamed The 37 Cluster, in Orion's Club (around 7⅓° north-northeast of Betelgeuse) provides a 3 that will take you right back to the days of dot-matrix printers.

While you're in the neighborhood, shift westward to Taurus, where you'll find the Hyades star cluster. Within the Hyades, about 1½° southwest of Aldebaran, lies a triplet of doubles that I call the **Yield Sign** because it demarks such a symmetrical triangle. For years I thought that *was* the Hyades, and all the other stars around it were merely window dressing. The stars that make up the Yield Sign are all part of the cluster and lie at a distance of about 150 light-years, but they're far enough apart that they probably aren't true doubles. The pairs are a little more than ½° from each other, though, which leads to an interesting but quite rare phenomenon: The Moon occasionally nestles right between all six stars. Such an event only lasts for a couple of minutes and only happens once in a great while (the next one is in 2035), but it's a stunning sight when it happens. Or so I'm told. I haven't seen this yet, either.

There's one more asterism that I think might very well be the most delightful stellar triplet in the sky. You'll find it in Corvus, some 4⅔° north-northeast of Delta Corvi. Called **The Stargate**, it's a triangle within a triangle, and the two triangles are oriented with their vertices almost perfectly opposite each other. One of the inner three stars is fainter than the others and is probably variable since it's sometimes much harder to see than at other times — but the overall impression is so regular and so impossible-seeming that it looks like an artificial arrangement. You can just imagine starships slipping in and out of hyperspace through that gateway on their way to and from the Sombrero Galaxy (M104), only 1° to the east-northeast.

Clusterings of Clusters

Asterisms lead naturally to the consideration of open clusters. Do they congregate, too? Sure they do. One of my favorite groupings is in Cassiopeia, about 6° northwest of the famous Double Cluster in Perseus. Between the stars that make up the Perseus-facing bar of the W, you'll find **NGC 663**, the most obvious of the group, with **NGC 654** and **NGC 659** nearby. NGC 663 is a bright, showy cluster at magnitude 7.1, while NGC 654 is smaller but brighter at magnitude 6.5, and NGC 659 lies south at magnitude 7.9. Each cluster is beautiful in itself, but they all fit within a 1.5°, low-power field. The bonus for me, though, is how in the autumn when

ALL SKETCHES BY JERRY OLTION UNLESS OTHERWISE NOTED they're rising in the east, NGC 659 and NGC 663 and the stars in between them look like a goat. NGC 659 is the tail of the goat, the arch of stars between clusters is the back, and NGC 663 is the head. There are even strings of stars sticking downward to make legs. It's pretty distinctive. Once you see this one, you can't un-see it.

In the winter sky, you'll find another nice set of open clusters — 6.1-magnitude **M46**, 4.4-magnitude **M47**, and 6.7-magnitude **NGC 2423** — about 13° almost due east of Sirius. This trio spans 1.5°, so you'll need your lowest power to see them all at once, but it's also fun to move the telescope around and watch each concentration of stars fill the eyepiece in turn. They're great in binoculars, with each cluster standing out well against the background. As you might expect from their catalog numbers, NGC 2423 is the runt of the litter, but it's still distinctive enough to fool a lot of people into thinking they're seeing M46. Nope, M46 is on the other side of M47, which is the showiest of the trio.

M46 has an Easter egg in it: The planetary nebula NGC 2438 is superimposed on its northern edge (see, for example, page 41 in the February issue for an image).

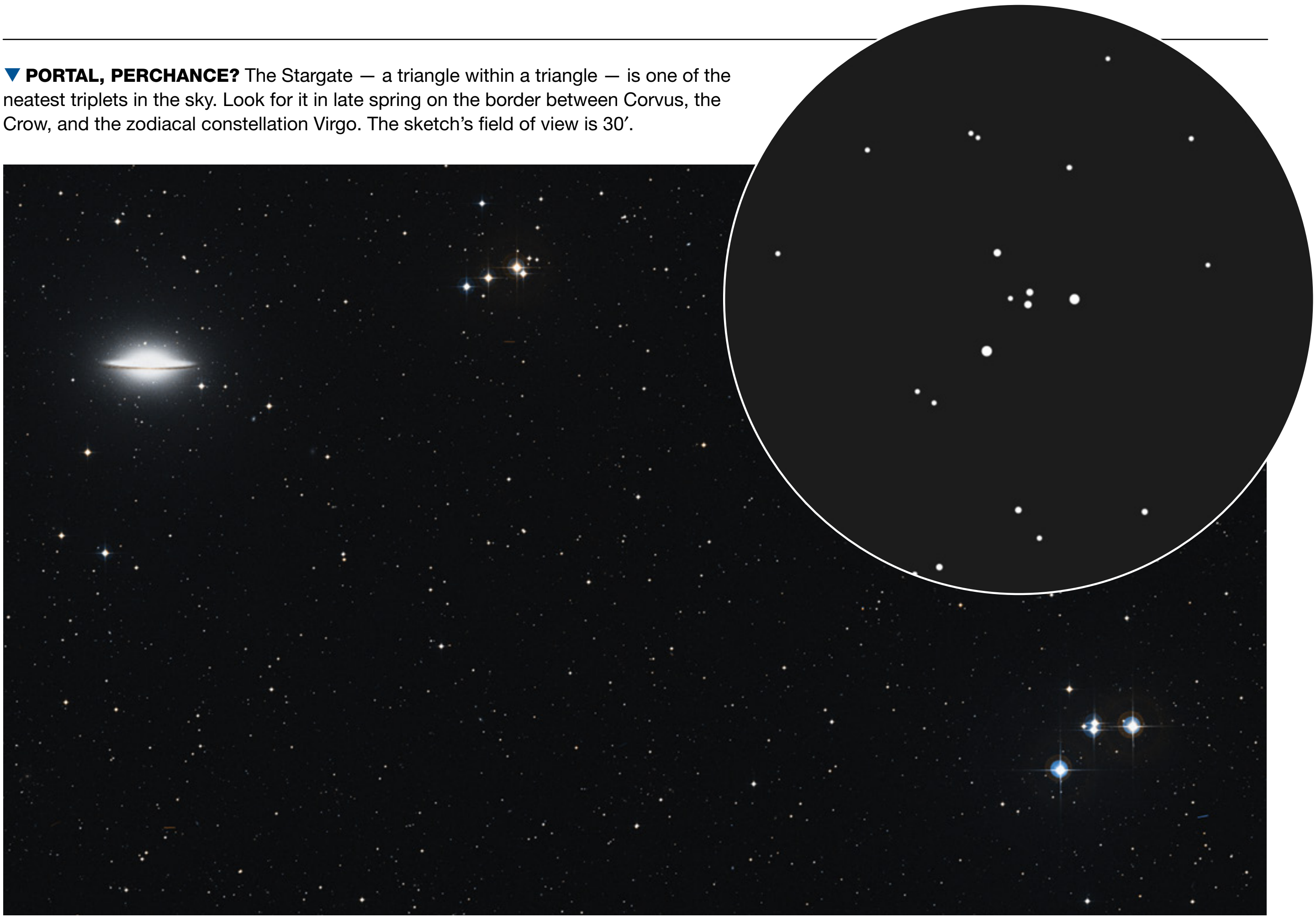
Globular clusters sometimes bunch together, too, but not tightly enough for any of them to really feel like a triplet. So, let's look at an interesting triple formation *within* one of the sky's most famous globular clusters: **M13**. You'll find the 5.8-magnitude globular about two-thirds of the way on a line connecting Zeta (ζ) to Eta (η) Herculis. The Great Hercules Cluster, as it's also known, has a subtle trefoil of dark lanes within it called the Propeller. It's hard to spot; you need high magnification and good transparency to bring out the contrast, but if you keep looking it will slowly emerge for you until it becomes quite obvious. It's off-center, southeast of the core, and only spans about a third of the cluster. It's surprisingly symmetrical, like a triple-bladed airplane propeller, hence its name.

Nebulous Trios

How about nebulae? The **Trifid Nebula** (M20) is of course the most famous three-part nebula in the sky. Look for it a little bit more than 6° northeast of Lambda (λ) Sagittarii, or Kaus Borealis, the topmost star in the lid of the Teapot in Sagittarius. A dark dust lane cuts the bright emission nebula into three sections. (Although to be honest, it looks like four sections to me.) A nebula filter helps considerably with the contrast.

The Trifid is triple in another way as well: It's made up of three different *types* of nebula. There's the emission nebula

▼ **PORTAL, PERCHANCE?** The Stargate — a triangle within a triangle — is one of the neatest triplets in the sky. Look for it in late spring on the border between Corvus, the Crow, and the zodiacal constellation Virgo. The sketch's field of view is 30′.



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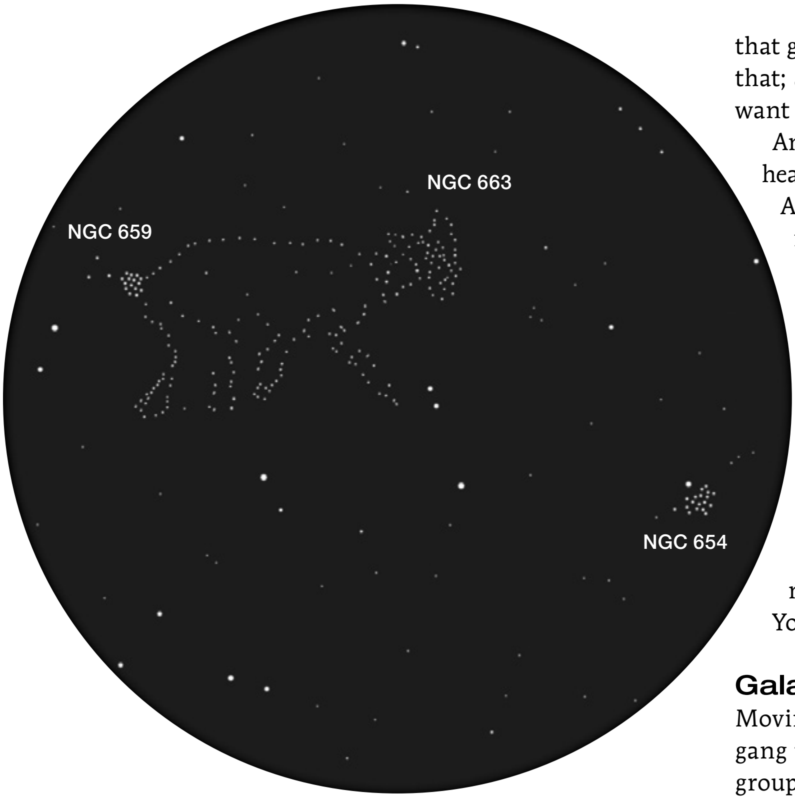


▲ **DO YOU SEE IT?** NGC 659 and NGC 663 plus the intervening stars form an easily discernible telescopic goat when rising in the autumn, with NGC 654 out in front. FOV = 1° 40′.

that glows red in photographs; the dark nebula in front of that; and a fainter, blue reflection nebula to the north. You'll want to remove the filter for the latter.

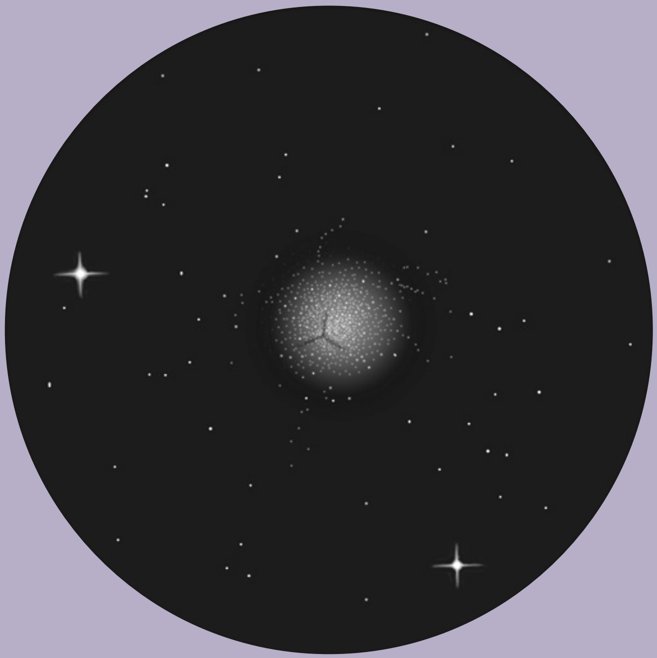
And while you've got the filter off, there's a bonus at the heart of the emission nebula: The central star is a triple. Another reason to call it the Trifid! You'll need extra magnification and steady sky to see all three stars, but they're a nice treat next time you're in the neighborhood.

The Trifid may be the most famous triple nebula, but I find **Barnard's E Nebula**, sometimes called the Triple Cave Nebula, to be even more sublime. Just 1° west of Tarazed, or Gamma (γ) Aquilae, this dark nebula looks like a giant capital letter E against the Milky Way background. The three horizontal bars are quite distinct, as is the upper half of the vertical part of the E, but the bottom bar stands by itself. This triplet is best seen in binoculars, which always seem to make dark nebulae stand out better than in telescopes. You'll need good, rural skies to see it, though.

Galactic Trifectas

Moving farther afield we have entire galaxies that often gang together like starlings. But we're just interested in groups of three.

The most famous galaxy trio is probably the Leo Triplet, comprising **M65**, **M66**, and **NGC 3628** just under the hindquarters of Leo, the Lion, approximately halfway on a line connecting Theta (θ) Leonis with Iota Leonis. They're



▲ **VISION IN A GLOBULAR** Summer skies bring Hercules nicely into view, along with its majestic globular cluster M13. The Propeller in the cluster's center is difficult to spot at first, but then it becomes difficult not to see. FOV = 35′.

▲ **TRIPLE TRIPLE** The Trifid Nebula, in Sagittarius, is triple in three ways: It's composed of three types of nebula (emission, reflection, and dark), the dark nebula cuts the emission nebula into three parts, and the central star is triple. FOV = 35′.

tight enough and bright enough (magnitudes 9.3, 8.9, and 9.5, respectively) to be visible in just about any telescope at low power. About 7½° east, there's another galaxy triplet just under Leo's belly, this one made up of **M95**, **M96**, and **M105** (magnitudes 9.7, 9.3, 9.3). This group is a little more widely separated (1.3°), so it might not fit in one eyepiece field unless you have a fairly short focal-length telescope. But there's a bonus: Next to M105 are **NGC 3384** and **NGC 3389** (magnitudes 9.9 and 11.9), which make a very tight (9.8′) little triplet all of their own.

But there's a much bigger, much more impressive trio of galaxies that most observers completely ignore. I'm talking about the one we're part of. The **Milky Way**, the **Andromeda Galaxy** (M31), and the **Pinwheel Galaxy** (M33) all pack into a tight little group only 2.8 million light-years across. (Yes, that's close for galaxies.) They're by far the three largest, most impressive galaxies in the Local Group, and they're the only galaxy trio that can be seen with the naked eye. Admittedly, M33 is right on the edge of perception even under a very dark sky, but I've managed it on many nights, and if you dark-adapt your eyes, so can you. And because M33 and M31 are only 30° and 15° away from the Milky Way as it cruises through Cassiopeia, all three are within one easy field of view . . . of your eyes.

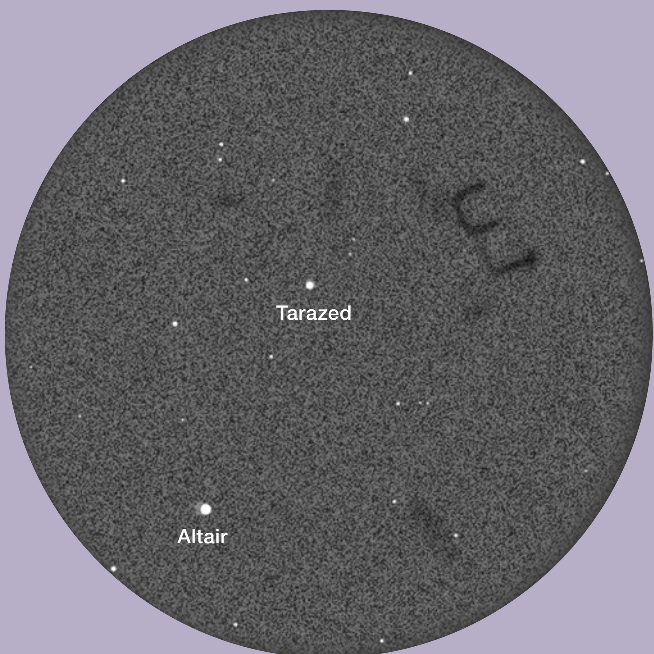
This is what I call "conceptually cool" rather than visually cool, although when you gaze directly at M31 and get the Milky Way and M33 in your peripheral vision all at once, you can lose yourself in the beauty of it.

I have one other favorite galaxy triplet, and this one fits nicely in an eyepiece at 100× or so: **NGC 5981**, **NGC 5982**, and **NGC 5985**. They're in the body of Draco, the Dragon, about 1¾° east-northeast of Iota Draconis, so they're often called the "Draco Triplet." As seen on page 20, all three galaxies are in a straight line less than ¼° long, and the cool thing about them is that each displays a distinctly different aspect: NGC 5981 is an edge-on spiral, while NGC 5982 is an elliptical and NGC 5985 is a face-on spiral. The latter two, both at magnitude 11.1, are fairly easy to see under moderately dark sky, but the edge-on galaxy, NGC 5981, is more difficult at magnitude 13.0. It's worth the effort to check them out under dark sky, though. I think this is possibly the neatest galaxy triplet out there.

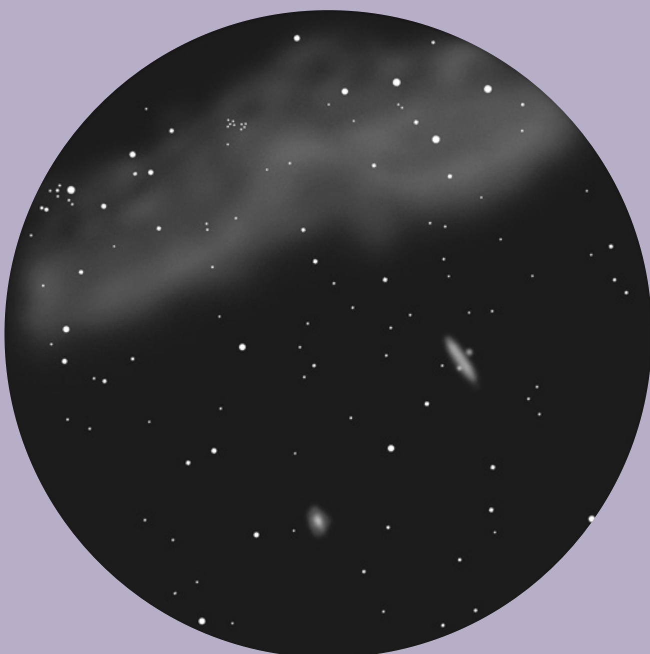
There's another rule in both writing and comedy: Never do a setup without a payoff. I started this article by talking about jokes, so here you go: Three astronomers, heavily bundled up against the winter cold, walk into an observatory. The first one says, "I want to see the Christmas Tree Cluster." The second one says, "I want to see the Blue Snowball Nebula." The third one blows on her fingers to warm them up and says, "I want to see the Summer Triangle."

■ Contributing Editor **JERRY OLTION** thinks four-leaf clovers are overkill. Contact Jerry at **j.oltion@gmail.com**.

TABLES AND CHARTS: Go to **https://is.gd/cosmic_triplets** for a table of data and finder charts for the targets discussed here.



▲ **WRITING IN THE SKY** Barnard's E, also known as the Triple Cave Nebula, is one of the most distinctive dark nebulae in the sky. It's big, so binoculars show it to best advantage. Look for it in late summer or early autumn, as the nights grow longer. FOV = 5°.



▲ **IN THE NEIGHBORHOOD** During the longest nights of the year in the Northern Hemisphere, linger on our spectacular Local Group neighbors. The Milky Way is part of a triplet with the Andromeda Galaxy (M31) and the Pinwheel Galaxy (M33). FOV = 40°.

Fast Radio Bursts Hit Prime Time

Less than two decades after their discovery, these cosmic flashes have revealed much about their nature — but we still debate how they're created.

The more I study the universe, the more I am in awe of its beautifully complex detail. It's a dynamic and turbulent place: While the sky appears largely unchanging to our human eyes, it puts on a spectacular display of fireworks every day that's detectable with the eyes of a radio telescope.

Over the last two decades, we've developed the ability to study rapid changes in the radio universe, catching signals that typically last less than the blink of an eye. Such advances resulted in the breakthrough discovery of *fast radio bursts* (FRBs, *S&T:* July 2016, p. 24). These signals are mysterious cosmic explosions that originate in distant galaxies and release a terrific rush of energy in just a millisecond — sometimes as much as the Sun emits in a few days. To date, we still don't know what causes them, but we know it must be something very powerful yet remarkably small, roughly the size of a city.

▲ **COSMIC HERALD** Artistic view of the fast radio burst FRB 20180916B hitting the heart of the LOFAR array in the Netherlands. Intergalactic gas delays lower frequencies more than it does higher ones, so the lower frequencies (redder colors) take longer to reach the detectors. The FRB's repeated bursts enabled astronomers to locate its source in the spiral galaxy SDSS J0158+6542, which lies 500 million light-years from Earth (inset).

DANIËLLE FUTSELAAR / ASTRON / HST

Every day, hundreds to thousands of FRBs occur above our heads, making them more common than most other transient events, such as supernovae. We have now detected 614 FRBs from all over the sky — approximately 100 times more than were known in 2014 when I began my PhD in this field.

The Serendipitous Discovery

The frenzy began in 2007, while astronomers were looking for extragalactic radio pulsars — rapidly spinning neutron stars that release intense radiation beams that sweep across the sky as the star whirls around. The researchers were digging through archival data from the 64-meter Parkes radio telescope, run by Australia's national science agency, the Commonwealth Scientific and Industrial Research Organisation (CSIRO). To find new pulsars in the Milky Way's neighborhood, the observers searched for signals across a wide range of *dispersion measure* (DM) values. Dispersion is essentially how smeared out a radio signal becomes as it travels through space. The signal encounters unbound electrons in the gas along its path, which delay its arrival at the detectors. This effect is frequency-dependent, so that lower-frequency signals arrive noticeably later than those at higher frequencies. More severe dispersion indicates that the signal passed through more electrons and thus that it came from a more distant source.

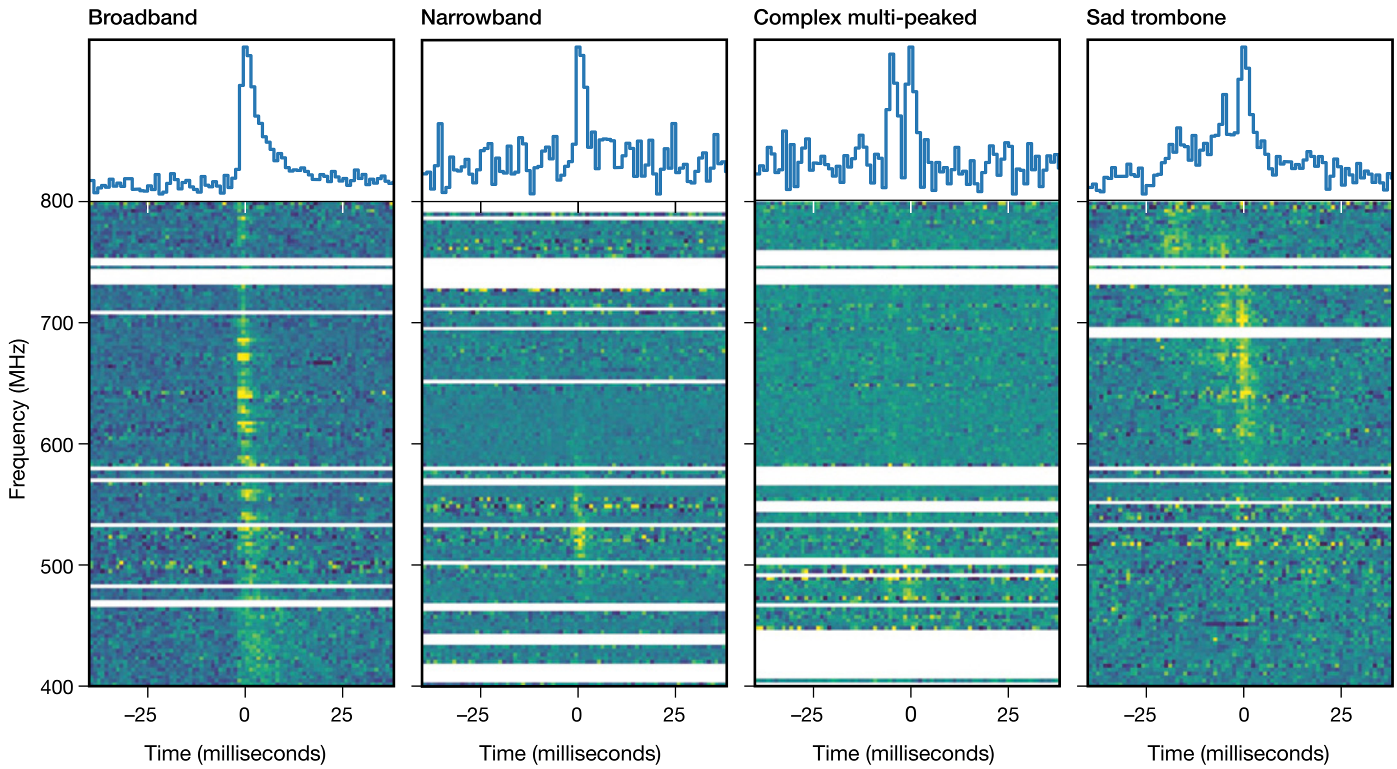
It was in these Parkes data that student David Narkevic (then at West Virginia University) found a 5-millisecond-long, highly dispersed burst. It was so strong that it had initially been rejected as terrestrial radio interference! This discovery, since known as the Lorimer burst after Narkevic's advisor and the paper's lead author, Duncan Lorimer, is an excellent example of the role serendipity still plays in scientific discoveries.

The Lorimer burst's dispersion suggested that it originated some 3 billion light-years from Earth — far beyond the Milky Way's galactic neighborhood. Not all scientists were convinced that the Lorimer burst came from outside our galaxy, though, or even from something astrophysical. But when astronomers began to fine-tune their searches, they found more bursts from Parkes as well as from telescopes around the world, including those at Arecibo and Green Bank. After several years, it became clear that we had a new class of mysterious astrophysical signals on our hands, flashing at us from distant galaxies. The skepticism transformed into a race to find more FRBs in real time and to determine what produces them.

A Population Explosion

The majority of known FRBs appear to be one-off events — never to be seen again, highly unpredictable, and difficult to catch. Finally, a much-awaited breakthrough happened in 2016: FRB 121102A, discovered originally with the Arecibo telescope in 2012, was observed to repeat! A cluster of bursts from this repeater hit the Arecibo telescope from the same spot in the sky, revealing its location in the constellation Auriga, the Charioteer. The repeats also told us that the source hadn't destroyed itself.

Astronomers have discovered several other repeater events since FRB 121102A, but their appearance is sporadic. Two of the repeaters are active for a few days every few weeks to months. Periodicity of this sort cannot be easily explained by a single rotating, city-size object; more likely, these FRB sources have a companion they orbit and regularly interact with on these time scales.



▲ **FOUR FLAVORS** With hundreds of detections in hand, astronomers have found FRBs come in four types, distinguished by their time and frequency characteristics. From left to right, the four examples are the FRBs 190527C, 190515D, 181117B, and the August 10, 2019, burst of the repeater 190117A. (Apparent knots of intensity are from the instrument, not the FRB.)

Do all FRBs repeat? Are there two populations of FRBs? Is there any connection between them? As the number of FRB detections increased, so did our questions.

In the effort to find answers, wide-field searches have proven to be game-changing. An initial search in 2017 and 2018 used a subset of antennas at CSIRO's Australian Square Kilometre Array Pathfinder (ASKAP), a national facility at Western Australia's Murchison radio astronomy observatory. ASKAP consists of 36 dishes, each 12 meters across and separated by a maximum distance of 6 km. These dishes join together to act as a single large telescope, called an *interferometer*, creating sharp images of the sky. Covering an area equivalent to 100 full Moons, ASKAP's search resulted in the detection of 20 FRBs, nearly doubling the known population at that time.

Another paradigm shift has come with the onset of the Canadian Hydrogen Intensity Mapping Experiment (CHIME), a sensitive radio telescope made of four cylindrical parabolic antennas with no moving parts. They look like long half-pipes, set side-by-side to make a giant, corrugated array. With a field of view of roughly 200 square degrees — similar to midsize constellations such as Lacerta, the Lizard — and high sensitivity, CHIME has already detected about 500 FRBs, of which 24 emit repeating bursts.

Now that we have so many FRBs, we've started to identify patterns within their short signals. FRBs come in a variety of flavors, which we classify based on their time and frequency characteristics: 1) *broadband bursts*, simple bursts with a single peak in time that spans a broad range of frequencies; 2) *narrowband bursts*, which span a narrow range of frequencies; 3) *complex bursts* with multiple peaks of the same or different intensities (these peaks can also be either broadband or narrowband); and 4) complex bursts with multiple sub-bursts that drift downward in frequency as time passes, popularly known as the *sad-trombone effect*.

We've discovered some differences between repeating and non-repeating FRBs, too. Bursts from repeating sources last longer in time and shine over a narrower range of frequencies than non-repeating FRBs. Also, the sad-trombone effect is mostly seen in signals from repeating FRBs.

Moreover, because of the new live-detection systems in place, scientists can now save the raw data and zoom in to study FRB signals on small time scales. This zoomed-in view reveals that an FRB's emission changes on time scales ranging from tens of microseconds to a few microseconds and even nanoseconds! One FRB even had a forest of sub-microsecond structures that are similar to the signals seen coming from the brightest pulses emitted by the Crab pulsar. Because light travels at a finite speed, the duration of the pulse tells us about the size of the emission region, and fluctuations within the pulse place constraints on the emission process.

While the majority of FRBs are detected above 400 MHz, one repeating source has recently shown itself at frequencies as low as 110 MHz using the Low-Frequency Array (LOFAR) in the Netherlands. Low-frequency observations are the next big thing in FRB research, because they're more sensitive to how the magnetized, ionized gas between us and an FRB source affects the signal as it travels. This novel look at the local environment of FRB 20180916B, for example, shows that we have an unobscured line of sight to the emitter and that there's an ambient, varying magnetic field surrounding the source. Low-frequency observations are also helping us rule out some emission mechanisms.

Getting Personal with FRBs

The incredible energy these brilliant explosions produce

MARK HALPERN / UNIVERSITY OF BRITISH COLUMBIA

▲ **CHIME** The CHIME array in Canada shortly before it became operational in 2017. CHIME later joined the FRB hunt and has provided a remarkable boost to the number of bursts detected.

suggests that they're made in a way we've never seen before. The only other sources we know of that emit radio bursts of similar duration are pulsars. But we've only found radio pulsars in the Milky Way and nearby Large and Small Magellanic Clouds; we can't see them beyond our galactic backyard. Conversely, FRBs originate in faraway galaxies, at distances sometimes a million times greater than pulsars, and their emission must be a trillion times more energetic. This has sparked a flurry of theoretical speculation about what's causing these bursts.

According to theorists, some FRBs could arise in catastrophic scenarios, such as the collapse of a heavyweight neutron star or the violent and rare collisions of compact objects, such as neutron stars and white dwarfs. These cases would only produce one-off events, though. Repeatable bursts could instead be magnificent flares from young, rapidly spinning neutron stars, such as pulsars or *magnetars* (the latter are neutron stars' highly magnetized cousins).

Alternatively, some astronomers have suggested that both types of FRBs might arise from interactions within the hot accreting gas surrounding the supermassive black hole at the heart of a galaxy — an *active galactic nucleus* (AGN).

Astronomers still can't pinpoint the positions of most FRBs, limiting our ability to identify their host galaxies. But one advantage of the repeaters is that they enable astronomers to point interferometers at the patch of sky from whence these bursts emerge, in order to capture the source in action. The source of the first repeating FRB 121102A did not disappoint: For the first time, observers pinpointed an FRB's location — in this case, a tiny star-forming dwarf galaxy that lies some 3 billion light-years away. The location overlapped with a compact persistent radio source in the galaxy, suggesting that the burst's source is probably embedded in a nebula.

Further to that, FRB 121102A's repeat bursts showed signs of originating from within a highly magnetic environment. This information, combined with the properties of the host galaxy, led to a model for FRBs in which bursts originate from young magnetars themselves produced in high-powered supernovae, which fill the magnetar's surrounding environment with gas and dust.

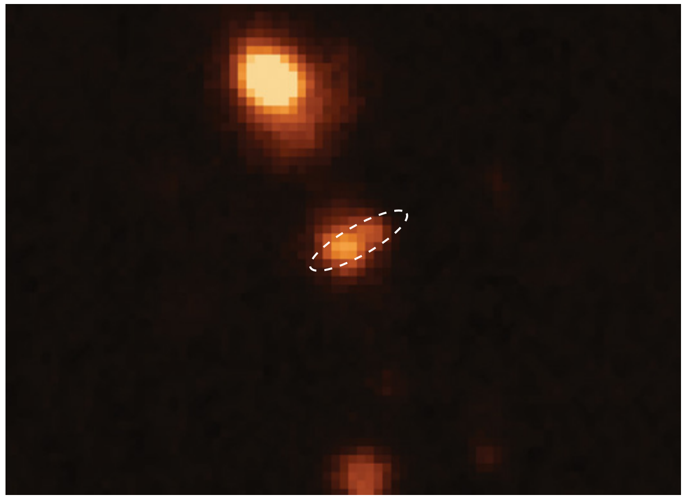
A few years later, however, astronomers found another repeating FRB in a massive spiral galaxy that was associated with neither a radio source nor a highly magnetic environment. An eagle-eye view of its neighborhood revealed that the burst was offset from the galaxy's star-forming region. Star-forming regions are chaotic factories that produce a large number of stars quickly; these stars will also die frequently, resulting in many young magnetars. The offset of this FRB from such a region meant its source is likely older than we'd expect for a young magnetar. Thus, with only two sources, we began to notice diversity in repeaters' host environments.

Observations from the world's largest radio telescope, the Chinese Five-Hundred-Meter Aperture Spherical Radio Telescope (FAST), recently revealed an FRB 121102A twin: FRB 190520B, also located in a dwarf galaxy and accompanied by a persistent radio source. Furthermore, these two FRBs repeat more frequently than others, implying that more active repeaters may be young sources surrounded by dense, magnetized plasma.

Another recently discovered repeater was pinpointed to a globular cluster in the nearby spiral galaxy M81 (*S&T:* June 2022, p. 11). This was a jaw-dropping discovery! Globular clusters consist of hundreds of thousands of tightly bound and very old stars. The massive stars in such a cluster will have exploded early in its history, and the remnant magnetars they formed will have lost their magnetic energy after 10,000 years or so. If magnetars are indeed the source of repeating FRBs, then how can one still exist in an old globular cluster? This discovery has us scratching our heads, wondering if there is another way to make a magnetar. The best guesses include merging neutron stars or white dwarfs, or the collapse of a white dwarf that siphoned too much material from a companion star.

But what about FRBs that do not repeat? What does their home environment look like? Catching one-off bursts well enough to pinpoint their locations is indeed a difficult task, but ASKAP has accomplished it. Thanks to a special mode, ASKAP captures a burst just as it hits the telescope, saves the rawest form of data from each of the 36 dishes, and replays it to create an image of the FRB, thereby determining its precise location on the sky.

When my colleagues and I zoomed in on the host galaxies of one-off FRBs, we discovered that the sources prefer the outer, quieter suburbs of the galaxy rather than the downtown center. As a result, we knew right away that the progenitors had nothing to do with the supermassive black holes that reside at the center of these galaxies, hence ruling out



▲ **FINDING ONE-OFF BURSTS** This image by the Very Large Telescope in Chile shows the host galaxy of the non-repeating FRB 181112, pinpointed thanks to ASKAP's data. The ellipse marks the FRB's approximate location. Analysis revealed that the signal had passed through the halo of a massive galaxy (top of image) en route to Earth, giving astronomers unique information about the halo's gas.

ESO / X. PROCHASKA ET AL.

AGN-related scenarios. We also discovered that the galaxies have stars with a broader range of ages than expected if FRBs were always tied to young stellar populations. The majority of these galaxies are massive and only moderately producing stars, much like our own Milky Way.

As a result, it's unclear whether there are any significant differences between the host environments of repeating and non-repeating FRBs. However, it *is* clear that FRBs can originate in a variety of environments. The current evidence also points to at least two distinct mechanisms: a luminous explosion of dying stars or the collision of compact objects. Either scenario could produce a magnetar, which could be on its own or part of a binary system. The magnetar could emit an FRB via the unleashing of magnetic energy within its magnetosphere, perhaps by means of powerful magnetic waves or the violent rearrangement of the magnetic field. Alternatively, particles launched from this compact object could slam into the ambient medium at relativistic speeds, creating bursts far outside the magnetosphere.

10^{33} ERG/S
Sun's luminosity

10^{43} ERG/S
Type Ia supernova's peak luminosity

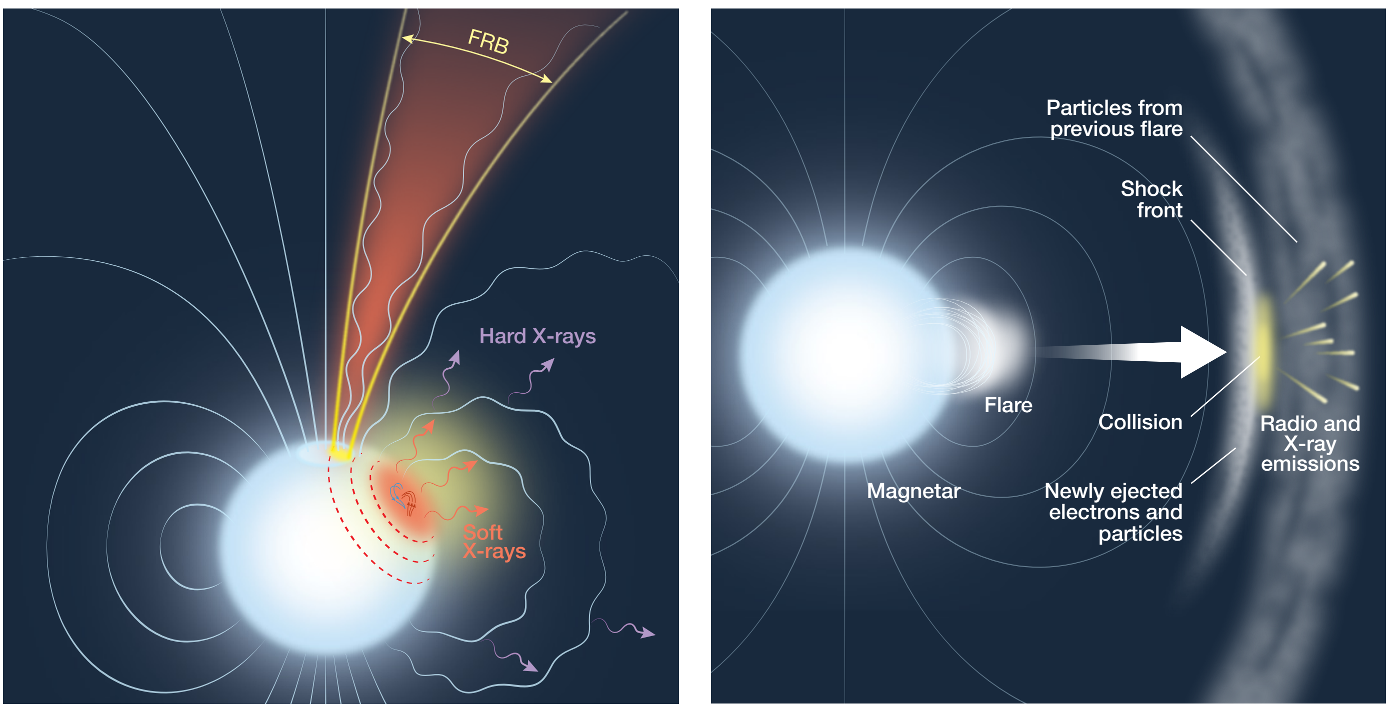
10^{38} to 10^{46} ERG/S
FRB peak luminosities

FRB in the Milky Way

While scientists were searching for distant FRBs, something exciting happened back home in our Milky Way: An FRB-like burst (FRB 200428) was discovered by CHIME and the Survey for Transient Astronomical Radio Emission 2 (STARE2) telescope, coming from a magnetar called SGR 1935+2154 in our galaxy (*S&T:* Sept. 2020, p. 10). The energy of this burst was comparable to the faintest FRBs. Several space telescopes also detected a simultaneous X-ray signal from this magnetar. This finding provides the "smoking gun" demonstrating that these exotic objects can indeed produce some FRBs, and it bridges the energy gap between neutron stars in the Milky Way and FRBs far beyond it.

Despite this revolutionary discovery, FRBs remain a mystery. While magnetars may be the most prolific FRB producers, bursts from magnetars such as SGR 1935+2154 are unlikely to account for all observed FRBs, for several reasons. First, the brightest FRBs are a million times brighter than FRB 200428. Second, the rate of FRB-like bursts from this kind of magnetar in the local universe is not high enough to explain the observed FRB rate. Third, bursts like the one seen from SGR 1935+2154 cannot explain highly energetic repeating bursts: Repeater bursts are sporadic, vary in energy, and come in groups, behavior that this magnetar hasn't demonstrated.

▼ **MAGNETAR ORIGINS?** Among the many scenarios to explain FRBs are two broad categories of models involving magnetars. One places the burst's origin close to the star, the other much farther away. *Left:* A sudden release of magnetic energy disrupts the magnetar's surface and sends a fireball of charged particles into the magnetosphere. The event creates waves in the magnetic field. Conditions near the poles accelerate the particles to near the speed of light, creating a burst of radio emission. At lower latitudes, the closed magnetic field lines trap the particles, heating the neutron star's surface and creating X-rays. *Right:* Charged particles from a flare collide with other particles far from the star that were unleashed by previous activity. The collision creates a shock front and intense magnetic fields that accelerate electrons, producing radio emission. Electrons heated by the shock wave emit X-rays.



GREGG DINDERMAN / S&T

We don't know if extragalactic FRBs come with high-energy counterparts like SGR 1935+2154 did — we haven't discovered any, but that might be because our high-energy telescopes aren't sensitive enough to detect the signals from so far away. So while a significant piece of the FRB puzzle has been solved, many questions remain to be answered.

FRBs as Cosmological Probes

While the physical mechanism of FRBs is still unknown, the localized sample of bursts is proving to be an excellent cosmological probe. These events are a novel tool for studying the distribution of matter and magnetic fields in the universe. The bursts are imprinted with signatures of their journey through dense plasma, enabling definitive studies of the medium between the galaxies, which are nearly impossible otherwise.

According to our best estimates of the universe's composition, 70% is dark energy, 25% is dark matter, and the remaining 5% is baryonic mass (the everyday stuff that makes up you and me, the stars, the moons, planets, etc.). However, the sum of all the ordinary matter measured by cosmologists only amounts to about half of the 5% expected to be in the universe. Astronomers have looked for this "missing" matter in various ways and found it in the *warm-hot intergalactic medium* (WHIM) between galaxies (*S&T:* Jan. 2022, p. 34).

The beauty of FRBs is that they can provide an alternative and independent way of locating missing baryons. Using a sample of five localized FRBs observed with ASKAP, for example, scientists have also detected the missing matter in the WHIM. They still don't know how this matter is distributed, however.

This is just a beginning; we're still a long way from fully exploiting the potential of FRBs. When we reach the point of having hundreds of localized FRBs, it will be possible to use them in building our map of the cosmic web, the vast network of gas that connects galaxies. Finally, when we have thousands of localized FRBs, we might be able to answer cosmological questions like how fast the universe is expanding. Funny, it was a signal discovered by chance in archival data that now has the potential to revolutionize our understanding of the universe!

To find the FRBs we'll need for such endeavors, scientists and engineers will continue to fine-tune their instruments to make them more sensitive, as well as construct new facilities. ASKAP is currently undergoing an upgrade. The sensitive Meer ("more") Karoo Array Telescope (MeerKAT) in South Africa has started its quest for FRBs. LOFAR is being upgraded to search for FRBs at low frequencies at full power. The next generation of the Deep Synoptic Array (DSA-2000), the Hydrogen Intensity and Real-time Analysis Experiment (HIRAX), and the Canadian Hydrogen Observatory and Radio Transient Detector (CHORD) facilities are all on the horizon, promising to detect and localize thousands of FRBs per year. The future of FRBs appears to be as bright as they are!

■ **SHIVANI BHANDARI** is an astronomer at the Netherlands Institute for Radio Astronomy who enjoys studying what goes bang in the sky.

ASKAP Australia's ASKAP array combines thirty-six 12-meter antennas to obtain a sensitive, wide-field view of the radio sky. ASKAP and MeerKAT are both precursors to the multi-continental Square Kilometer Array.

CSIRO

Discovering
What *Really* Happened?

New research reveals that the popular story accepted for six decades is not quite right.

Since 1846, controversy has embroiled interpretation of the events leading to the discovery of Neptune, the solar system's most distant major planet. The basic historical facts have long been clear. Ever since William Herschel first located Uranus in 1781, the newly found planet's observed course kept diverging from orbital positions predicted by Newton's law of universal gravitation, baffling astronomers. Was Newton's theory wrong? Or was there some unseen, even more distant planet perturbing Uranus from its expected orbit?

Thanks to mathematicians Leonhard Euler, Pierre-Simon Laplace, and others, celestial mechanics had advanced to the point where by 1845 John Couch Adams (at the University of Cambridge in England) and Urbain Jean Joseph Le Verrier (at the Paris Observatory in France) independently pioneered a novel mathematical tour de force. The two brilliant astronomical theorists attacked an *inverse-perturbation problem* using Uranus's orbital deviations to calculate the anticipated position of a hypothetical, more distant planet. The approach was unprecedented. Both Adams and Le Verrier tried in vain to convince their respective countrymen to search telescopically for the putative planet.

Adams had been hammering away at the problem of Uranus's wayward motions since 1843 and tried three separate times to bring his work to the attention of George Biddell Airy, the Astronomer Royal and director of the Royal Observatory, Greenwich. Adams first tried to contact Airy in September 1845 (while Airy was traveling on the Continent), and twice again on October 21st. Each time, he dropped by the Astronomer Royal's private residence unannounced. On his final visit, Adams left a handwritten sheet of paper bearing his predicted positions. Two weeks later, on November 5th, Airy wrote back asking several follow-up mathematical questions, but Adams never responded. And there the matter lay for eight months.

▲ **STRAYING PLANET** Soon after William Herschel discovered Uranus on March 13, 1781, it seemed to drift from its expected path. John Couch Adams first suggested that the planet's orbital deviations could result from the gravitational pull of an unseen, distant massive planet.

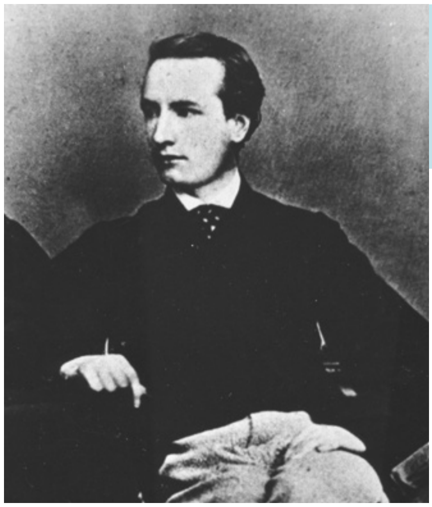
NASA / JPL

In June 1846, Le Verrier published his own predictions for the hypothetical distant planet, triggering a search for it at the Paris Observatory. However, the available star charts lacked the required precision, and there was some doubt that the observatory's 7.5-inch (19-cm) refractor was even up to the task, given the hopelessly urban Parisian skies. By mid-August, the search was suspended.

That same month, when Airy saw that both Adams and Le Verrier had predicted a heliocentric longitude near 325° for the planet, he pressured James Challis, Plumian Professor of Astronomy and Experimental Philosophy (and Adams's former professor), to conduct a major search with Cambridge University's 11.6-inch Northumberland refractor. Knowing that the uncertainty in the planet's predicted position was huge (plus or minus 10°), Airy and Challis anticipated the project might take some 300 hours. Starting on July 29th, the plan was to sweep various zones of the search area, charting star positions three separate times several nights apart, and then to compare the charts to see if a faint "star" had moved.

Meanwhile, Le Verrier wrote to Johann Gottfried Galle at the Berlin Observatory.

Galle and a young volunteer, Heinrich d'Arrest, turned the observatory's 9.6-inch Fraunhofer refractor skyward on the night of September 23–24, 1846. Having the unique advantage of a new star chart covering the predicted area, they identified Neptune's disk shortly after midnight, after less than an hour of searching. They found the planet scarcely more than 1° from Le Verrier's predicted position. Subsequently, Challis examined his own observations and was mortified to discover that six weeks earlier he himself had recorded Neptune on the nights of August 4th and 12th, without realizing what it was.



◀ **CO-PREDICTOR** This portrait of British astronomer and mathematician John Couch Adams was made about the time of the discovery of Neptune.

Credit Where Due

Almost immediately arguments erupted in Britain, France, and Germany over who should receive credit for Neptune's discovery. Should it be Adams for finding a solution first? Le Verrier for publishing his predictions first? Challis for unknowingly seeing it first? Or perhaps Galle and d'Arrest for recognizing it first? Paris Observatory director François Arago had no doubts — he proclaimed that Le Verrier "saw the new celestial object without needing to cast a single glance toward the sky; he saw it *at the tip of his pen*." But in England, Airy, along with John Herschel (son of William, the discoverer of Uranus) and several other eminent British astronomers, tried to secure recognition for Adams on the basis of his earlier unpublished predictions.

Airy promptly gathered key documents and prepared an official account that diplomatically presented Adams and Le Verrier as "co-predictors" of the planet whose existence was confirmed by Galle and d'Arrest. Nonetheless, many Cambridge graduates and English loyalists grumbled that Airy and Challis had let Neptune slip through their fingers by failing to mentor their junior colleague, Adams. The resentment remained so bitter that decades later, after Airy's death in 1892, plans to commemorate the Astronomer Royal's towering contributions to British science by burying him in Westminster Abbey in London were scrapped.

Scarcely had the dust settled when American mathematicians Benjamin Peirce (Perkins Professorship of Astronomy

▶ **BIG AND BLUE** Voyager 2 captured this Neptune image in August 1989, 143 years after Johann Gottfried Galle and Heinrich Louis d'Arrest initially recognized it in the eyepiece of the Berlin Observatory's 9.6-inch Fraunhofer refractor. The planet reaches opposition this month and shines at magnitude 7.8 from eastern Aquarius. (A finder chart and viewing information appear on page 49.)

Neptune

NEPTUNE: NASA / JPL; ADAMS: WORLD HISTORY ARCHIVE / ALAMY STOCK PHOTO and Mathematics at Harvard University) and Sears Cook Walker (of the U.S. Naval Observatory) stirred up additional controversy — and further irritated European astronomers — by finding several pre-discovery sightings of Neptune dating as far back as 1795. Including those sightings in their calculations revealed an unwelcome surprise.

The orbits that both Adams and Le Verrier predicted diverged greatly from Neptune's actual path. Remarkably, the observed positions coincided with the predicted ones for only a few decades around the time of Uranus's conjunction with Neptune in 1822. Had Adams and Le Verrier just been incredibly lucky?

In March 1847, Peirce went so far as to announce to the American Academy of Arts and Sciences:

> *THAT PLANET NEPTUNE IS NOT THE PLANET TO WHICH GEOMETRICAL ANALYSIS HAD DIRECTED THE TELESCOPE: that its orbit is not contained within the limits of space which have been explored by geometers searching for the disturbances; and that its discovery by Galle must be regarded as a happy accident.*

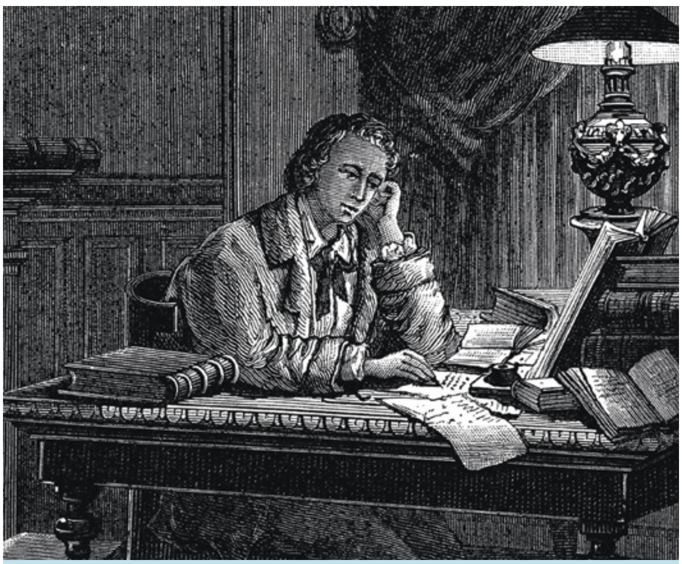
The extremely popular astronomical lectures of Cincinnati Observatory director Ormsby MacKnight Mitchel widely publicized Peirce's blockbuster "happy accident." For example, in New York City in December 1847, Mitchel stated that Le Verrier "occupies so unfortunate a position" because he "probably never will receive the credit due to him, in consequence of the fact that the planet so recently found is not the planet of his analysis."

New Findings and Interpretations

Morton Grosser's influential book *The Discovery of Neptune*, published in 1962, has perpetuated a simplistic story of the planet's discovery for the past six decades. Grosser's book portrayed Airy as a rigid bureaucrat obsessed with order and protocol, who refused to meet with the young, brilliant, bashful scholar Adams, whose genius was not recognized by his superiors. And poor Challis was tarred as a bumbler à la the slapstick Keystone Cops. Even as late as 1979, writer Isaac Asimov framed this as the tale of "Nice Guy Adams and Nasty Guys Challis and Airy" set in the context of a larger England-versus-France competition.

Simplistic narrative aside, important nagging questions remained. Why didn't Adams publish his calculations? Why didn't Airy enlist other British observers to search? But retracing events post-Grosser became impossible because sometime in the late 1960s, Airy's meticulously compiled letters and documents mysteriously disappeared from the Royal Observatory's archives. As a result, conspiracy theories arose portraying the British as trying to "steal" glory for the discovery from the French. Only when the documents were finally recovered in 1998 (from Chile, no less, after the death of the material's absconding historian Olin J. Eggen) were these key primary references once again available for study.

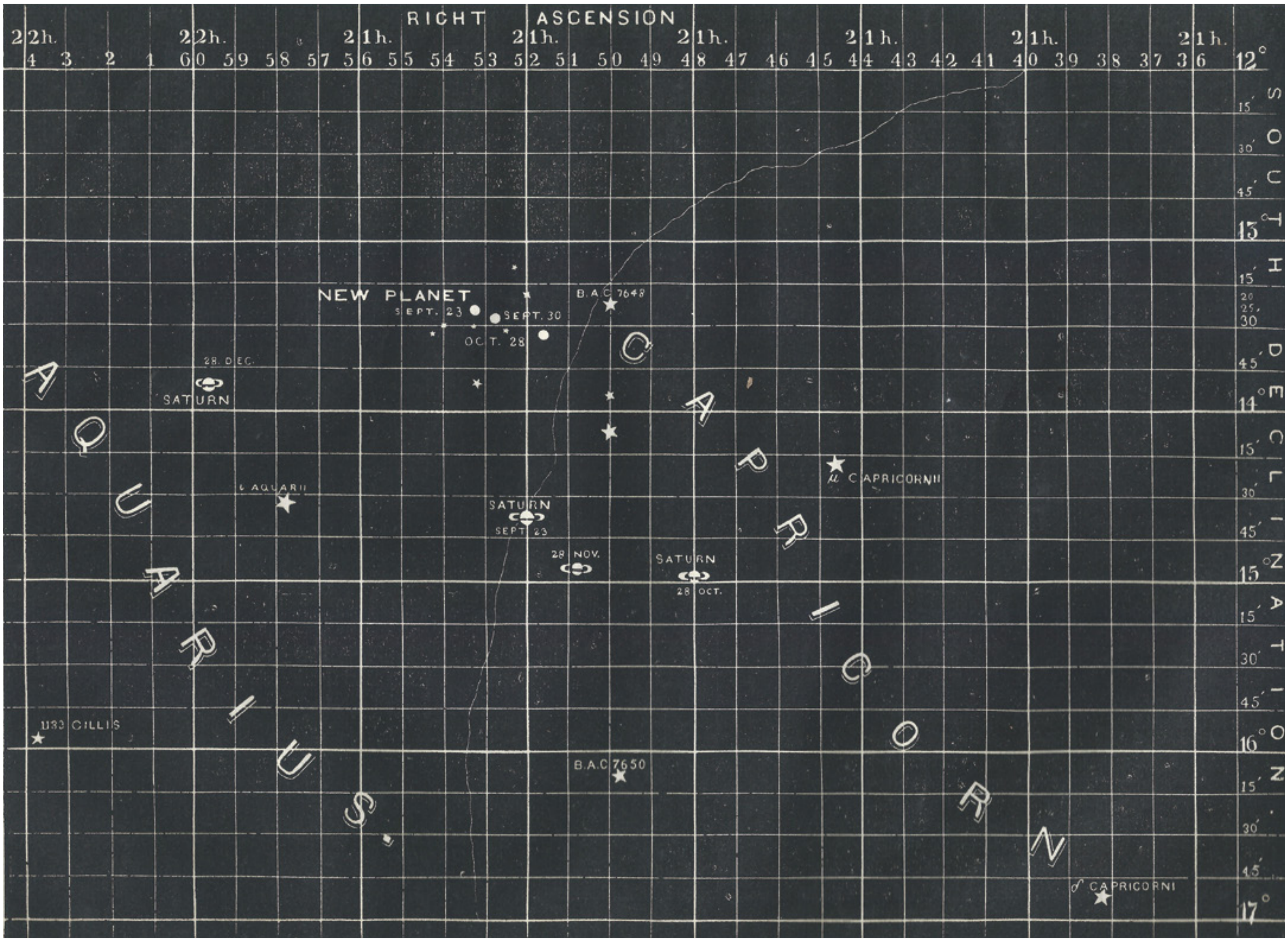
In the meantime, the practice of historical research continued to evolve. Instead of judgmentally viewing events in hindsight, the role of the historian came to be understood as (in the words of the historian Angus Macintyre) "seek[ing] an empathy with the actors of the past . . . by diligently finding all surviving evidence, then immersing ourselves in their



▲ **PLANET AT THE TIP OF HIS PEN** French astronomer and mathematician Urbain Jean Joseph Le Verrier is portrayed at work calculating positions for Neptune in this fanciful engraving (circa 1880). His predictions proved accurate, prompting Paris Observatory director François Arago to proclaim that Le Verrier saw Neptune "at the tip of his pen."

▲ **ASTRONOMER ROYAL** This portrait of George Biddell Airy from his autobiography shows him as he appeared some years after the discovery of Neptune. Airy had a distinguished career and served as the Astronomer Royal from 1835 to 1881.

LE VERRIER: WORLD HISTORY ARCHIVE / ALAMY STOCK PHOTO; AIRY: C. H. JEENS / *AUTOBIOGRAPHY OF SIR GEORGE BIDDELL AIRY* / COURTESY TRUDY E. BELL



▲ **FIRST SIGHTING FROM AMERICA** As soon as news of Neptune crossed the Atlantic in October 1846, Cincinnati Observatory director Ormsby MacKnight Mitchel turned the facility's 11-inch refractor (then the largest in the United States) to the planet's position. He first observed the planet on the night of October 28th, when he saw "a beautiful disk, so well defined that, without any knowledge of a previous discovery, it never would have been passed over for a moment." Mitchel made this map, which was originally published in the November 1846 issue of his journal *The Sidereal Messenger*.

COURTESY TRUDY E. BELL

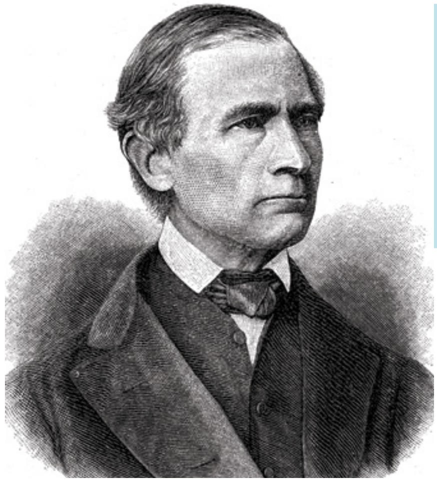
milieu, their circumstances." The object is to understand events *as the people then would have experienced them*, without foreknowledge of the future, as well as to consider the social context in which the people lived and the obstacles they faced. Historians also came to realize that assigning credit for discoveries could be messy, especially when a discovery was not made by a single individual or group from a defined location at a specific moment in time.

Nagging Questions Answered

Taking into account this new approach, together with advances in the mathematics of celestial mechanics and the recent discovery of important new primary historical documents, a dozen international historians have revisited events surrounding the discovery of Neptune. They've assembled a more balanced interpretation of what actually happened and offered answers to some of the story's long-standing questions.

A few key examples highlight just some of the new interpretations of events and motivations. For instance, although the Northumberland Telescope at the Cambridge Observatory was one of the largest refractors in Britain in 1846, larger telescopes existed. One was the equatorially mounted, 13.3-inch refractor of Edward Joshua Cooper at Markree Castle in Ireland. And two even larger, speculum-metal reflectors had gone into operation in 1845: the 24-inch equatorial of William Lassell in Liverpool, and the 72-inch Leviathan meridian instrument of William Parsons, the Third Earl of Rosse, at Birr Castle in Ireland. Why didn't Airy enlist one of these to search for the predicted planet?

One explanation proffered is that since all three were privately owned, Airy might have assumed they were therefore unavailable for such a long-duration project. However, several historians, including Robert W. Smith (University of Alberta), Roger Hutchins (author of *British University Observatories*), and the late Cambridge University historian David Dewhirst,



◀ **AT THE EYEPIECE** Johann Gottfried Galle was the first to lay eyes on Neptune, and also to recognize it for what it was. He could not have done it without the assistance of Heinrich d' Arrest, who knew where to find a just-published, accurate new star chart of the right area of the sky.

identified a symbiotic relationship between the Royal Observatory and Cambridge Observatory. The historians believe that the strong ties between the two institutions prompted Airy to try for a discovery specifically from Cambridge. By the 1840s, specialized mathematical education at Cambridge had come under some attack. It would have been a spectacular confirmation of the university's worth had the presence of the planet been both predicted and visually confirmed by Cambridge men.

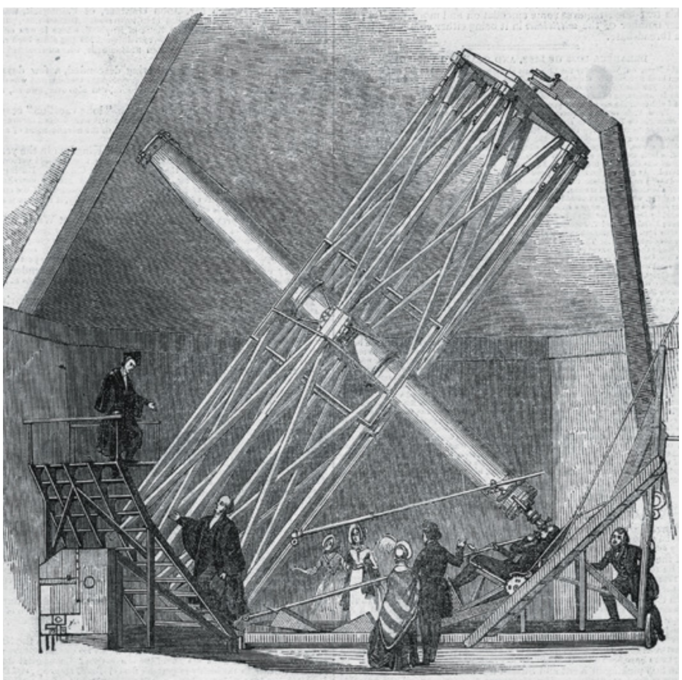
A bigger mystery is why didn't Adams respond to the follow-up queries in Airy's letter of November 5th? According to Grosser, Airy was widely known for answering correspondence right away, so taking two weeks to reply showed the "Astronomer Royal's negative feelings." As a result, Grosser contended, Adams felt "distinctly rebuffed" and never answered the letter "because he felt that Airy was putting him off."

Recent scholarship, however, reveals that both Adams and Airy were working under tremendous pressure. Adams was from a relatively poor working-class family, so tutoring was his only source of income. The demands on his time were so great that the only opportunities he had to work on investigating the wayward motions of Uranus were university vacations. In what little time he had to spare during school terms, he was tasked with calculating comet orbits for Challis.

Airy, too, was extraordinarily busy. In addition to his regular duties as director of the Royal Observatory, he was also interviewing engineers and testing trains in his capacity as Scientific Commissioner of the Rail Gauge Commission. Nonetheless, Airy likely was keenly interested in Adams's efforts, not least of all because he had learned during his European trip the previous month that Le Verrier was working on the Uranus problem. Never mind the highly irregular social faux pas of Adams (who was basically a 26-year-old junior faculty member) dropping in on Britain's most important astronomer without an appointment, but his timing on October 21, 1845, couldn't have been worse. Airy's 42-year-old wife was in her last week of pregnancy with the couple's ninth child — a worrisome time given that all her previous pregnancies had been difficult and dangerous. At the same time, Airy's long-time observatory assistant had just been dismissed for incest, leaving the Royal Observatory short-staffed. November 5th was likely the first moment Airy was free to respond to Adams's note.

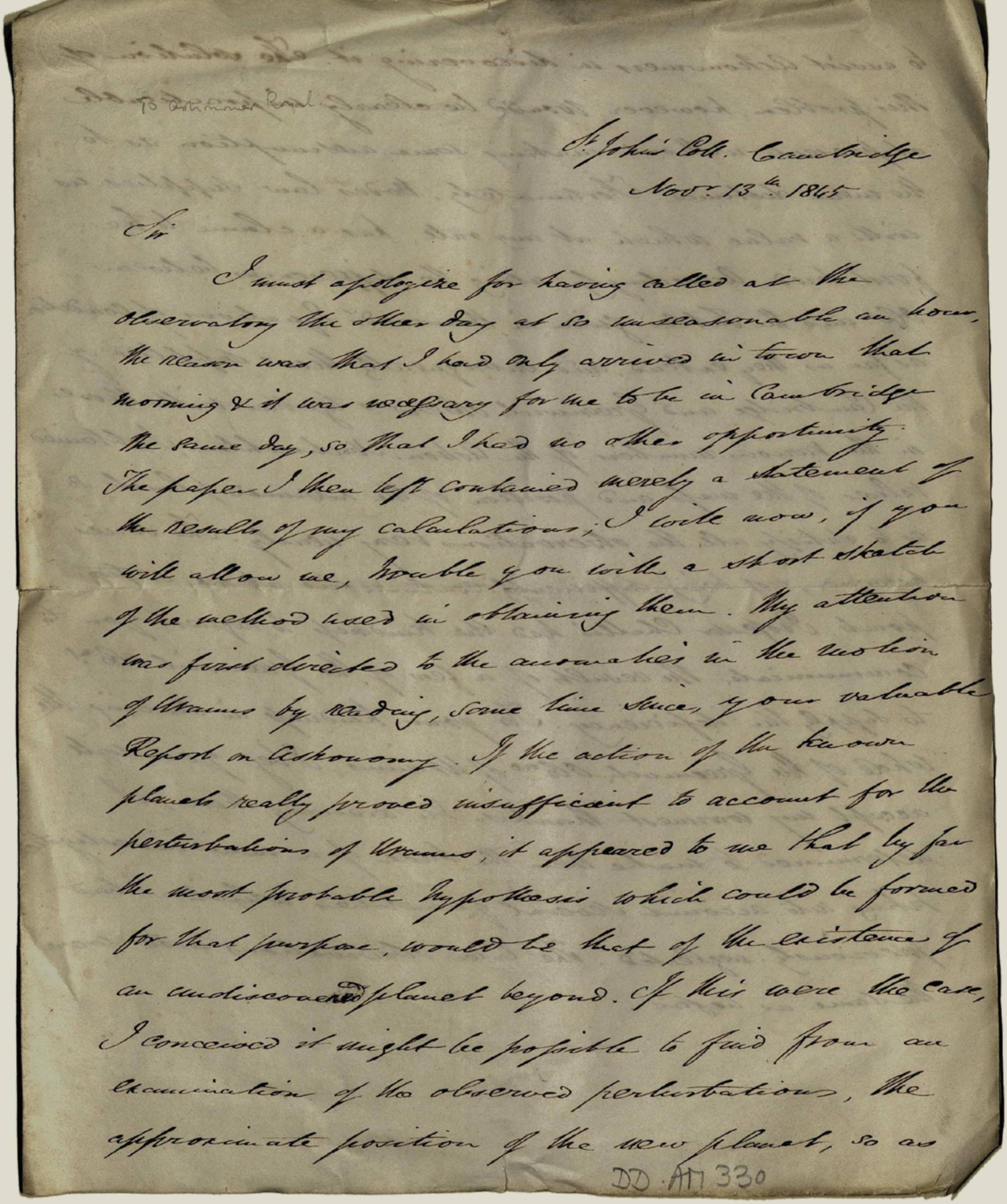
So, if it wasn't a matter of Adams feeling snubbed by the two-week delay, why didn't he respond to Airy's queries? In June 2004, when astronomy historian Craig B. Waff visited the Adams papers at the Cornwall Records Office, he discovered a revelatory, unfinished letter intended for Airy and dated November 13, 1845. In the document, Adams clearly struggled to find the right tone for detailing his methodology to the most important and internationally renowned astronomer in Britain. Adams tried to avoid sounding presumptuous or patronizing to the Astronomer Royal.

But he never mailed his reply. Quite simply, he appears to have dropped the ball. The only explanation Challis offered later was that Adams "experiences also a difficulty, which all young writers feel more or less, in putting into shape and order what he has done, and well done, so as to convey an adequate idea of it to others by writing." Challis always found Adams "more willing to communicate [verbally] than by writing." Furthermore, according to historian William Sheehan, Adams's failure to answer Airy's questions was, in modern terms, "rather like the failure of the author of a scientific paper to respond to the comments of a referee." Regardless, the honest misunderstandings between Adams and Airy had



◀ **ALMOST FAMOUS** The *Illustrated London News* published this rendering of the 11.6-inch (29.5-cm) Northumberland Telescope at the University of Cambridge in 1843. Observer James Challis used this telescope to hunt for Neptune, but because he didn't analyze his data in a timely fashion, he failed to realize he'd recorded sighting the planet twice in August 1846 — a month before Galle and d'Arrest spotted it.

GALLE: HISTORICAL IMAGE COLLECTION BY BILDAGENTUR-ONLINE / ALAMY STOCK PHOTO; NORTHUMBERLAND REFRACTOR: ANTIQUA PRINT GALLERY / ALAMY STOCK PHOTO


To Astronomer Royal

St. Johns Coll. Cambridge
Novr. 13th. 1845

Sir

I must apologize for having called at the observatory the other day at so unseasonable an hour, the reason was that I had only arrived in town that morning & it was necessary for me to be in Cambridge the same day, so that I had no other opportunity. The paper I then left contained merely a statement of the results of my calculations; I write now, if you will allow me, trouble you with a short sketch of the method used in obtaining them. My attention was first directed to the anomalies in the motion of Uranus by reading, some time since, your valuable Report on Astronomy. If the action of the known planets really proved insufficient to account for the perturbations of Uranus, it appeared to me that by far the most probable hypothesis which could be formed for that purpose, would be that of the existence of an undiscovered planet beyond. If this were the case, I conceived it might be possible to find from an examination of the observed perturbations, the approximate position of the new planet, so as

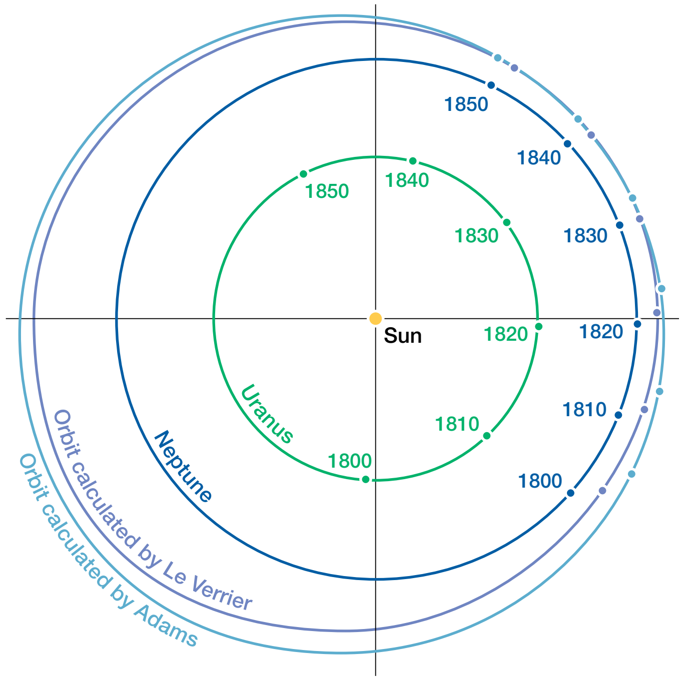
▲ **UNFINISHED BUSINESS** Shown here is the first page of an unsent letter by Adams to Airy, discovered in 2004 by the late historian Craig B. Waff. The document reveals that Adams did attempt to reply to Airy's mathematical queries in November 1845 but left off midway through. He begins with words of contrition: "I must apologize for having called at the observatory the other day at so unseasonable an hour . . ."

the effect of making further correspondence between the two astronomers impossible for nearly a year.

As for the battles over credit for Neptune's discovery, research by historian Robert W. Smith and others reveals that in the 1840s, scientists were already intensely focused on working out ground rules for establishing what, exactly, constitutes a discovery. Was Neptune "discovered" when its existence was mathematically predicted, or only after its presence was verified through a telescope? Were pre-discovery sightings actually themselves discoveries? The idea was emerging that there must be some connection between scientific merit, priority, and publication, but at that time there was no consensus.

A "Happy Accident," Indeed

Amongst everything else surrounding the discovery of Neptune, was the question of this event signifying the moment in which (in the words of the great historian of 19th-century astronomy Agnes Mary Clerke) "the last lingering doubts as to the absolute exactness of the Newtonian Law were dissipated"? Despite the apparent promise of the inverse-perturbation approach pioneered by Le Verrier and Adams, the mathematical feat was never again successfully repeated, though not for lack of trying. This includes Percival Lowell's well-known, fruitless attempts in the late 19th and early 20th centuries to find a "Planet X" more distant than Neptune.



▲ **COINCIDENTAL POSITIONS** The orbits predicted by Adams and Le Verrier for a hypothetical outer planet diverged not only from each other, but also from the actual orbit of Neptune. Remarkably, however, all the orbits approximately coincided for several decades in the early 19th century — just as the hunt for Neptune was underway.

▲ **PLANET CATCHER** Galle and d'Arrest used this magnificent, 9.6-inch Fraunhofer refractor to locate Neptune using positions calculated by Le Verrier. They found the planet after just one hour of searching, slightly more than 1° from the predicted position.

In 1892, mathematician Henri Poincaré published his monumental work *Les Méthodes Nouvelles de la Mécanique Céleste*. It revolutionized understanding and methodology of celestial mechanics, recasting calculations in terms of statistical probabilities, thus sounding the death knell of the Newtonian deterministic clockwork universe. Indeed, because of gravitational resonances among planetary orbits, computational models reveal that planetary positions and velocities fall not only into regions of regular predictable behavior, but also into regions of chaotic, *unpredictable* behavior.

So was the discovery of Neptune indeed just a happy accident? Modern mathematical analysis of Uranus reveals there were actually two solutions to the inverse-perturbation problem. "One solution was the one found by Adams and Le Verrier," concluded Sheehan and mathematician Kenneth Young, "the other is displaced 180 degrees opposite. The fact that Adams and Le Verrier found the correct solution (the one actually occupied by the planet at the time) would seem to be rather fortuitous."

So, the solar system's outermost major planet was found — not only through the efforts of a remarkable group of astronomers, but also because of extraordinary good fortune.

■ Contributing Editor **TRUDY E. BELL** is coeditor of *Neptune: From Grand Discovery to a World Revealed* (Springer, 2021). She wishes to thank historians Roger Hutchins, Carolyn Kennett, James Lequeux, Robert W. Smith, William Sheehan, and Brian Sheen for their helpful input to this article.

BERLIN OBSERVATORY TELESCOPE: DEUTSCHES MUSEUM; ORBIT: GREGG DINDERMAN / S&T; SOURCE: WILLIAM SHEEHAN / PUBLIC DOMAIN

◀ ALL-SKY MONITOR

Starlight Xpress announces the Oculus PRO All-Sky Camera (£995). This self-contained sky-monitoring system is based around the super-sensitive ICX825AL Sony ExView II interline CCD, with a 1,392 × 1,040 array of 6.45-micron-square pixels. It comes with your choice of lenses — a 1.55-mm f/2 fisheye lens with a 180-degree field of view that sees your entire sky all the way to the horizon, or a 2.55-mm f/1.2 lens with a 150-degree field of view. The system is housed in a polycarbonate dome enclosure measuring 150 × 95 millimeters (6 × 3¾ inches) that can be mounted on a post. It includes a built-in dew detection and prevention system that only heats the clear dome without increasing thermal noise in the detector itself. The camera connects via a USB 2.0 Mini-B cable and downloads a full-frame image in 0.6 seconds. The unit is powered through a 12-volt adapter with a 2.1-mm connector on its base.

Starlight Xpress
Unit 3, Brooklands Farm, Bottle Ln., Binfield, Berkshire, UK RG42 5QX
+44 (0)1184026898; sxccd.com

◀ COMPACT MOUNT

iOptron unveils its first mount to incorporate the latest drive technology: the HEM27 (starting at $1,888 for the head only). This lightweight, high-payload drive features the manufacturer's revolutionary hybrid-harmonic-drive system. The mount head weighs just 3.7 kg (8.2 lb) yet boasts a load capacity of 13½ kg without the need of cumbersome counterweights and shafts. The mount combines a harmonic drive in its RA axis with a worm-and-belt system on the DEC axis for precision slewing and tracking throughout the sky. The HEM27 includes an electronic-friction-brake system and power-down memory to safely stop and resume tracking after an abrupt power loss — no need to realign after a restart. The mount is controlled with iOptron's powerful Go2Nova hand paddle, which includes more than 212,000 objects in its internal database. Its black, CNC-machined casing encloses all wiring, and telescopes are secured with a dual Losmandy/Vixen-style saddle plate. Each purchase includes a soft carry case and a limited two-year warranty.

iOptron
6F Gill Street, Woburn, MA 01801
781-569-0200; ioptron.com

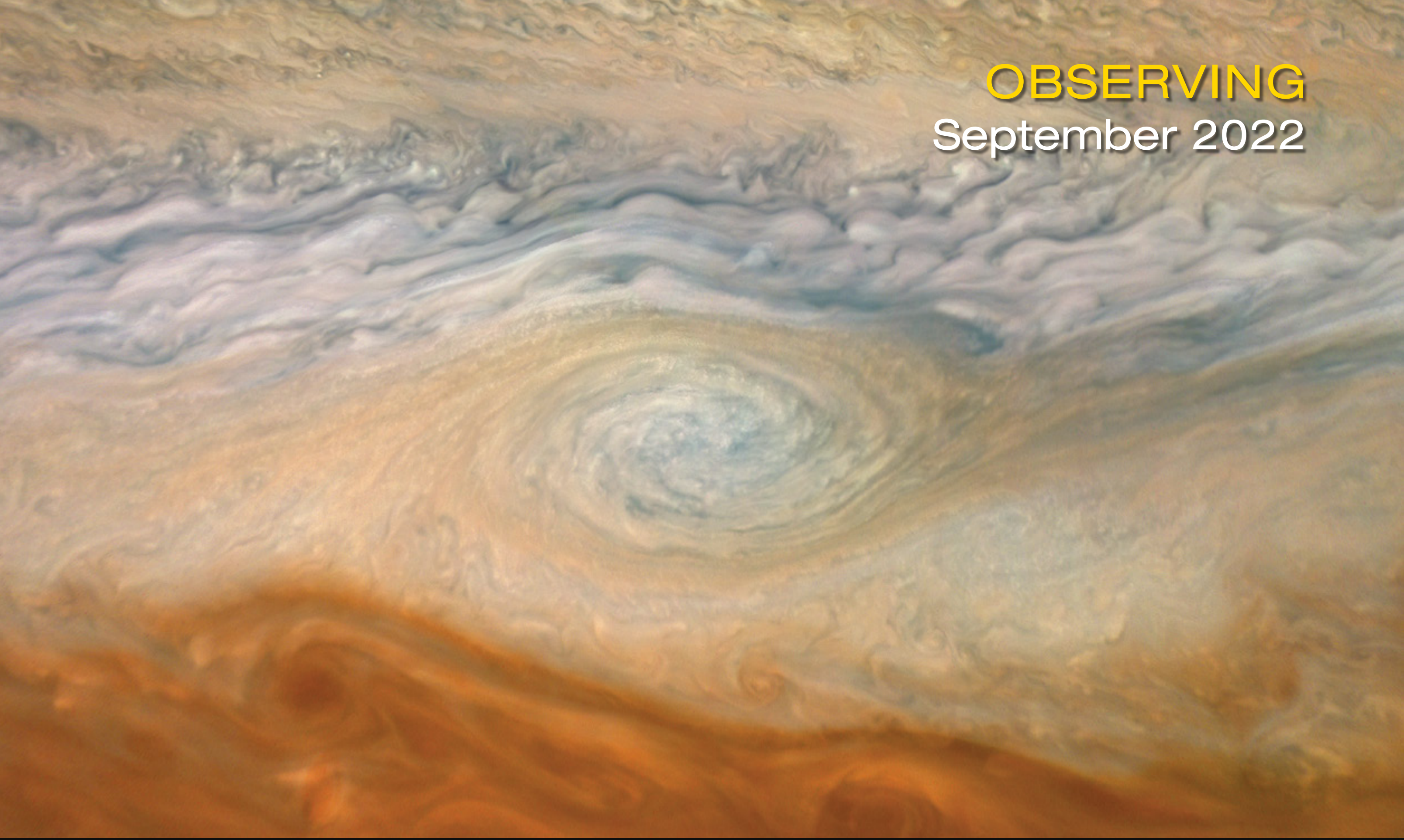
◀ GO TO SKY TRACKER

Sky-Watcher USA announces the Star Adventurer GTi (starting at $640 for the head only). This lightweight Go To mount is designed for both small-scope visual use and photography alike. Its mini-DC servo motors are capable of tracking at sidereal, lunar, and solar speeds, and the unit can bear a load of up to 11 lb. Its counterweight shaft includes two positions to permit equatorial tracking all the way from the equator to 70° in both the Northern and Southern Hemispheres. The Sky Adventurer GTi is powered by 8 AA batteries and controlled via the *SynScan Pro* smartphone app for Apple and Android devices, or through an optional SynScan Go To hand paddle. The mount also accepts ST4-compatible autoguiders and can directly connect and control most DSLR cameras through its SNAP port. The mount attaches to tripods and piers using a ⅜-inch threaded port on its base and accepts Vixen-style dovetail mounting bars. Each purchase includes an illuminated polar alignment scope and a 2¼-kg (5-lb) counterweight.

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

OBSERVING
September 2022



3 DUSK: Look to the south-southwest to see the first-quarter Moon about 5° left or upper left of the Scorpion's smoldering heart, Antares.

7 MORNING: High in the east, Mars and Aldebaran form a pretty pair; around 4° separates planet from star (see page 46).

7 EVENING: The waxing gibbous Moon gleams above the southern horizon about 7° lower right of Saturn.

9 EVENING: The almost-full Moon hangs nearly midway between Saturn and Jupiter. Look toward the southeast to admire this sight.

11 MORNING: It's Jupiter's turn for a lunar visit. The Moon sits less than 5° below the gas giant in the southwest.

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

15 EVENING: The Moon rises in the east-northeast, preceded by the Pleiades and trailed by Mars. The threesome form a pretty picture as they rise higher in the sky.

16 EVENING: The Moon, Mars, Aldebaran, and the tip of the Bull's western horn, Beta (β) Taurii (also known as Elnath) are arranged in a pleasing line above the east-northeastern horizon.

17 EVENING: Algol shines at minimum brightness for roughly two hours centered at 9:31 p.m. EDT.

20 DAWN: Look high in the east to see the waning crescent Moon in Gemini, less than 3° below Pollux.

21 DAWN: The Moon visits Cancer and sits a bit more than 3° upper left of the Beehive Cluster (M44).

22 AUTUMN BEGINS in the Northern Hemisphere at the equinox, 9:04 p.m. EDT.

23 DAWN: The thin lunar crescent and Regulus rise in the east-northeast, with 4½° separating the pair. Catch this sight before sunup.

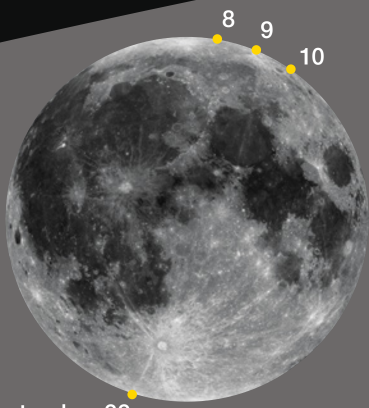
26 ALL NIGHT: Magnificent Jupiter arrives at opposition (see page 48). The gas giant is also at its closest to Earth since October 1963, at a distance of about 591 million kilometers (367 million miles).

30 DUSK: We conclude the month with the Moon back in Scorpius — this time it's around 1½° above Antares. Follow the duo as they sink toward the southwestern horizon.

— **DIANA HANNIKAINEN**

Majestic Jupiter will be at opposition toward the end of this month. This JunoCam image from July 2019 shows White Spot Z, one of several long-lived storms in the planet's atmosphere.

SEPTEMBER 2022 OBSERVING
Lunar Almanac
Northern Hemisphere Sky Chart



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

MOON PHASES

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

FIRST QUARTER
September 3
18:08 UT

FULL MOON
September 10
09:59 UT

LAST QUARTER
September 17
21:52 UT

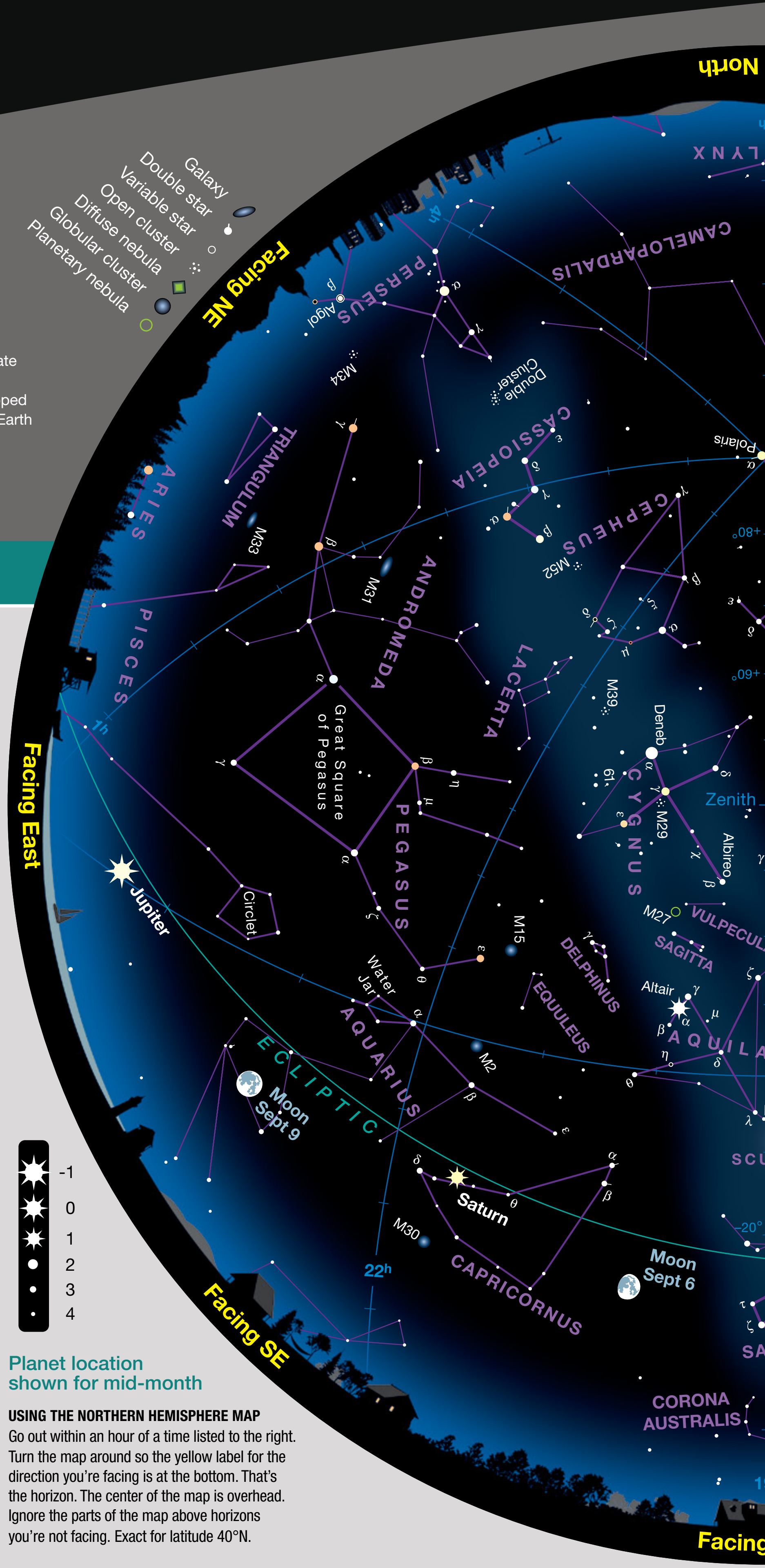
NEW MOON
September 25
21:55 UT

DISTANCES

Perigee	September 7, 18^h UT
364,494 km	Diameter 32′ 47″
Apogee	September 19, 15^h UT
404,555 km	Diameter 29′ 32″

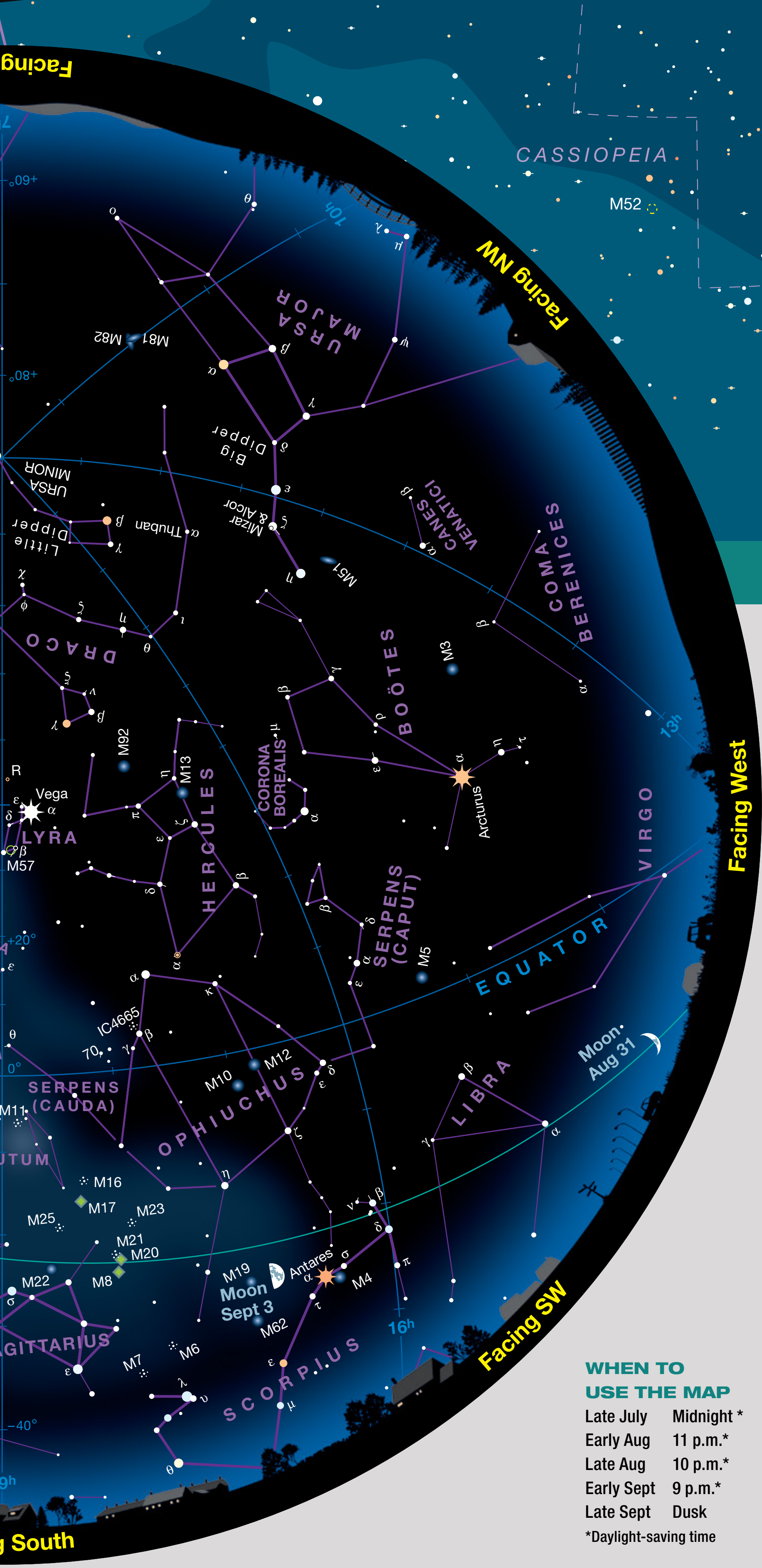
FAVORABLE LIBRATIONS

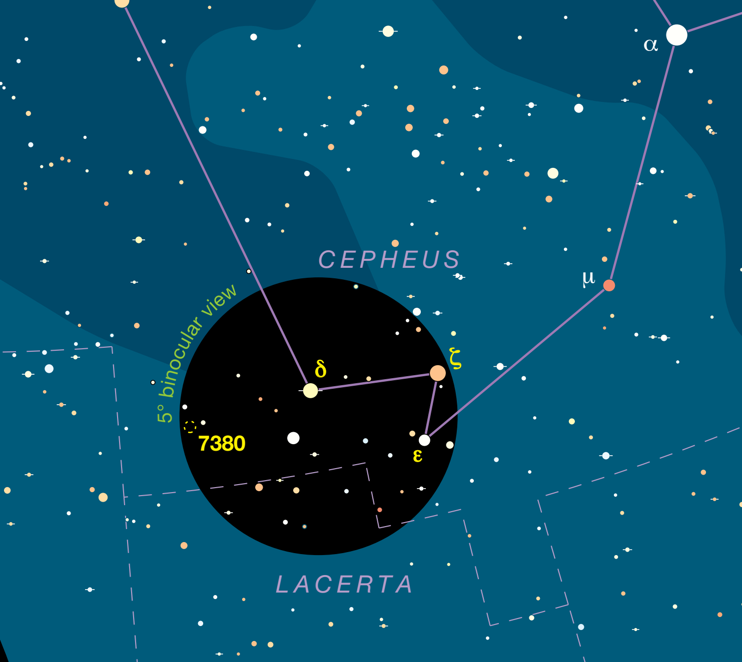
- Byrd Crater — September 8
- Cusanus Crater — September 9
- Mare Humboldtianum — September 10
- Bailly Crater — September 22



Planet location shown for mid-month

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





Binocular Highlight by Mathew Wedel

In the Footsteps of Giants

Delta (δ) Cephei is one of the more interesting stars in the constellation Cepheus, the King. This massive furnace is the prototype Cepheid variable star. Its core has run out of hydrogen and must now fuse heavier elements. Delta Cephei pulsates, roughly doubling in brightness approximately every 5 days and 9 hours, from magnitude 4.4 to 3.5. Although Delta's cycle can be followed without optics, binoculars make the task much easier — especially if light pollution interferes.

Tracking Delta Cephei's fluctuations is straightforward, thanks to a couple of comparably bright neighbors. At magnitude 3.3, **Zeta (ζ) Cephei** approximates Delta at its brightest, and 4.2-magnitude **Epsilon (ε) Cephei** is close to Delta at its dimmest. All three stars fit comfortably into a 3° field. Zeta, a true red giant, looks more distinctly yellow or orange to my eyes than either Delta or Epsilon. Delta has one more trick up its sleeve: A 6.3-magnitude companion, HD 213307, sits 41″ away. Theoretically you could split them at 10×, but I need 15× for this uneven pair.

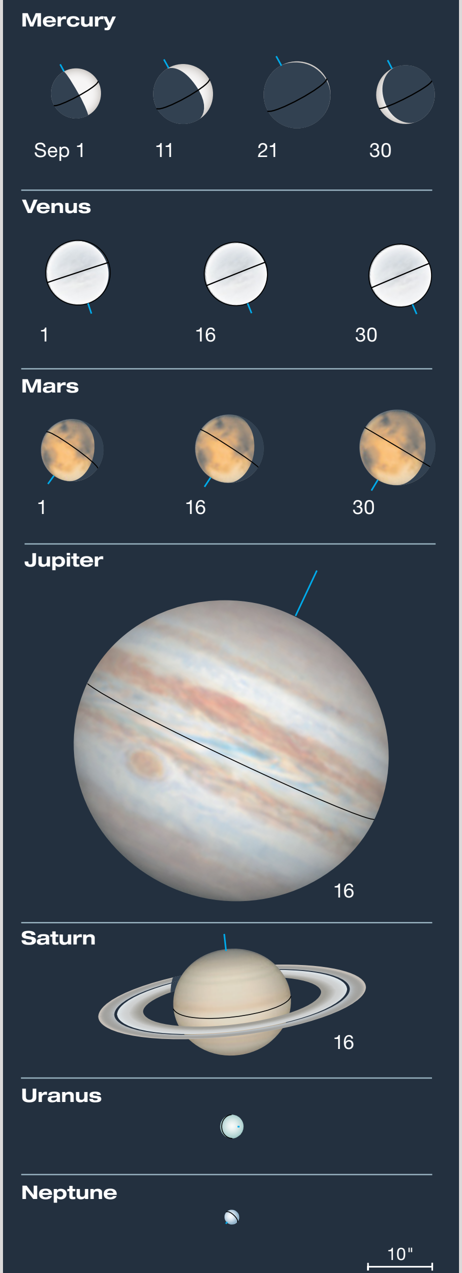
While you're in the area, have a look at the nearby open cluster **NGC 7380**. At a distance of roughly 6,500 light-years, it's about eight times farther from us than Delta Cephei is. At magnitude 7.2 and sprawling across a third of a degree, NGC 7380 can be challenging to pull out of the rich Milky Way star field. The first person to manage that feat was Caroline Herschel, who discovered the cluster in 1787, only three years after John Goodricke discovered that Delta Cephei was a variable star. Grab your binoculars and follow in their footsteps.

■ **MATT WEDEL** has discovered countless celestial wonders. Of course, he wasn't the first to discover anything, but that hasn't dented his enjoyment.

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



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

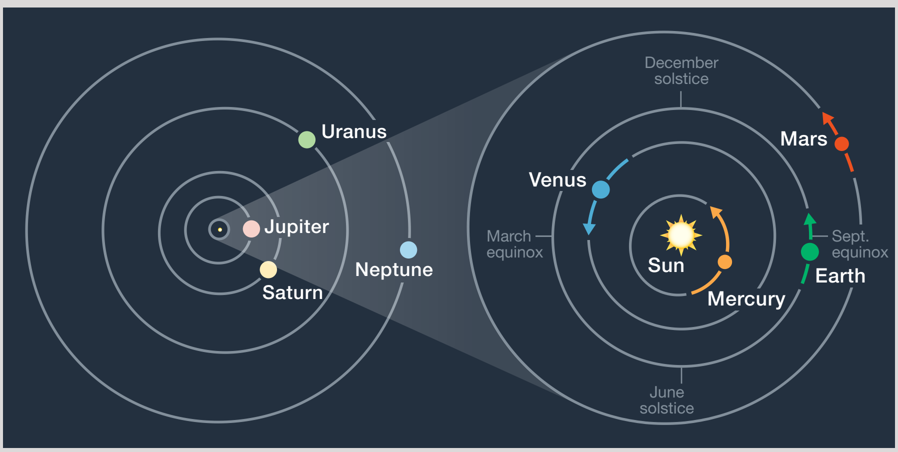
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during September. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** is lost in the Sun's glare all month • **Venus** visible low at dawn all month • **Mars** rises in the evening and is visible until dawn • **Jupiter** is visible all night • **Saturn** is visible at dusk and sets before dawn.

September Sun & Planets

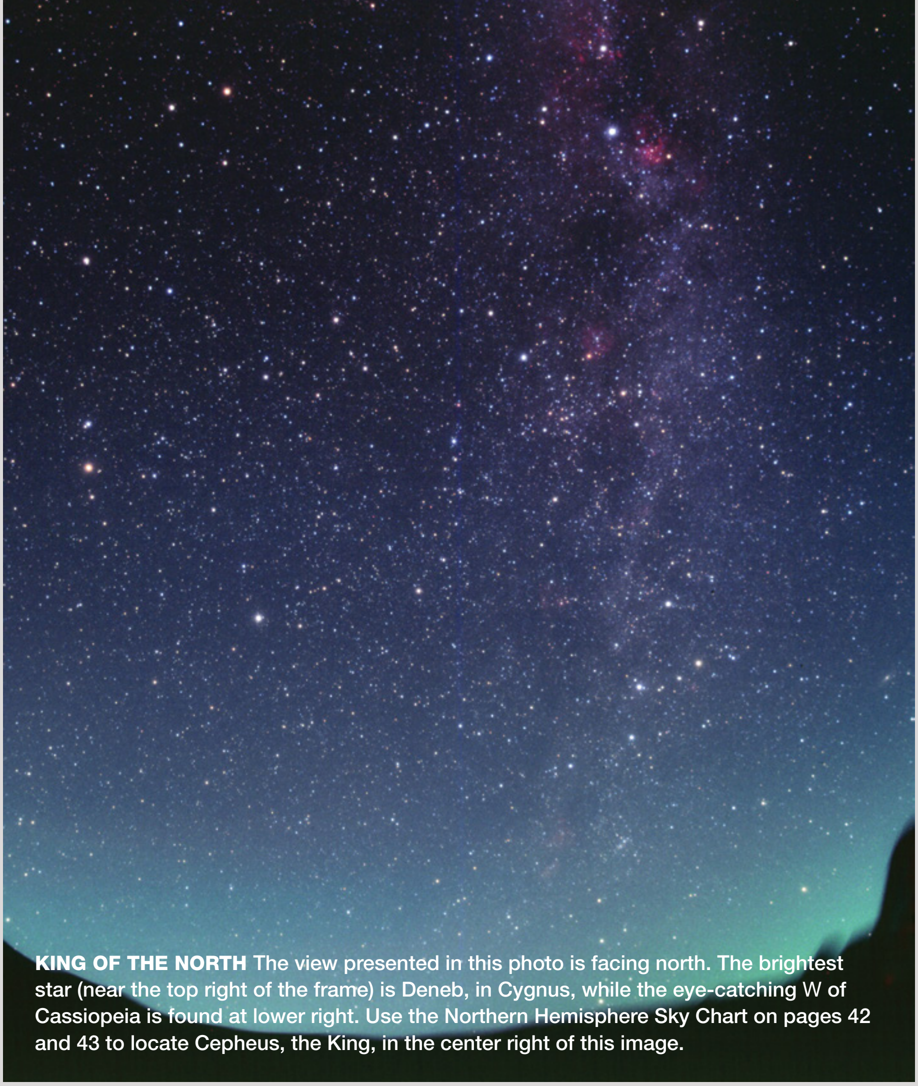
	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$10^{h}\,39.6^{m}$	+8° 29′	—	–26.8	31′ 42″	—	1.009
	30	$12^{h}\,23.9^{m}$	–2° 35′	—	–26.8	31′ 56″	—	1.002
Mercury	1	$12^{h}\,13.6^{m}$	–4° 39′	27° Ev	+0.3	7.8″	46%	0.863
	11	$12^{h}\,25.1^{m}$	–7° 08′	21° Ev	+1.1	9.3″	24%	0.720
	21	$12^{h}\,03.3^{m}$	–4° 05′	6° Ev	+4.6	10.4″	2%	0.645
	30	$11^{h}\,38.3^{m}$	+1° 36′	12° Mo	+1.9	9.1″	12%	0.736
Venus	1	$9^{h}\,48.9^{m}$	+14° 23′	14° Mo	–3.9	10.1″	97%	1.658
	11	$10^{h}\,36.5^{m}$	+10° 12′	11° Mo	–3.9	9.9″	98%	1.680
	21	$11^{h}\,23.0^{m}$	+5° 32′	8° Mo	–3.9	9.8″	99%	1.697
	30	$12^{h}\,04.2^{m}$	+1° 06′	6° Mo	–3.9	9.8″	99%	1.708
Mars	1	$4^{h}\,18.5^{m}$	+20° 04′	92° Mo	–0.1	9.8″	85%	0.959
	16	$4^{h}\,49.9^{m}$	+21° 26′	99° Mo	–0.3	10.7″	86%	0.872
	30	$5^{h}\,14.2^{m}$	+22° 21′	107° Mo	–0.6	11.8″	87%	0.790
Jupiter	1	$0^{h}\,26.6^{m}$	+1° 09′	152° Mo	–2.9	48.7″	100%	4.045
	30	$0^{h}\,13.4^{m}$	–0° 19′	176° Ev	–2.9	49.8″	100%	3.955
Saturn	1	$21^{h}\,32.6^{m}$	–15° 58′	162° Ev	+0.3	18.7″	100%	8.900
	30	$21^{h}\,26.3^{m}$	–16° 28′	132° Ev	+0.5	18.1″	100%	9.158
Uranus	16	$3^{h}\,04.2^{m}$	+16° 57′	124° Mo	+5.7	3.7″	100%	19.100
Neptune	16	$23^{h}\,38.9^{m}$	–3° 37′	178° Mo	+7.8	2.4″	100%	28.910

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



Visiting the House of Cepheus

This circumpolar constellation is full of fascinating finds.



KING OF THE NORTH The view presented in this photo is facing north. The brightest star (near the top right of the frame) is Deneb, in Cygnus, while the eye-catching W of Cassiopeia is found at lower right. Use the Northern Hemisphere Sky Chart on pages 42 and 43 to locate Cepheus, the King, in the center right of this image.

AKIRA FUJII

On September evenings there's a temptation to begin a night of stargazing with the bright constellations of summer that still linger near the meridian. But let's not be hasty. If you turn your attention toward the north, your eye will doubtlessly be drawn to the distinctive W of Cassiopeia, the Queen, rising in the northeast. But it's her mythological consort, Cepheus, the King, that's positioned higher in the evening sky. And although Cepheus is much dimmer, it's a truly varied and fascinating constellation.

My favorite path to Cepheus at this time of year is via the bright Cygnus Milky Way. In last month's column I mentioned the big, dark notch in the Milky Way centered about 7° north-northeast of Deneb. If you proceed northward from this feature, you'll arrive at a dim, little triangle of stars that includes the outstandingly important variable star, Delta (δ) Cephei. (More about Delta later.) This triangle lies almost exactly halfway between Deneb and Cassiopeia and is only a small part of Cepheus.

The basic pattern of Cepheus resembles a simple house with a steep roof. The roof's peak is marked by 3.2-magnitude Gamma (γ) Cephei, also known as Errai. In 1988 Gamma became famous as the first star around which an exoplanet was detected. However, the existence of that planet was only confirmed in 2002 — and by then, dozens of other worlds had been found orbiting other stars.

But Errai has another claim to fame. With the exception of Polaris, it's the brightest star within 15° of the north celestial pole. Thanks to the precession of Earth's axis, it will become the next major North Star, shining near the celestial pole about 2,000 years from now.

The rest of the main pattern of Cepheus is the square of the house itself. At its northwestern corner is Beta Cephei, commonly known as Alfirk. It shines at about the same brightness as Errai, as does Zeta (ζ) Cephei, which occupies the house's southeastern corner. Holding down the northeast corner is 3.5-magnitude Iota (ι) Cephei, which is by a very slight margin the house's faintest star. At the opposite (southwestern) corner is the constellation's brightest star, 2.5-magnitude Alpha (α) Cephei, also known as Alderamin.

The southeastern corner is notable not just for Zeta, but also for Epsilon (ε) and Delta — the two other stars that join Zeta to complete the compact triangle mentioned earlier. Delta is well known as the archetype of the Cepheid class of variable stars. Remarkably, the length of a Cepheid's period is proportional to its luminosity — the longer the period, the more luminous the star. First noted by Henrietta Swan Leavitt, this period-luminosity relation makes Cepheids crucial yardsticks for measuring distances (*S&T:* Dec. 2021, p. 12). Delta Cephei itself dims from 3.5 to 4.4 in about four days, then returns to maximum again in about a day and a half.

Another notable variable star in Cepheus is the vast, cool supergiant Mu (μ) Cephei. Its brightness ranges typically from about 3.9 to 4.5, with extremes of 3.4 and 5.1. The changes are irregular over an average period of 835 days. Binoculars reveal Mu's very red hue, which earned it the title of Herschel's Garnet Star.

■ FRED SCHAAF is now beginning his 17th year teaching astronomy at Rowan University in Glassboro, New Jersey.

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

Plenty of Pairings

The Moon, Mars, and Jupiter steal the show.

MONDAY, SEPTEMBER 5

Venus, the glorious Morning Star, is finally nearing the end of its current reign. The brilliant planet first appeared in the dusk sky in January and will hang on until mid-October, but it's clearly losing ground each passing day. At the start of September, Venus precedes the Sun by 70 minutes, but that figure drops to just 30 minutes by month's end.

On the morning of the 5th, Venus rises alongside **Regulus**, the brightest star in the constellation Leo. The two objects are separated by less than 1°, but the brightness contrast between them is extreme. Venus is a beacon of magnitude –3.9 next to the 1.4-magnitude glint of Regulus — that's a 132× difference! Seek out a viewing location with a relatively unobstructed east-northeastern horizon and begin looking for Regulus shortly after Venus pops up. Because the pair appear during brightening twilight, don't be surprised if you need binoculars to fish Regulus out from the muck and the glare. Once you succeed with optics, try with your eyes alone. You might just spot the star looking like a little satellite of Venus.

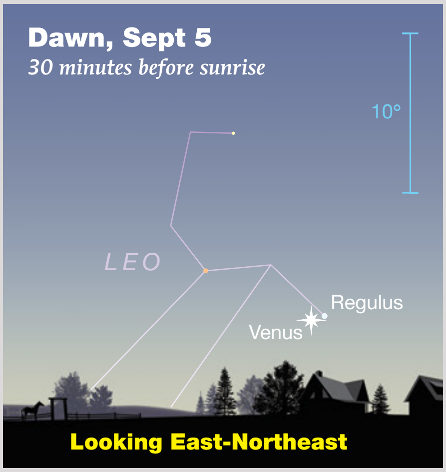
WEDNESDAY, SEPTEMBER 7

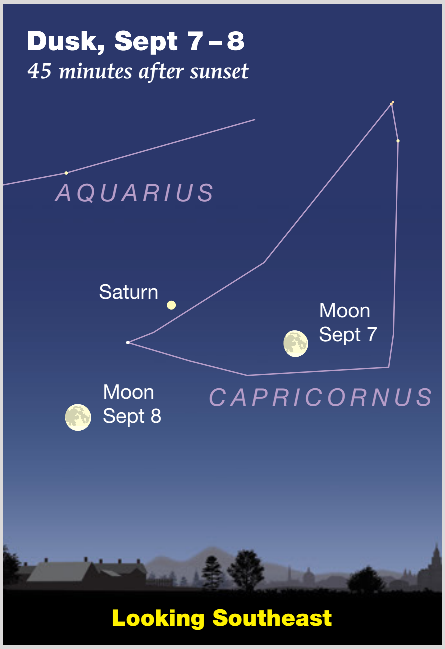
Mars has been slowly creeping up on **Aldebaran** over the past several weeks, and this morning it's at its closest to the star, just a little less than 4½° away. But picking this specific date is really an exercise in hair splitting. Mars has been within 4½° of Aldebaran since the morning of the 5th and will remain so until the 10th. The star and the planet are similarly orange-hued and comparably bright, with Mars shining at magnitude –0.2 compared with Aldebaran's +0.9. That's a big enough difference that you should be able to tell Mars is brighter even with a casual glance. And since you're up before dawn to take in this conjunction, you can't fail to notice the other winter-sky luminaries currently climbing to the meridian. Indeed, Mars's eastward drift has now carried it into the Winter Hexagon — a strikingly arrayed collection of first-magnitude stars. Shift your gaze westward and you'll spot Jupiter, which outshines Mars and all the Hexagon's stars. And if you wait long enough this morning, you'll see the pretty scene completed by Venus, low in the east-northeast.

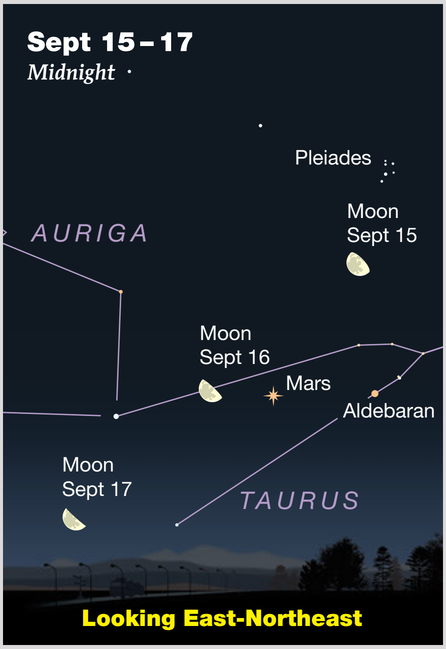
SUNDAY, SEPTEMBER 11

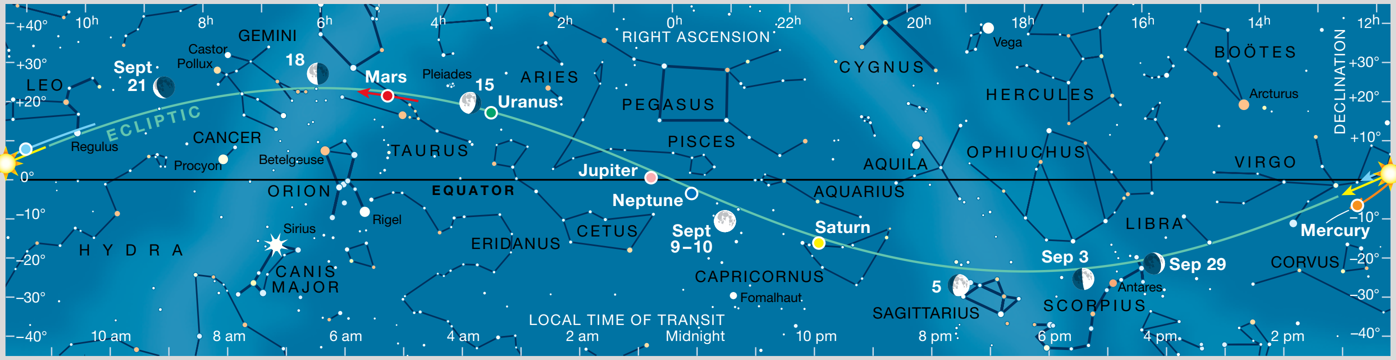
So far this month it's the early risers who are getting all the breaks. And so it is with this predawn pairing of **Jupiter** and the waning gibbous **Moon**. As the duo descend toward the west-

▼▶ 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.



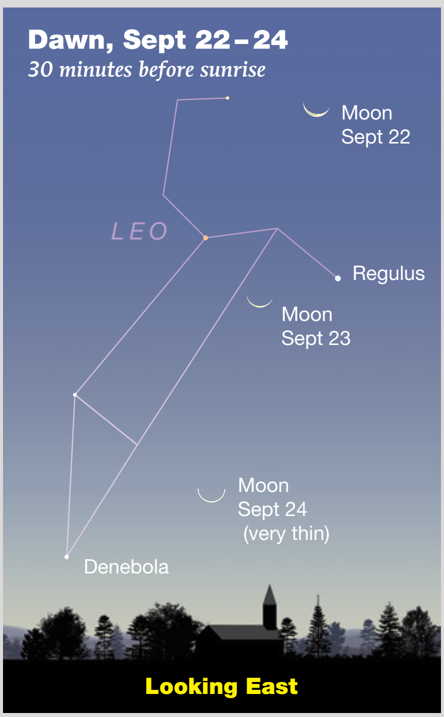






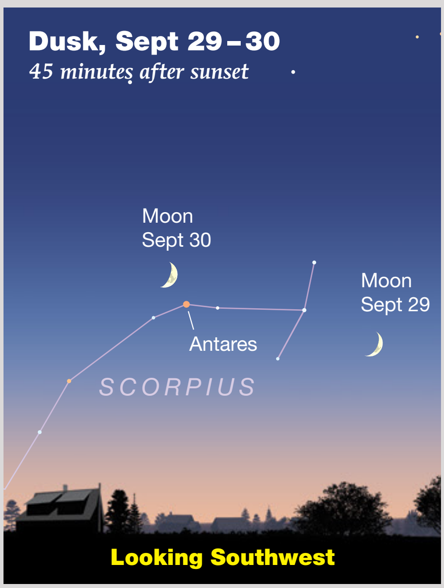
▲ The Sun and planets are positioned for mid-September; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of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

southwestern horizon at dawn, they're separated by some 4½°. The Moon is only a day past full, but if there's one planet that can hold its own against a nearly full Moon, it's Jupiter. (Venus never encounters the full Moon, so it's out of the running.) On this particular occasion Big Jove is only two weeks away from opposition (see page 48) and shines near its brightest at magnitude –2.9. Jupiter's proximity to the full Moon is another clue that the planet is near opposition. If you're *really* not a morning person, you can wait until this evening to see the Moon and Jupiter rise together, albeit now separated by 6°.



FRIDAY, SEPTEMBER 16

Both the **Moon** and **Mars** are travelling eastward but at radically different rates. Right now, the Red Planet is advancing a little less than ½° per day (roughly one Moon diameter per day, as it happens), while the Moon covers that same span in less than one hour. Since the 7th, Mars has travelled past Aldebaran and the Hyades, while the Moon has zipped along the zodiac from Capricornus, through Aquarius, Pisces, and Aries, all the way to Taurus, where it now joins Mars. On the 16th they rise together late in the evening with less than 4° between them. This is the closest Moon-planet pairing of the month for observers in the Americas, so it's definitely worth a look. A little later — as the 16th transitions into the 17th — the Moon's motion carries it just a bit farther east, and it lines up nicely with Mars and Aldebaran for a showy three-in-a-row sight. The symmetry isn't perfect, however. Mars is now more than 4° from the Moon but nearly 6½° from Aldebaran. Still, it's a lovely naked-eye sight.

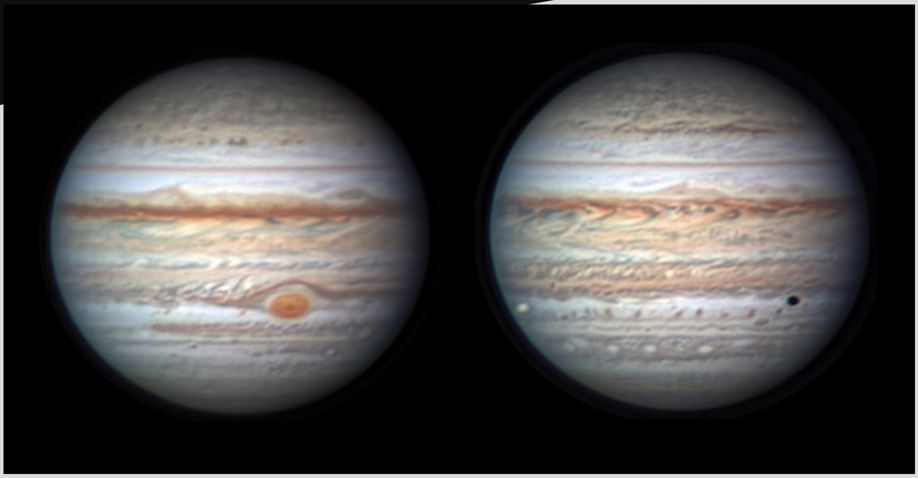


FRIDAY, SEPTEMBER 30

Finally, an event for the after-dinner crowd. Have a look toward the south-southwest as darkness falls to enjoy the waxing crescent **Moon** paired up with orangey **Antares**, the heart of Scorpius. I always think of Scorpius as *the* summer constellation. Unlike Cygnus, for example, which arrives in the evening sky early in spring and hangs around until mid-winter, Scorpius is with us only for a few months and reaches its prime in July.

With the equinox occurring on September 22nd, summer is now officially over, but sighting the Moon 1½° from Antares is a fine way to bid that fair-weather season farewell. Try to catch the pair in binoculars at dusk before the sky loses its deep blue color — that'll make Antares appear even more richly orange. By the time the Moon swings around and returns to the early evening sky in late October, Antares will be near the horizon and lost in a wash of bright twilight.

■ Consulting Editor **GARY SERONIK** keeps an eye on the sky and tries to make summer last as long as possible.



◀ Jupiter presents two feature-rich hemispheres in this pair of photos made on May 11th (left) and May 12th. At left, the Great Red Spot is prominent, while oval BA appears close to the right (west) limb below and right of the GRS. In the other image, Europa and its shadow are transiting the planet. North is up.

A New, Old Jupiter

September is a good time to explore the solar system's biggest planet.

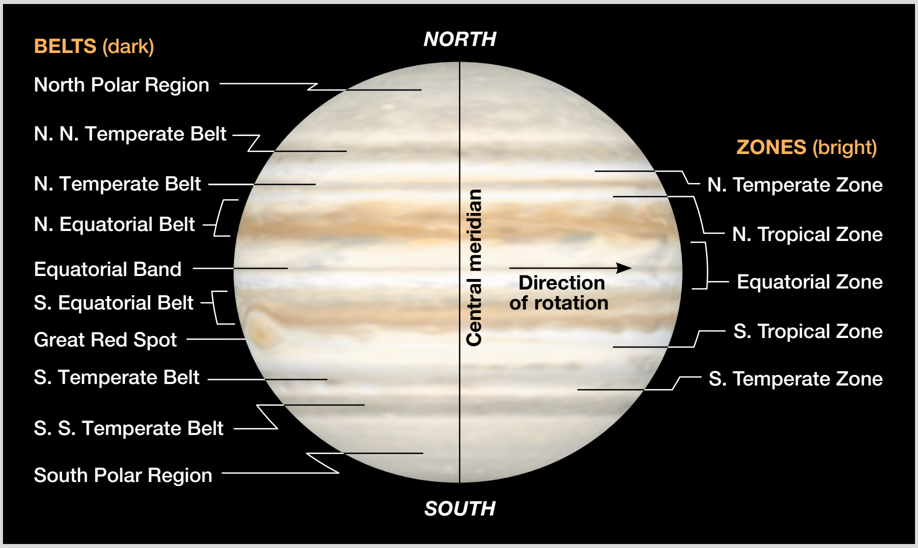
Jupiter reaches opposition this year on September 26th, when it sits astride the celestial equator in Pisces, shines at magnitude –2.9, and presents a disk 49.9″ across. It's also unusually close this year. That's because the planet will be at *perihelion* (nearest to the Sun) less than four months after opposition. As a result, on the 26th Jupiter beams from a distance of just 591 million kilometers (367 million miles). To find a closer opposition, you have to go back to October 8, 1963. And the planet won't be this near again until October 7, 2129 — 107 years into the future!

NASA's Juno mission has enhanced our understanding of Jupiter in recent years. We now know that whirling, continent-size storms crowd the planet's polar regions like revelers at a packed rock concert. Powerful, east-to-west and west-to-east *zonal winds* define the planet's belts and zones, which extend thousands of kilometers deep into the Jovian atmosphere. Swoop down into those clouds and you'll be pelted by water-and-ammonia-rich mushballs similar to semisolid hail. The Great Red Spot goes deep as well, with roots that burrow down more than 300 km.

Jupiter's core isn't the compact sphere depicted in older textbooks either. Rather, it's shockingly large, with a diameter half that of the entire planet. And instead of a symmetrical, dipolar magnetic field like Earth's, Jupiter's field lines sprout from multiple locations. Its north magnetic pole is spread across a band positioned south of the rotational north pole, and there's also a separate, wayward "pole" just south of the equator, dubbed the Great Blue Spot. Its south magnetic pole, on the other hand, is exactly where it should be.

Naturally, none of these Juno discoveries is visible in backyard telescopes save perhaps for glimpses of those big storms, but information always informs what we see at the eyepiece — and there's no planet more satisfying visually than Jupiter. Its disk is striped with multiple dark belts and bright zones that define descending and ascending cloud layers, respectively. The easiest to see are the North and South Equatorial Belts that sit either side of the equator. This apparition, the North Equatorial Belt may well be the darker and redder of the two belts. Watch for gray-blue festoons that resemble garlands extending from either belt into the pale Equatorial Zone.

Depending on seeing conditions, the planet's ever-changing weather, and which side is viewable, you may see more than a dozen belts and zones. After the equatorial belts, try for the broad South Tropical Zone, which is bordered by the South Temperate Belt. Similarly, you should be able to make out the narrow North Temperate Belt as well.



◀ Jupiter's clouds are segregated into parallel dark belts and bright zones. Features move from east (following) to west (preceding). The planet's rapid rotation (a little less than 10 hours) flattens its disk into a slight oval — an effect readily seen even in small telescopes. North is up in this diagram.

JUPITER PAIR: CHRISTOPHER GO; JUPITER BELT DIAGRAM: S&T

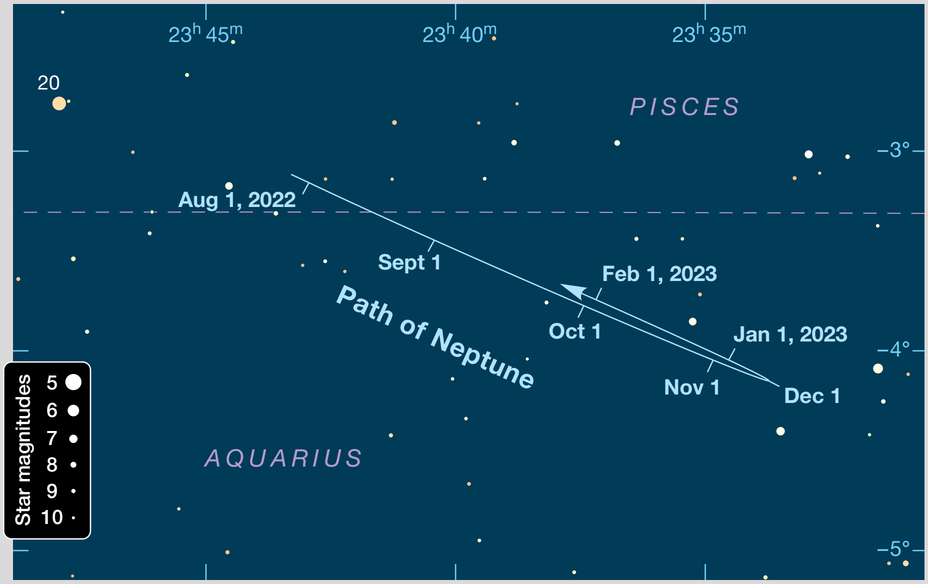
Seeing Jupiter's Great Red Spot (GRS) is always exciting. Although the GRS is smaller now than it's been historically (just 1.3 times Earth's diameter, compared to four times as big in the late 19th century), a 4-inch scope will show it as a slightly flattened, pinkish-orange oval. This majestic vortex is a high-pressure storm cell that's been observed since the 17th century. The Red Spot Hollow, an eyebrow-like cloud that wraps north around the Spot and frames it, is at least as prominent as the GRS itself.

A smaller oval designated BA, in the South Temperate Belt, may also take on a pinkish coloration. It's about one-third as wide as the GRS and overtakes it every two years. To enhance the visibility of orange and red features such as these, try a #80A blue filter.

Although planetary enthusiasts may relish parsing Jupiter's spots, belts, and zones, it's fair to say that most other people find the four bright Galilean moons the planet's most captivating aspect. If you're doing sidewalk astronomy, Io, Europa, Ganymede, and Callisto will likely steal the show. Jupiter interacts with its satellites by occasionally eclipsing them. The moons also transit across the planet's face, accompanied by their shadows, which appear as razor-sharp, black dots. These satellite events are listed on page 51.

If you're up for a naked-eye challenge, how about trying to glimpse the outermost Galilean satellites, Ganymede and Callisto. At opposition, Callisto is magnitude 5.5 and swings up to 10′ east or west of Jupiter. Ganymede, at magnitude 4.4, has a range of 5.5′. Select a time when either moon lies at its maximum elongation, then hide Jupiter behind a roofline or tree and use averted vision. Refer to the Jupiter's Moons diagram on page 51 to find the best times to try. This is a difficult observation to make — I'd love to hear if you succeed. Email me at **nightsky55@gmail.com**.

Neptune and Juno at Their Best

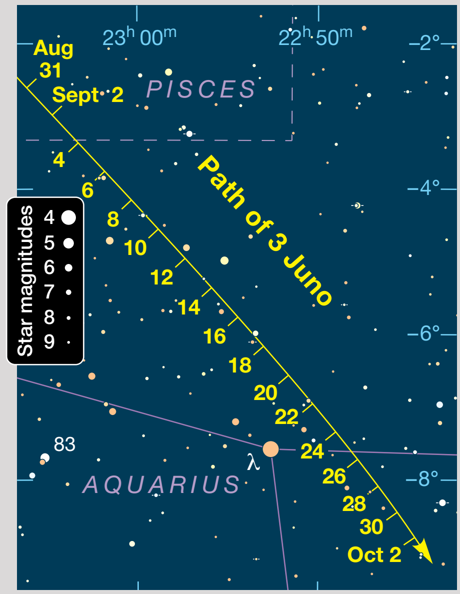


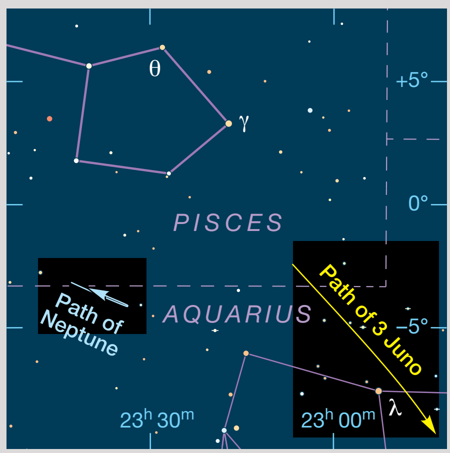
NEPTUNE COMES TO OPPOSITION on September 16th in eastern Aquarius, where it shines at magnitude 7.8. The distant planet's disk spans just 2.4″, but with a magnification of 200× under very steady seeing conditions, I can discern a tiny, pale blue disk in my 10-inch reflector. Even a 4-inch will give a similar view with enough magnification.

Observers with 8-inch or larger telescopes can zero in on Neptune's brightest moon, 13.4-magnitude Triton, which circles the planet in a retrograde orbit. To check the moon's position, use the *Triton Tracker* app, found on the Tools page at **skyandtelescope.org**.

Minor planet 3 Juno joins the opposition party when it reaches that milestone on September 8th. Like Neptune, Juno shines at magnitude 7.8. From September 20th to 24th the asteroid will sit within 1° of 3.8-magnitude Lambda (λ) Aquarii, which should make the object easy to locate in a small telescope.

First sighted by German astronomer Karl Ludwig Harding in 1804, Juno became the third minor planet discovered in a tally that now exceeds one million objects. With a diameter of 254 km, it's the 12th largest asteroid.

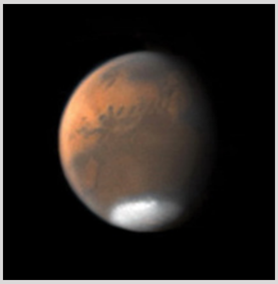




▲▶ These charts plot Neptune and 3 Juno at 0^h UT on the dates indicated.

Red Planet Turning Point

MARS WON'T BE at opposition until December 8th, but it reaches a crucial milestone this month when its diameter crosses the 10″ threshold on the 5th. While it's possible to eke out details when the disk is smaller, at this size we're in the comfort zone where a magnification of 200× under steady skies begins to show modest detail.



◀ Mars was 10″ across when this image was captured on May 16, 2020. This month the Martian disk reaches that diameter for the first time this apparition.

The Association of Lunar and Planetary Observers describes the current apparition as transitional between *perihelic* (close approaches) and *aphelic* (distant ones). Mars nudges nearest Earth on December 1st, when its disk will grow to 17.2″.

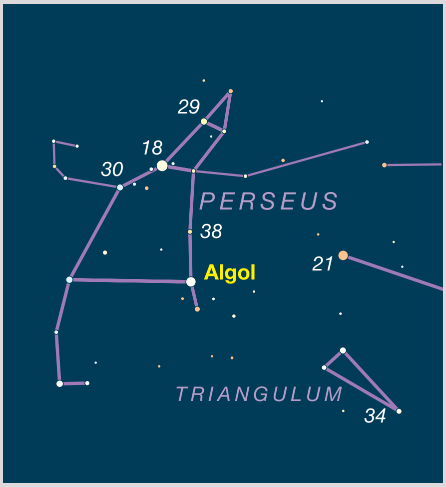
With the planet's south pole tipped less than 4° in our direction at mid-month, features in both the northern and southern hemispheres are in good view. The Martian disk is gibbous and illuminated 85% at the start of the month and 88% by its end. During that same span, it grows from 9.8″ to 11.9″.

Unfortunately, we're unlikely to see either polar cap. With the southern hemisphere steeped in summer, the South Polar Cap will be tiny. The North Polar Cap will be mostly hidden, but later in the month, you may catch sight of the white fringe of the North Polar Hood on the planet's northern limb.

Minima of Algol

Aug.	UT	Sept.	UT
3	4:33	2	21:09
6	1:21	5	17:58
8	22:10	8	14:46
11	18:59	11	11:35
14	15:47	14	8:23
17	12:36	17	5:12
20	9:25	20	2:01
23	6:13	22	22:49
26	3:02	25	19:38
28	23:50	28	16:27
31	0:39		

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 rises out of the northeast and reaches the zenith during predawn hours in September. Every 2.7 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to estimate its brightness in respect to comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).

Action at Jupiter

AS NOTED ON PAGE 48, September is opposition month for Jupiter, when it rises at sunset and is visible all night long. The planet reaches that milestone on the 26th, and for many observers the date marks the unofficial start of the prime Jupiter-observing season. Also as noted on page 48, the planet is unusually close this opposition.

As September begins, the gas giant shines at magnitude –2.9 and presents a telescopic disk spanning a generous 49″. Both those figures improve (but imperceptibly so) on opposition night. The planet is currently drifting westward in *retrograde* motion through Pisces — something it will continue doing until November 24th, when it momentarily pauses, then resumes its normal eastward, *direct* motion.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. The moons orbit Jupiter at different rates, changing positions along an almost straight line from our point of view on Earth. Use the diagram on the facing page to identify them by their relative positions on any given date and time. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. 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: 8:47, 18:43; **2**: 4:39, 14:34; **3**: 0:30, 10:25, 20:21; **4**: 6:17, 16:12; **5**: 2:08, 12:04, 21:59; **6**: 7:55, 17:51; **7**: 3:46, 13:42, 23:37; **8**: 9:33, 19:29; **9**: 5:24, 15:20; **10**: 1:15, 11:11, 21:07; **11**: 7:02, 16:58; **12**: 2:53, 12:49, 22:45; **13**: 8:40, 18:36; **14**: 4:32, 14:27; **15**: 0:23, 10:18, 20:14; **16**: 6:10, 16:05; **17**: 2:01, 11:56, 21:52; **18**: 7:48, 17:43; **19**: 3:39, 13:34, 23:30; **20**: 9:26, 19:21; **21**: 5:17, 15:12; **22**: 1:08, 11:04, 20:59; **23**: 6:55, 16:51;

MARS: DAMIAN PEACH

24: 2:46, 12:42, 22:37; **25**: 8:33, 18:29; **26**: 4:24, 14:20; **27**: 0:15, 10:11, 20:06; **28**: 6:02, 15:58; **29**: 1:53, 11:49, 21:44; **30**: 7:40, 17:36; **31**: 3:31, 13:27, 23:22

September 1: 9:18, 19:14; **2**: 5:09, 15:05; **3**: 1:00, 10:56, 20:52; **4**: 6:47, 16:43; **5**: 2:38, 12:34, 22:29; **6**: 8:25, 18:21; **7**: 4:16, 14:12; **8**: 0:07, 10:03, 19:59; **9**: 5:54, 15:50; **10**: 1:45, 11:41, 21:36; **11**: 7:32, 17:28; **12**: 3:23, 13:19, 23:14; **13**: 9:10, 19:06; **14**: 5:01, 14:57; **15**: 0:52, 10:48, 20:43; **16**: 6:39, 16:35; **17**: 2:30, 12:26, 22:21; **18**: 8:17, 18:13; **19**: 4:08, 14:04, 23:59; **20**: 9:55, 19:50; **21**: 5:46, 15:42; **22**: 1:37, 11:33, 21:28; **23**: 7:24, 17:19; **24**: 3:15, 13:11, 23:06; **25**: 9:02, 18:57; **26**: 4:53, 14:49; **27**: 0:44, 10:40, 20:35; **28**: 6:31, 16:27; **29**: 2:22, 12:18, 22:13; **30**: 8:09, 18:04

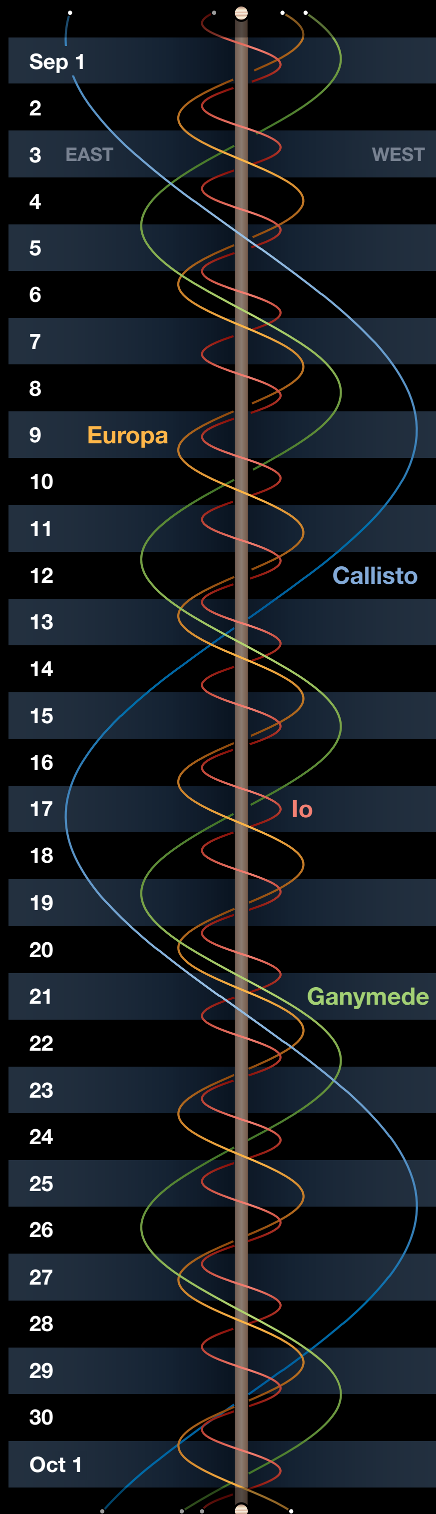
These times assume that the spot will be centered at System II longitude 23° on September 1st. If the Great Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 23° and $1\frac{2}{3}$ minutes later for each degree more than 23°.

Phenomena of Jupiter's Moons, September 2022

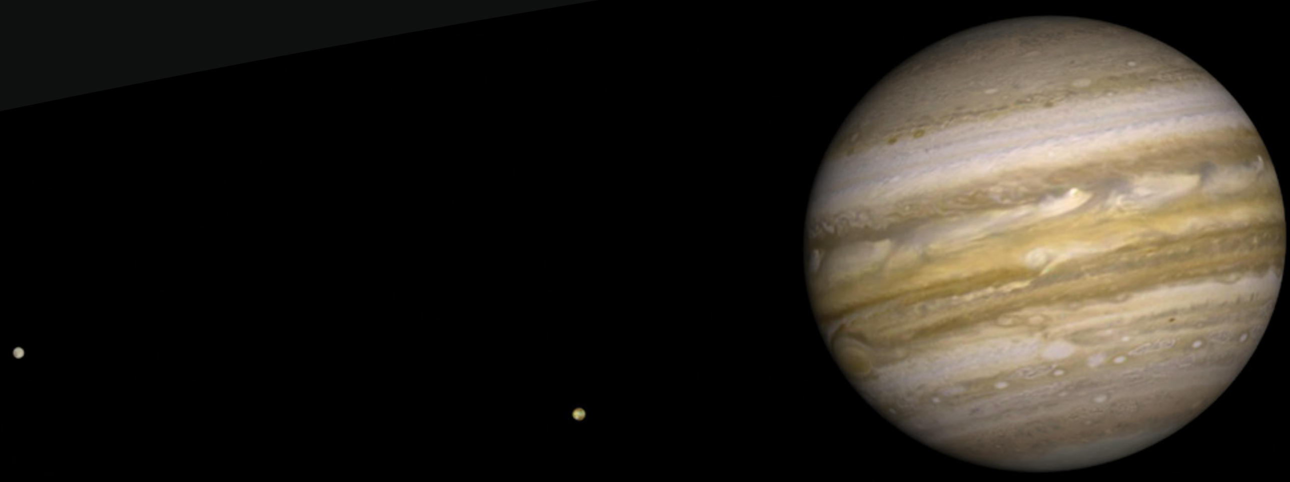
Sept. 1	1:41	I.Sh.I
	2:21	I.Tr.I
	3:55	I.Sh.E
	4:33	I.Tr.E
	17:28	II.Ec.D
	21:17	II.Oc.R
	23:00	I.Ec.D
Sept. 2	1:50	I.Oc.R
	20:10	I.Sh.I
	20:47	I.Tr.I
	22:24	I.Sh.E
	22:59	I.Tr.E
Sept. 3	1:57	III.Ec.D
	7:07	III.Oc.R
	12:29	II.Sh.I
	13:43	II.Tr.I
	15:02	II.Sh.E
	16:08	II.Tr.E
	17:29	I.Ec.D
	20:16	I.Oc.R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

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

Jupiter's Moons



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



A Lingering Jovian Mystery

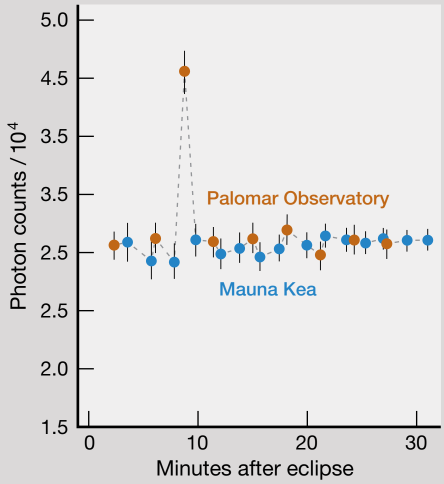
What caused a bright flash on Io in 1983?

Io is the innermost of Jupiter's four Galilean satellites and the most geologically active body in the solar system. A world of fire and brimstone, the 3,643-km-wide (2,264-mile-wide) moon is dotted with hundreds of active volcanoes powered by tidal heating generated as the moon is rhythmically tugged by the gravitational pull of Jupiter and the other Galilean satellites. The high and ebb tides raise and lower Io's crust by tens of meters, supplying the energy for eruptions that hurl plumes of vaporized sulfur and sulfur-dioxide gas to heights of hundreds of kilometers.

Io's brightness can increase by as much as 15% when it emerges from Jupiter's frigid shadow, gradually fading back to normal in about 20 minutes. It's theorized that during an eclipse, sulfur dioxide emitted by Io's volcanoes condenses as brilliant frost that quickly evaporates when sunlight returns. The amount of sulfur dioxide present depends on the level of volcanic activity, which can vary dramatically on a time scale of days or even hours (*S&T:* Jan. 2015, p. 54).

I recently came across an observation reported in 1993 by planetary scientists Heidi Hammel and Robert Nelson in the British scientific journal *Nature*. On July 26, 1983, an observing team from the Jet Propulsion Laboratory led by Nelson was monitoring Io's brightness as it emerged from an eclipse. The team employed a violet filter to maximize the contrast between Io's white frost and its yellowish surface materials.

Using a Vidicon camera as a photometer at the Cassegrain focus of Palomar Observatory's 1.5-meter (60-inch) Ritchey-Chrétien reflector, Nelson's team recorded fourteen 10-second exposures at 3-minute intervals after



▲ Photometric measurements of Io in violet light with a 1.5-meter telescope at Palomar Observatory (orange) and with a 0.61-meter at Mauna Kea (blue). The Palomar data set contains the anomalous brightening at 6:22:50 UT on July 26, 1983.

▲ This simulation shows the positions of Europa, Io, and Jupiter as the innermost moon emerged from the shadow of the planet on the night of July 26, 1983. Europa was on the sunward side of the planet at the time.

Io emerged from Jupiter's shadow. The moon's brightness increased by a whopping 50% in the third frame, taken 6 minutes after the eclipse ended. None of the other frames recorded any appreciable brightness enhancement.

At the time, Hammel was a member of a University of Hawai'i team that was also monitoring Io's brightness at Mauna Kea Observatory that night. Their series of twenty-one 3-second frames at 2-minute intervals failed to record the flash but did bracket it, constraining its duration to less than 2 minutes. In all other respects the Mauna Kea data were in excellent agreement with the Mount Palomar results.

But were the results real? A malfunction of the Nelson team's detector seems unlikely. The brightness of both the background sky and the nearby satellite Europa remained constant in every frame. All 12 pixels comprising Io's image brightened during the flash, so the event wasn't a spurious artifact.

A colossal impact on Io can also be ruled out. A comparison of high-resolution 1979 Voyager images with

SIMULATION OF JUPITER IN 1983: WINJUPOS; GRAPH: *S&T* ILLUSTRATION, SOURCE: H. HAMMEL, R. NELSON, ET. AL. / *NATURE* 1993 those taken by the Galileo spacecraft 20 years later reveals no feature that can be attributed to an impact in 1983.

The brief duration of the flash is hardly consistent with a volcanic eruption. While Io's lavas glow brightly at infrared wavelengths of 3 microns or longer, they have no appreciable emission in the violet region of the spectrum.

In 1993, Hammel and Nelson speculated that Io may have acted like a mirror, reflecting the momentary glare of a large impact on Jupiter's averted hemisphere. (Europa was on the Earthward side of Jupiter when the anomalous flash on Io occurred.) Theoretical models suggest that the impact of an object at least 5 kilometers in diameter would be required for its reflected fireball to increase the apparent brightness of Io by 50%. At the time this seemed to be a very plausible explanation.

During an unforgettable week in July of 1994, the fragments of Comet Shoemaker-Levy 9 struck Jupiter's nightside just over the planet's morning limb. At the urging of Hammel and Nelson, astronomers in Italy, Spain, Ukraine, Brazil, Japan, and Australia monitored the brightness of the Galilean satellites using sensitive high-speed photometers in a concerted effort to detect light echoes. The results were disappointing. The reflections of even the largest fireballs were so feeble that their photometric signals barely rose above the background noise.

If the flash on Io was the light echo of a Jovian impact, the object must have been considerably larger than even the biggest comet pieces. Many of the SL9 fragments produced dark "bruises" that were by far the most visually prominent features ever seen on Jupiter. Their sooty particulates quickly encircled Jupiter's globe and remained aloft for months.

My review of the records of the Association of Lunar and Planetary Observers and the British Astronomical Association failed to turn up any reports of an unusual Jovian feature in the summer or autumn of 1983. It's hard to imagine that the scar of a large impact would have eluded the scores of observers monitoring the planet. But Hammel and Nelson had cited one other possible explanation, the reflection of a "superbolt" of lightning in Jupiter's atmosphere.

On Earth, a typical lightning discharge measures about 10 kilometers long, lasts for about one-fifth of a second, and heats the surrounding air to 20,000°C (36,000°F). A network of satellites in geostationary orbits jointly operated by NASA and the National Oceanic and Atmospheric Administration (NOAA) have recorded unusually violent thunderstorms producing megaflashes of incredible size and energy on very rare occasions.

The current record is held by an April 2020 discharge over the southern United States that traveled horizontally for 768 kilometers, comparable to the length of the Florida peninsula. A June 2020 discharge over Uruguay and northern Argentina lasting more than 17 seconds holds the current record for duration.

Instruments aboard the Voyager and Galileo spacecraft detected the radio static generated by huge thunderstorms in Jupiter's turbulent atmosphere that routinely produce lightning discharges hundreds of times more powerful than their terrestrial counterparts. Until recently these bolts were assumed to occur only 45 to 65 kilometers beneath the visible cloud deck of frozen ammonia crystals, where temperatures are warm enough for charge-transporting droplets of liquid water to exist.

Three years ago, the navigation camera aboard the Juno spacecraft detected frequent flashes of "shallow lightning" at the very top of the cloud canopy on Jupiter's nightside. In these cold clouds, ammonia gas dissolves in water and acts like antifreeze, allowing droplets to exist at temperatures as low as –90°C. This unexpected discovery lends new credibility to the notion that the 1983 flash on Io may have been the reflection of a Jovian megaflash and could be the key to unraveling a four-decade-old mystery.

■ Contributing Editor **TOM DOBBINS** has observed rare phenomena on many bodies within our solar system, both real and imaginary.

FESUS ROBERT / SHUTTERSTOCK.COM

The longest lightning "megaflash" on Earth stretched for 768 kilometers. Two discharges detected by satellites lasted more than 16 seconds. Could even larger, stronger bolts occur high in Jupiter's turbulent cloud canopy?

◀ **HERE'S BLINKING AT YOU** Residing about 2,200 light-years away in Cygnus, planetary nebula NGC 6826 is well known as the Blinking Planetary for the way the nebula appears and disappears, depending on how you look at it. The 10.6-magnitude central star outshines its ghostly shell. High-velocity winds from the white dwarf have energized the ejected material to luminescence. Plainly visible in this image — but difficult to detect in amateur telescopes — are the red-hued Fast Low-Ionization Emission Regions, or FLIERS, flanking the bubble of gas.

NASA / STSCI

Cygnus on the Wing

The heavenly swan, in flight along the Milky Way, is a celestial wonderland.

As summer winds down, Cygnus rides high at nightfall. Urban stargazers can easily recognize this iconic constellation as the Northern Cross, while rural observers might picture the elegant celestial Swan, its broad wings outlined by faint stars. Either way, Cygnus is loaded with deep-sky objects — even for city dwellers.

I haven't enough space here to cover all of Cygnus in one go. For now, I'll focus on just the Swan's western wing. Working in my suburban yard last summer, I explored the region using a 120-mm (4.7-inch) f/7.5 apochromatic refractor and a 10-inch f/6 Newtonian reflector. Each scope showed me every target on my west-wing bucket list.

Wing Walk

My star-hop began roughly at mid-wing with **Delta (δ) Cygni**. A challenging binary star, 2.9-magnitude Delta harbors a 6.3-magnitude companion 2.8″ to the southwest. Both scopes split Delta into its strongly uneven parts at around 130×, though the resolution was cleaner at 200×. The high-power view of the blip hugging big-dot Delta was immensely satisfying. I realized the companion wasn't a planet, but it was easy to imagine that it was.

From Delta, I nudged the scope 2° northwestward, past 5th- and 6th-magnitude stars, toward the 6.8-magnitude open cluster **NGC 6811**. The 120-mm refractor quickly swept up a ¼°-wide clump of glitter — but it wasn't NGC 6811. Highlighted by a 7.2-magnitude yellow sun (HD 184938), the faux cluster contained about two dozen "members" down to magnitude 11. Three stars, one of 8th magnitude and two of 9th magnitude, formed a tiny triangle at the south end of the clump. Nice catch — but the *real* NGC 6811 was almost ¼° east-south-east of that triangle.

I found NGC 6811 nested inside a larger triangle of 10th-magnitude stars arrayed northward, southward, and westward. In addition, a 10.3-magnitude star lay on the cluster's northwest edge, while a 10.7-magnitude one abutted the northeastern edge. The interior members were fainter. Using the refractor at 75× revealed maybe 30 stars inside the triangle. My reflector at 64× didn't do any better, but 169× captured at least 60 stars. Oddly, they outlined a ragged edge surrounding a weak middle. NGC 6811 needs to get to the gym and bulk up!

Next, I aimed the scopes 3⅔° northward, at 4.5-magnitude Theta (θ) Cygni. Theta comes with extras. I noted a

West Wing Wonders

Object	Type	Mag(v)	Size/Sep/Period	RA	Dec.
Delta Cyg	Double star	2.9, 6.3	2.8″	$19^h\ 45.0^m$	+45° 08′
NGC 6811	Open cluster	6.8	15′	$19^h\ 37.2^m$	+46° 23′
R Cyg	Variable star	6.1 – 14.4	426 days	$19^h\ 36.5^m$	+50° 12′
16 Cyg	Double star	6.0, 6.2	39.7″	$19^h\ 41.8^m$	+50° 32′
NGC 6826	Planetary nebula	8.8	24″ × 27″	$19^h\ 44.8^m$	+50° 32′

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

6.5-magnitude star about 5′ arcminutes west of Theta, plus two much dimmer stars 4′ eastward. The faint tandem spans 92″, oriented north-south. The northern component is a white star of magnitude 9.9; the southern one is reddish **R Cygni**, a long-period variable that takes some 426 days to complete a cycle. When R is at minimum (mag 14.4), it's beyond reach; at maximum (mag 6.1), R outshines its neighbor — and it did so the night I observed it.

The Blinking Planetary

Casting 1° east-northeast of Theta netted **16 Cygni**, a striking double star whose nearly identical elements, magnitudes 6.0 and 6.2, are 39.7″ apart. This headlight double was fabulous in the refractor at 28×. Finally, nudging the scope ½° from 16 Cygni gave me **NGC 6826**, a visually enticing planetary nebula popularly known as the Blinking Planetary.

The term *planetary nebula* is a misnomer. A planetary nebula is formed when a decaying red giant star sheds its outer layers to create an expanding shell of gas. What remains inside the shedded shell is a hot white dwarf that energizes the ejected material. Very few of these dim dwarfs are visible in backyard telescopes, but the ejected shells often resemble ghostly planets. NGC 6826 is a notable exception — its 10.6-magnitude white dwarf dominates the nebulosity. Indeed, it's one of the brightest central stars in any planetary nebula.

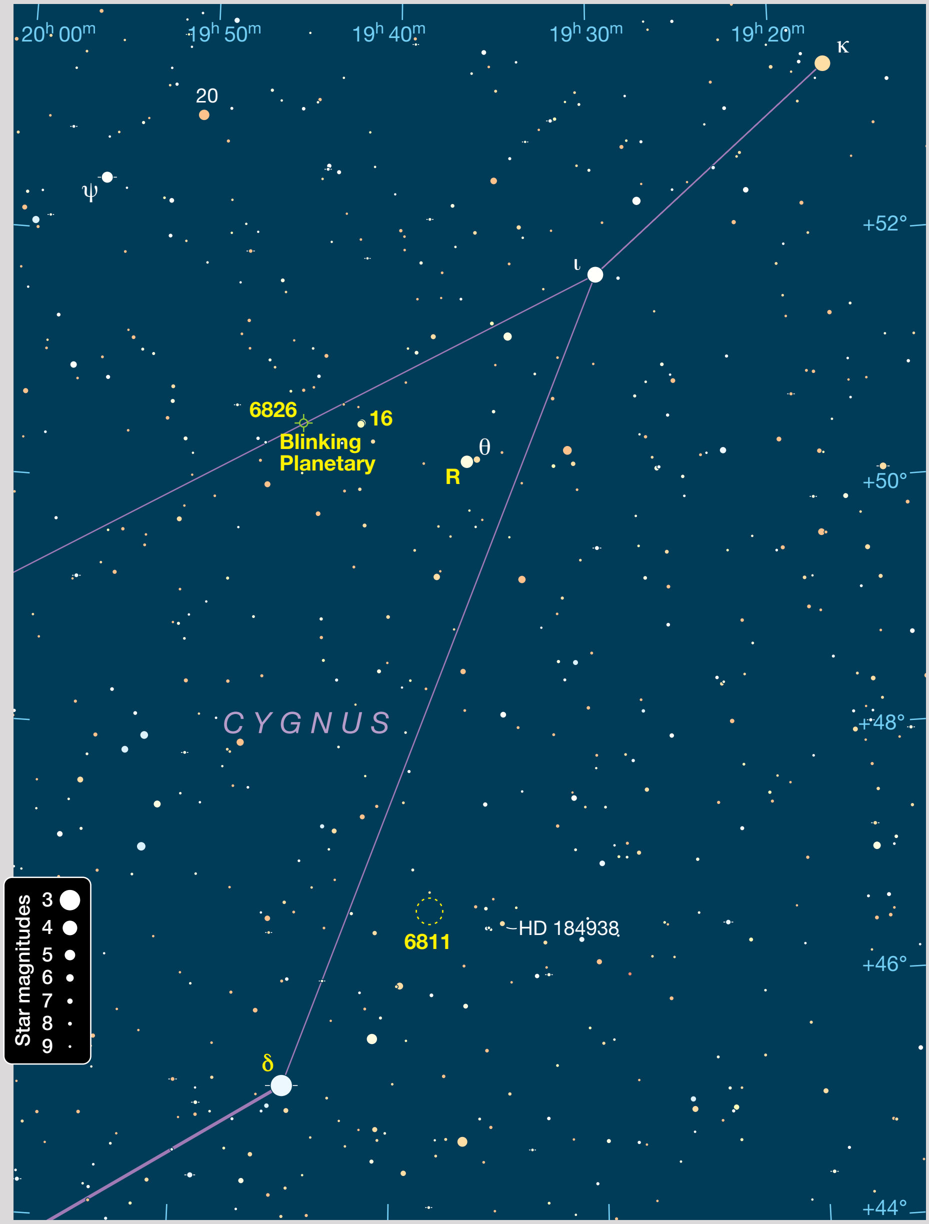
Glowing at magnitude 8.8 and measuring 27″ by 24″, NGC 6826 is approximately as bright as M57, the famous Ring Nebula, in Lyra. However, the Cygnus planetary is way smaller than M57 — it could fit inside the Ring's central hole. In my refractor at 38×, NGC 6826 was barely more than stellar, but doubling the magnification produced a distinct disc with a gleaming center. Upping the magnification to 100× confirmed that the delicate pinpoint middle was actually the white dwarf progenitor.

Then the "blinking" fun began. When I looked directly at NGC 6826, the nebulosity simply disappeared. A sideways glance — using a technique known as *averted vision* — forced the fuzz to reappear. Casting my gaze back and forth made the nebula blink on and off. NGC 6826's Blinking Nebula moniker is certainly well earned, though the now-you-see-it, now-you-don't effect is not unique. A few other planetaries sporting prominent central stars, such as NGC 2392 in Gemini and NGC 6543 in Draco, exhibit similar behavior. In any case, the on/off act didn't work as well at higher power. In the apo at 129×, the misty disk held its own.

Filter Fun and Folly

Adding a doubly ionized oxygen (O III) narrowband filter strengthened the planetary's disk. The O III passes light from only a few specific wavelengths, including those at which the nebula shines most prominently. In effect, the filter boosts contrast by attenuating starlight while dimming the nebula's glow only slightly.

In truth, I found the O III presentation less than ideal. I saw no stars across the filter-blackened field, nor did I perceive extra detail in the disk.



▲ **WESTERN WING** An area of sky in northwestern Cygnus measuring roughly 6° by 4° includes every object described in this article. The brightest star shown is 2.9-magnitude Delta (δ) Cygni.

▲ **MODEST CLUSTER** The small open cluster NGC 6811 (pictured above) is no prizewinner but is easily located 2° northwest of Delta Cygni. About ¼° to the northwest of NGC 6811 is a coarse clump of stars that the author could see in his 8×50 finderscope. (North is to the upper right.)

BOB FRANKE

The central sun was blocked entirely. The celebrated Blinking Planetary was all disk and no star. Also, my ambient neighborhood light compromised the experience. Even when cupping my hands around the eyepiece, the O III enhancement was difficult to appreciate.

My 10-inch Dobsonian reflector provided a brighter field of view and lots more magnification. The central star was distinct at 64× without a filter, and the nebula's misty shell was compact and luminous. The blinking phenomenon was a delight. At 169×, the mist looked moderately oval and exuded a bluish hue. At 227×, the nebulosity shrank under my direct gaze but never disappeared entirely. The urban light pollution I love to hate failed to swamp the delicate halo of NGC 6826. Sweet victory!

Repeating the above magnifications with the O III was delayed when I allowed the coin-sized filter to slip from my grasp and fall into my not-recently-mowed, dew-laden lawn. (Expert tip: Don't do this.) Many moments later, after finding the soaked accessory and restoring it with a hair dryer, I carefully threaded it into a 9-mm eyepiece. The filter treatment at 169× was worth the wait. The compact cloud appeared as a well-defined, oval disk that was bright around the edge and dusky in the middle. Alas, the O III view was devoid of color and the central star was devoid, period. I could behold the nebula but not the dying sun that created it.

Unfiltered Final Thoughts

Narrowband filters such as the O III or an Ultra-High-Contrast (UHC) can be extremely helpful, or even crucial, for detecting pale nebulae in gray city skies. Nebulae barely noticeable without the aid of filters are greatly enhanced when filtered. But there are tradeoffs. For example, an attractive star field surrounding a nebula can be badly blunted by a narrowband filter. And in the case of the few planetaries that boast conspicuous central stars, that rare feature is usually blocked as well.

NGC 6826 is bright enough on its own to show in my light-polluted suburban sky (as are NGC 2392 and NGC 6543, noted earlier). It's special not just because it blinks, but because of the plainly visible white dwarf inside it. I like the whole package — nebulosity and star. That's why I prefer the non-filtered view.

And for a klutz like me, it's one less thing to drop.

■ Experienced observer and longtime Contributing Editor **KEN HEWITT-WHITE** selflessly drop-tested his precious O III filter especially for this column.

The Search Is On

Might you be the one to spot the first galactic supernova in more than 400 years?

KEPLER'S SUPERNOVA A massive star exploded in the constellation Ophiuchus in 1604. Its remnant is still expanding at a rate of 2,000 km/s (4 million miles per hour).

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

You and the paper (or screen) on which you're reading this are both here thanks to dying stars. Previous generations of stars forged elements heavier than hydrogen and helium — such as the carbon in the wood pulp in this magazine's paper — and then spewed said elements into space at the ends of their stellar lives, sometimes in cataclysmic events called supernovae.

Supernova explosions captivate us — you may remember (or at least have later read about) the flurry surrounding the 1987 event in the Large Magellanic Cloud. The last supernova to visibly explode in our own galaxy did so in 1604, as German astronomer Johannes Kepler recorded in his book *De Stella Nova*. We know from X-ray and radio data that another star did go supernova some 140 years ago, but as it was near the center of our galaxy, its optical signal didn't make it through the intervening layers of gas and dust, and so nobody saw it.

Estimates tell us that one or two stars should shred themselves to bits in the Milky Way every 100 years or so. And the more people poised to observe when the next supernova goes off, the better chance we have of gathering crucial data.

Sign up! How do we go about planning observations for something unpredictable? The first clue that a star has exploded arrives not in the form of an optical signal but as a burst of neutrinos. Upon detecting these bursts, neutrino telescopes around the world trigger alerts to the global astronomical community. However, supernovae are bright — they can shine as bright as Venus right after they explode. Targets as bright as this will overwhelm professional facilities designed to probe down to magnitudes of 30 or so. Instead, amateur-operated instruments are *ideal* for the all-important follow-up observations that tell us about the star and how it died.

So, what should you do if you're keen to be the first person in more than 400 years to record a new supernova in our galaxy? Start by signing up for alerts with the Supernova Early Warning System at **snews2.org**. (*Sky & Telescope*'s former editor in chief Rick Fienberg and Senior Contributing Editor Roger Sinnott played an important role in the first iteration, SNEWS, when it debuted.)

Get Ready! Now you've signed up to the alert list, and lo, you get a ping. Then what? Maybe you have a game plan, like Finnish amateur Arto Oksanen, who's been thinking about this a long time.

Were he to receive an alert, the first thing Oksanen would do is ensure that three things converge: that the event is visible from Finland; that it's cloudless; and that it's nighttime. ("Some luck is needed," he notes wryly.) Provided all three criteria are fulfilled, he'd scrutinize the sky to see if he can spot the "new star." Then he'd immediately set up his DSLR camera on a tripod and point at the area of sky where the purported supernova occurred. Oksanen advises taking images all night that first night (at a frequency of one per minute) and for several nights thereafter (once per night) using the same setup. "This procedure should yield a useful photometric light curve, especially when combined with other observers' data," says Oksanen.

Check your first few images, even while your camera is still working away. If you notice a "star" that doesn't appear in any star chart, point your scope at it so as to obtain more accurate coordinates and its magnitude. Then report your data straightaway! Where, you ask? The AAVSO, for one, is coordinating the efforts between SNEWS 2.0 and the amateur community. Go to **aavso.org/snews-campaign** for details.

Even if the supernova has been localized by other means, start collecting data — get your astronomical camera out, your spectroscope if you have one . . . capturing those precious first few moments of the supernova event is absolutely crucial. And remember, the professional telescopes likely won't be able to observe for a while yet.

What if it's cloudy in Finland? "I would consider traveling to where the supernova is observable," Oksanen says. "This would be a once-in-a-lifetime event not to miss!"

Make sure you don't miss it, either.

■ Observing Editor **DIANA HANNIKAINEN** really hopes to see a galactic supernova.

Explore the North America and Pelican Nebulae

Spend some time in the Celestial Swan with a selection of captivating targets these late summer nights.

DIVE IN William Herschel discovered NGC 7000 in 1786. German astronomer Max Wolf originally dubbed it the America Nebula, but it was E. E. Barnard who eventually bestowed upon it the name by which we know it today. It took more than 100 years after Herschel's discovery of NGC 7000 for the Pelican Nebula to be recognized, which it was when the Reverend Thomas Espin detected it in 1899.

FIONA MORRIS

Over the years I've observed **NGC 7000**, the North America Nebula, in Cygnus many times. I've used a variety of instruments and have even seen it with my unaided eyes. To me, without optics it has a distinctive triangular shape, but I've since learned that such claims are controversial. Some observers suggest that what's visible is the associated star cloud outlined by dark nebulae, and not the nebulosity. Tony Flanders, a *Sky & Telescope* contributing editor, investigated this and notes, "From my rural backyard I can sort of see the North America Nebula naked-eye without filters, but I find it impossible to separate the nebula from the adjacent, extremely bright star cloud. When I hold my O III filter in front of my left eye and my UHC [Ultra High Contrast] filter in front of my right eye (or vice versa), NGC 7000 becomes an easy naked-eye object under Bortle 4 skies or better. The filters almost obliterate the star cloud, leaving the nebula itself quite obvious."

I've also enjoyed many unfiltered views with my 7×50 binoculars and 4.2-inch Astroscan reflector while sweeping the Milky Way. I waxed lyrical while observing it and the adjacent Pelican Nebula, **IC 5070**, with *S&T* Consulting Editor Gary Seronik's 6-inch f/6 Newtonian at 23× (yielding a giant 3° field of view) and an Ultrablock filter. But this was at the 2000 Mount Kobau Star Party, and others were sharing the eyepiece, so I had no opportunity to make the detailed notes required for an article. But I didn't forget that sight, and I knew that one day I'd eventually return to that part of the sky.

Nosing Around the North America Nebula

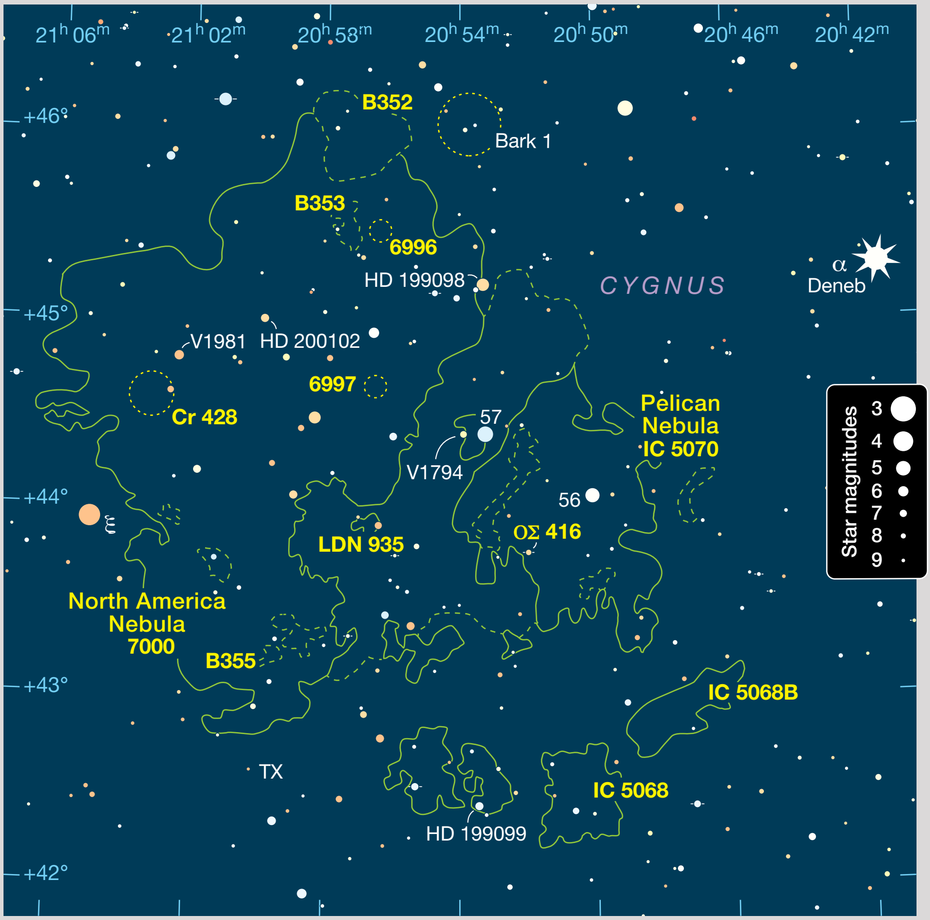
On five nights in July 2020, I used my backyard observatory's 16-inch f/4.5 Newtonian on the North America and Pelican Nebulae at 114× with a UHC filter. I worked from charts 1126 and 1106 in the *Millennium Star Atlas* (*MSA*), my favorite resource for observing emission and dark nebulae. If you don't have the *MSA*, you can use the finder chart at right. I chose the UHC filter over an O III because I would be star-hopping around the nebula's boundary as depicted in the *MSA*, and UHC filters don't drown stars like O III filters do. All five nights had excellent transparency.

By far the most prominent — and geographically recognizable — parts of NGC 7000 are Central America, Mexico, and Florida (although the nebulosity representing Florida is too broad) that surround the black Gulf of Mexico, which is formed by part of the dark nebula **LDN 935**. An unnamed dark nebula forms the Pacific Coast of Central America, and I also saw adjacent **B355** just to the southeast. Immediately south of declination +43° I detected the southernmost nebulous peninsula marked on the *MSA* (and visible in the chart at right), between a deep dark inlet and TX Cygni.

The *MSA* shows nebulosity west of Mexico that I couldn't detect, but my view again matches the charts near Xi (ξ) Cygni. I noted the Pacific Coast (though not at the level of detail plotted in the *MSA*) north of Xi Cygni to a faint V of stars located 23′ north of 6.2-magnitude V1981 Cygni (HD 200527).

In the eyepiece, the open cluster **Collinder 428** presents as a very elongated ellipse of 10 stars, with perhaps some stars adjacent to it. I could barely detect the faint arc of nebulosity visible in images between Cr 428 and V1981 Cygni with sweeping. But I more easily found the brighter arc of nebulosity lying between two north-south star chains. Its center is ¼° northwest of 6.6-magnitude HD 200102, which anchors the eastern star chain. I first saw this nebulosity on a photograph, and then decided to hunt it down. This feature is the only prominent arc of bright red nebulosity visible in the image at left — you'll find it in the northern reaches of the North America Nebula, approximately where Montana is.

Starting at HD 200102, I followed the eastern star chain for 1° northwards along the 21^h line of right ascension; about halfway it bends to the north-northwest and leads to the discernible northern tip of NGC 7000.



▲ **TARGETS WITHIN TARGETS** Not only are the two nebulae discussed here beautiful sights themselves, but they also offer the opportunity to check in on other objects.

West of the tip lies the big, triangular dark nebula **B352** — one of the most obvious dark nebulae in Cygnus thanks to the rich star fields surrounding it.

The nebulous Atlantic Coast is obvious from Florida up to declination +45° — or nearly up to the 5.5-magnitude star HD 199098. But I didn't see the nebula boundary plotted on the *MSA* north of there.

The open cluster **NGC 6997** looks like two concentric ovals (for those with the *MSA* open in front of you, note that the cluster's not plotted, but we've included it in the finder above). Scan 37′ northeast of 57 Cygni to find the cluster. There's also a scattered clump of stars 18′ northwest of NGC 6997, but no open cluster is cataloged at that position. At 141× unfiltered I saw the poor straggling open cluster **NGC 6996**. (In my observing notes I questioned whether it really was a cluster, and the authoritative book by Brent A. Archinal and Steven J. Hynes, *Star Clusters*, lists it as a possible asterism). The dark nebula **B353** is draped around its eastern side.

Poking Around the Pelican

The northern extension of the dark nebula LDN 935 separates the North America Nebula from IC 5070, the Pelican Nebula. The Pelican has a bright band from its northern tip to its southern edge, approximately along the line of right ascension at $20^h 51^m$. The northern part of the band forms the body of the Pelican, but it extends southwards, far past the body. The nebulosity that makes the Pelican's bill is obvious — although I couldn't make out its actual shape — and continues southeastwards to about ½° south of V1794 Cygni (HD 199178). I could also clearly see the long dark nebula immediately to the southwest that intrudes deep into IC 5070.

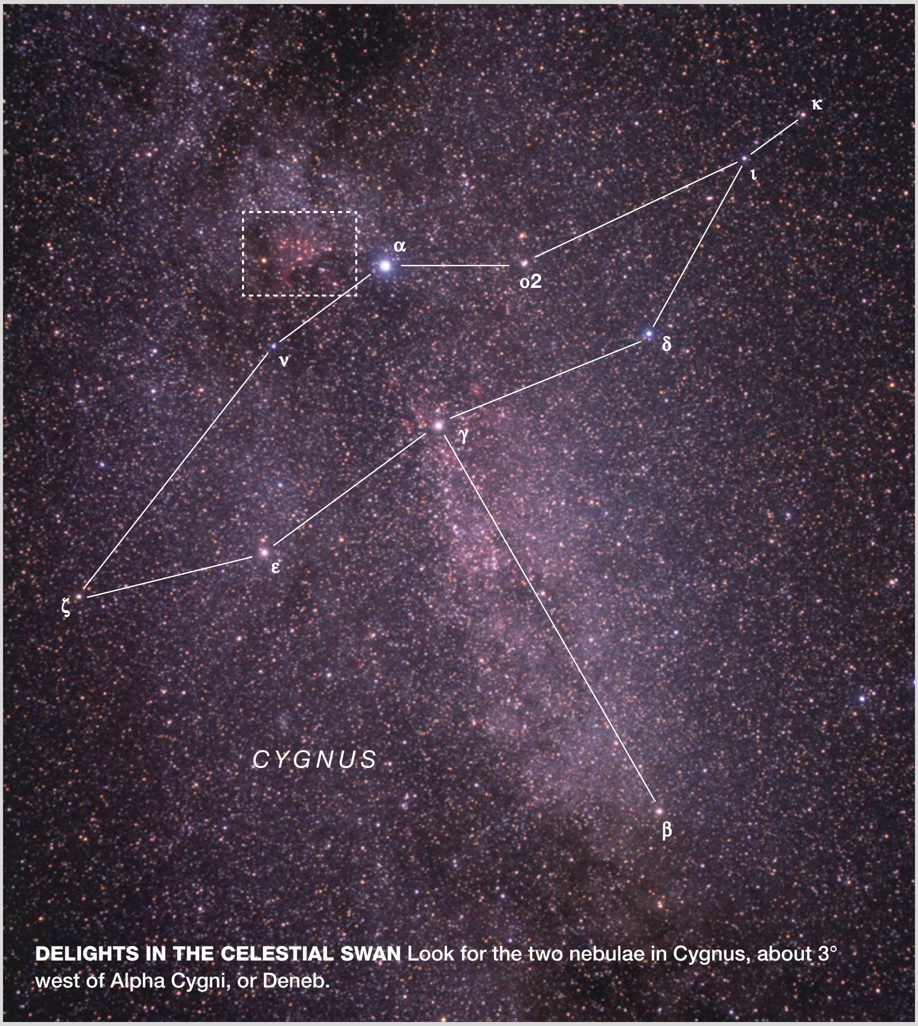
A dark bay runs northwards to the matched double **OΣ 416** (stars of magnitudes 8.6 and 8.9, with a separation of 9.6″), and the peninsula on the eastern side of the bay is obvious. The tip of the peninsula lies 0.8° due south of 57 Cygni. In summary, all the nebulosity between the brighter band along 20^h 51^m and the line of right ascension of 20^h 54^m is visible.

So, a surprising amount of the Pelican Nebula shows itself. But in its faint western third I only detected a few small patches of nebulosity, including the boundary around 13′ west of 56 Cygni as plotted in the *MSA*, as well as a short band near the southwestern corner, immediately west of four stars that form a diamond. You'll find the center of the diamond 25′ south of 56 Cygni. I tried the O III filter there and several other places, and I was pleased to find that the UHC showed the nebulosity better (as the nebula's emission has a hydrogen-beta component).

Four nebulae lie south of the Pelican, around 1½° from 56 Cygni. These patches are all considered to be part of **IC 5068**. The western component, **IC 5068B**, had an easy, fairly bright band, about ½° long. The next component over to the east had a little suspected patch on its northern side. Later I checked an image and my suspected nebulosity appeared as the brightest part of that region in the photo. The third component showed up as a very faint patch about 11′ north of HD 199099, while the easternmost section had a tiny spot visible at its easternmost tip. I've made a note to myself that the next time I observe IC 5068, I'll switch to an O III filter.

I hope you'll enjoy spending time on these objects as much as I did. Because both nebulae are large, with few small details within them, a smaller instrument at a low power will show almost as much as a large scope. Just make sure you take the time to linger in the area.

■ Contributing Editor **ALAN WHITMAN** is disappointed that the North America Nebula omits much of his country, Canada.



DELIGHTS IN THE CELESTIAL SWAN Look for the two nebulae in Cygnus, about 3° west of Alpha Cygni, or Deneb.

AKIRA FUJII

Catches in Cygnus

Object	Type	Mag(v)	Size/Sep	RA	Dec.
NGC 7000	Emission nebula	—	120′ × 100′	20^h 59.3^m	+44° 31′
IC 5070	Emission nebula	—	60′ × 50′	20^h 51.0^m	+44° 24′
LDN 935	Dark nebula	—	90′ × 20′	20^h 56.8^m	+43° 52′
B355	Dark nebula	—	5′ × 5′	20^h 59.6^m	+43° 11′
Collinder 428	Open cluster	8.7	10′	21^h 03.2^m	+44° 35′
B352	Dark nebula	—	20′ × 10′	20^h 57.2^m	+45° 54′
NGC 6997	Open cluster	10.0	8′	20^h 56.5^m	+44° 39′
NGC 6996	Star cloud	10.0	5′	20^h 56.4^m	+45° 28′
B353	Dark nebula	—	12′ × 6′	20^h 57.4^m	+45° 29′
OΣ 416	Double star	8.6, 8.9	9.6″	20^h 52.0^m	+43° 45′
IC 5068	Emission nebula	—	40′ × 30′	20^h 50.8^m	+42° 31′
IC 5068B	Emission nebula	—	42′ × 14′	20^h 47.3^m	+43° 00′

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

STAR APPEAL Our perception of the quality of an image is highly influenced by how the field stars look, even when they're not the main subject.

Star Power

Taking special care of the stars in your astrophoto will make the entire image shine.

For many of us, looking up at the stars got us hooked on astronomy. Stars are the most abundant objects in every deep-sky image, whether you're targeting the thick of the Milky Way or framing a distant, isolated galaxy. In open and globular clusters, they're literally the stars of the show. But in other compositions, bright stars can overwhelm dim structures such as the faint spiral arms of galaxies or the tenuous tendrils of supernova remnants.

The bottom line is that stars strongly influence our appreciation of an image, including our perception of its quality and beauty. Being mindful of how they look throughout the entire imaging process helps to strengthen their contributions to your overall composition. Here are some techniques I use to help the stars in my images shine brightly without stealing the show.

Work Begins at Acquisition

Most imagers agree that stars should appear small and round (though brighter stars will appear bigger) and brighten towards the center. Their colors vary, rather than appearing as white balls. The myriad suns in natural-color astrophotos ideally should display a range of hues, from blue to gold and even a few reddish ones.

Careful image processing can do wonders to repair all kinds of image flaws, but most would agree that it's better to prevent those flaws in the first place. Star quality — the size,

ALL IMAGES COURTESY OF AUTHOR

shape, and brightness profile — is a good indicator of the level of detail in the underlying data. Keeping stars tightly focused and perfectly round ensures that you'll get the most detail out of your intended deep-sky target.

No matter what optics you use, excellent polar alignment is essential to minimize drift during long exposures. I image at a scale of ¾ arcseconds per pixel, so I align my mount to within a few arcminutes of the pole. This produces no visible drift or field rotation in exposures up to 20 minutes duration. A coarser image scale, say, 3 or 4 arcseconds per pixel, is more forgiving of polar-alignment errors.

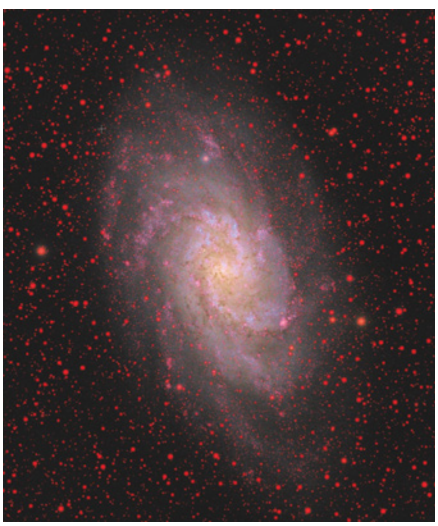
After polar alignment, the next critical step to ensuring good stars in your image is perfect focus. Every telescope on the market today changes focus slightly throughout the night as the temperature drops, causing the tube and optics to shrink slightly. That's why you need to check focus frequently during the night. In my locale, the temperature can drop more than 15°C (27°F) during an all-night imaging run. As a rule, I check focus every 30 minutes. The small amount of time this takes — about two minutes per hour of imaging time — is repaid in the end with tightly focused stars in virtually every subframe. Some acquisition software, like the freeware *N.I.N.A.* (**nighttime-imaging.eu**), automatically detects increasing star-size trends, refocusing as necessary.

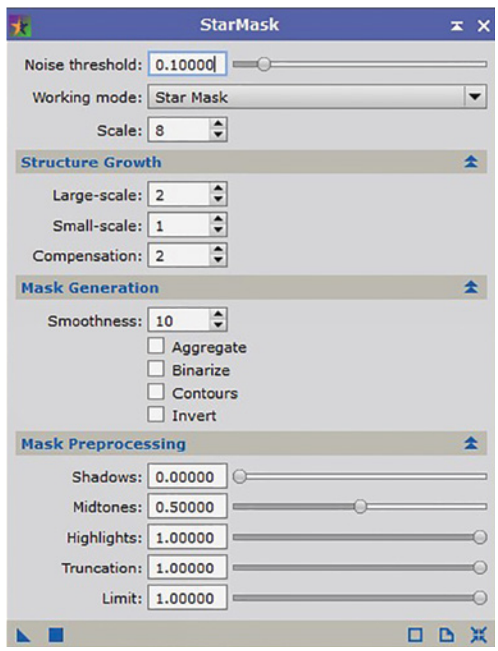
Chances are good that the various filters you need when color imaging with a monochrome camera won't all come to focus at the same position. To compensate, you should plan to refocus after every filter change. Some camera-control programs include a focus-offset option that allows you to program the focus position for each filter. After that, you only focus with one filter every time, and the software automatically makes the necessary focus adjustments when other filters are selected.

▲ **HIGH DYNAMIC RANGE** Some targets have such a wide range of brightness that they can't be recorded in a single image. The solution is to record them with exposures of varying lengths. This image of globular cluster M22 comprises 3-minute exposures to record the bright inner regions combined with 10-minute shots that record the faint outer regions. Both sets of data were processed separately then combined together so that the short image fills in the over-exposed core region in the 10-minute stack.

Star images quickly reveal any problems with your imaging system. For example, if the in-focus stars at the center of the field look great, but stars are oblong in one or two corners of the frame, this indicates that your camera's detector isn't positioned squarely to the focal plane. Many issues can be diagnosed with a short exposure of a star field. Making sure every connection is fastened securely and you've followed the manufacturer's spacing requirements for your field flattener or focal reducer are both critical to achieving sharp, round stars across the entire field. A difference of a single millimeter can noticeably distort the stars at the edges of the field.

▼ **STELLAR STENCIL** Use a mask to target the stars for specific adjustments or shield them from processes intended for the faint nebulosity or galaxy arms in an image. This mask made with *PixInsight*'s *StarMask* tool (inset) appears as red over the image of spiral galaxy M33. The mask protects the stars from enhancements made to the galaxy and background sky.





SUNS EVERYWHERE Stars are the subject in photos of open clusters. Here the smaller, redder color of distant members of NGC 2158 (lower right) are a strong visual cue that the object is farther away and older than sprawling Messier 35 at the center of the field.

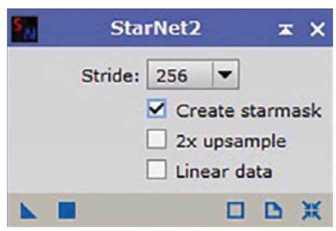
Another important consideration when recording your image is finding the right exposure. Some objects have a huge brightness range and can be surprisingly challenging to capture and process. Densely packed globular clusters like M22, or the cores of galaxies like M31 (the Andromeda Galaxy), may saturate in exposures of about 10 minutes, but very short exposures don't record the faint outer areas in such targets. The solution is to shoot both short and long exposures and combine them, using the short-exposure image to replace the saturated pixels in the long-exposure frames. This type of blending is known as high-dynamic-range (HDR) imaging.

Controlling Stars in Processing

Once you've mastered the acquisition stage with careful attention to the stars in your chosen field, it's time to make the most of your hard-won images. I prefer *PixInsight* for processing my deep-sky astrophotos, but you can adapt the tips described in this article to your preferred software.

The current trend in deep-sky image processing is to isolate the stars from the rest of the image elements (nebulosity, for example) during certain stages. The most direct approach is to create a star mask, which works like a "star stencil" that permits changes to the stars without affecting the rest of the image, and vice versa. Isolating the stars allows you to boost star colors, for example, without affecting the surrounding nebulosity. Similarly, you don't necessarily want the contrast adjustments you make to the nebulosity to apply to your stars. Most software packages include simple tools for making such a mask; in *PixInsight* this is done with the ***StarMask*** tool. A similar mask is made in *Adobe Photoshop* using the ***Color Range*** tool, selecting a few stars, and clicking the ***Add a Mask*** option at the bottom of the Layers window. Masks can themselves be processed like any other image and made to be more effective at meeting your specific needs. For example, you can enlarge or reduce the white parts of the mask, soften or sharpen edges, or adjust the contrast to allow it to better select/protect different image elements.

Another method for isolating stars is to temporarily remove them completely from an image and replace them later. The method was pioneered by astro-imager J-P Metsävainio (**astroanarchy.zenfolio.com**), whose work led to the development of sophisticated star-removal-tool software and plug-ins in recent years. *PixInsight*'s standard installation includes the original *Starnet++* process. The freeware *StarNet v2* is superior and is available for Windows, MacOS, and even as a command line tool for Linux at **starnetastro.com**. There's also a plug-in by Russ Croman called *StarXTerminator* for both *Adobe Photoshop* and *PixInsight* that works well.



SEPARATE TREATMENT Completely removing the stars permits more aggressive enhancement and noise reduction to other parts of the image that can adversely affect the stars. This example shows the *StarNet2* tool in *PixInsight* separating the stars from a picture of M33. The two sections are recombined later in the process.

It's offered at **www.rc-astro.com** for $59.95. I use ***StarNet2*** in *PixInsight* on my images after I've combined all my RGB and luminance data. I then run the resulting file through the ***StarNet2*** process, which generates a starless image. This starless image lets me be a little more assertive with the processing steps aimed at the non-stellar parts of the image and apply stronger noise reduction, sharpening, and contrast adjustments — all of which can potentially damage the field stars. The stars are then reinserted using ***PixelMath*** in *PixInsight,* where I add together the starless version with the file that includes the stars. I can also vary the prominence of the stars by reducing or increasing the value that the star layer contributes to the result, depending on the desired outcome.

Reducing Stellar Profiles

Prominent stars or a particularly star-rich field can overwhelm adjacent deep-sky objects that are typically our main imaging subject. A good example of this is the Veil Nebula supernova remnant in Cygnus. In situations like this, I often employ a two-step process in *PixInsight* to reduce the intensity of the stars. I start by making a star mask then applying a shape-changing process to shrink the stars using the ***MorphologicalTransformation*** tool. I adjust the amount of reduction using the ***Amount*** slider — a little bit goes a very long way, so don't go more than 0.5. If this dims the stars too much, apply a slight brightness boost using the ***CurvesTransformation*** tool with the mask still in place.

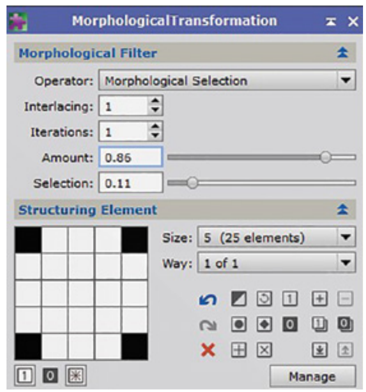
Sometimes there's just one very bright star that requires taming. I dial its brightness down without affecting the rest of the image by using a mask that selects only that star and its halo. I often make a large, single-star mask using the *GAME* custom script for *PixInsight*, which is available from **https://is.gd/piplugin**. I make sure the mask edges are nice and soft so the modified star maintains a natural appearance and blends in well with its surroundings.

Fixing Guiding Errors

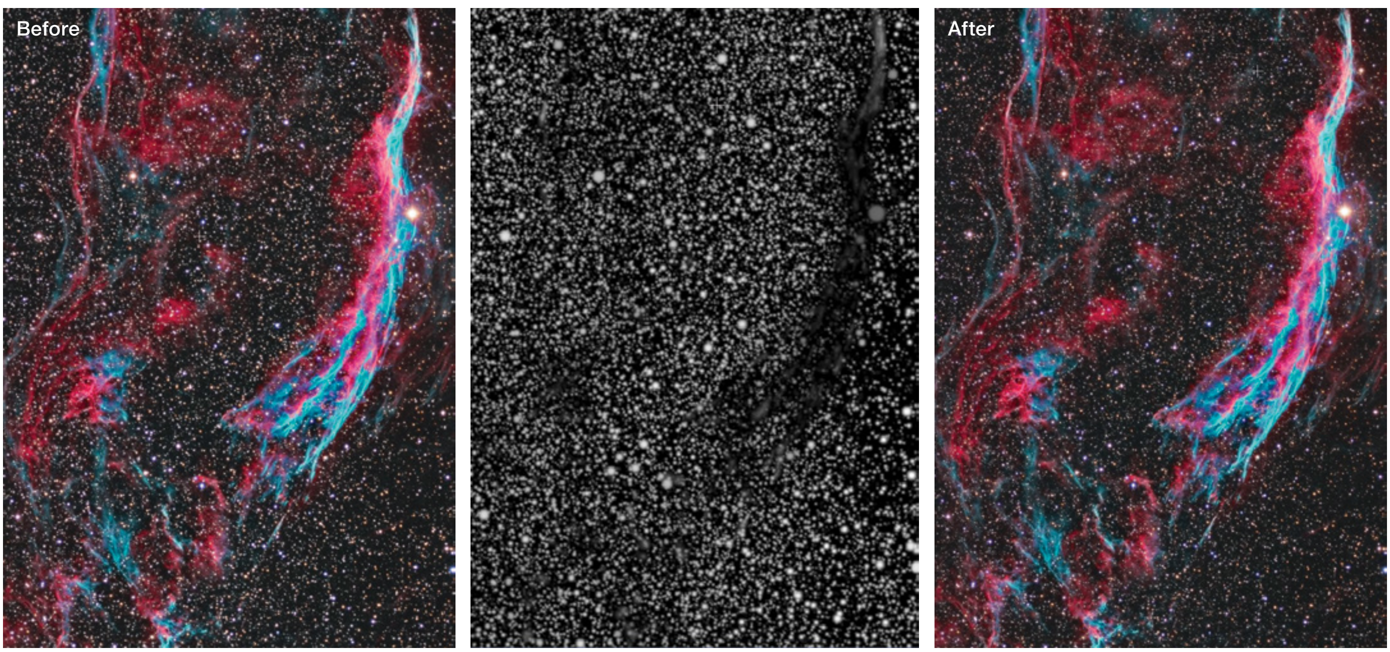
Don't despair if, despite your best efforts, the stars in your raw images are slightly elongated throughout the field. You can fix very minor tracking errors in processing, but understand that if the stars are elongated in your image, then so is everything else. That means that the nebulae or galaxies in your picture will be slightly blurred.

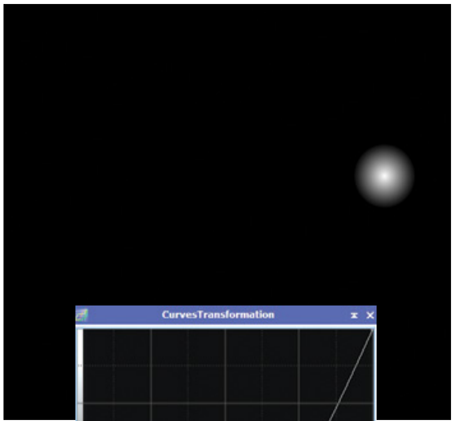
Correcting elongated stars should happen before applying any non-linear stretching. I make a star mask, then use the ***Deconvolution*** tool, where I select the ***Motion Blur PSF*** tab. I can then adjust the ***Length*** and ***Angle*** sliders until I see the star become round in the preview window. Another option is to open the ***MorphologicalTransformation*** tool and select the ***min+max/2*** mode to round out the stars. I sometimes need to try more than one method and experiment with each tool's settings to get natural-looking results.

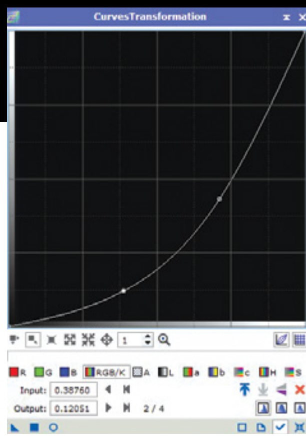
Elongated, color-separated stars that appear toward the corners of a frame is a type of optical error known as *lateral chromatic aberration*. Fast camera lenses and some



▼ **LESS IS MORE** Reducing the size of the stars helps to improve the prominence of non-stellar subjects in some star-dense areas of the Milky Way. Here the author applies the *MorphologicalTransformation* tool (upper right) with a star mask (center) to protect the background sky and supernova remnant.







▲ **ONE AND DONE** An exceedingly bright star may distract attention from the main subject of a composition. Here, a mask is used to tone down the prominence of 6.6-magnitude SAO 43270. The star's brightness was then reduced with the *CurvesTransformation* tool to put the focus back on galaxy NGC 3184.

refractors using field flatteners and focal reducers are prone to this defect. The problem is easily correctable early in the workflow by using a high-precision star-alignment tool to improve registration of the individual color channels. Simply align the red- and blue-filtered images to the green one and then combine to make a color image as usual. Astroimagers using color cameras will need to separate the color channels into the three primary color components first, then align them and recombine the results. In *PixInsight* I use the ***StarAlignment*** tool in its ***Thin-plate Splines*** mode, with the ***Local Distortion*** option engaged to get the most precise alignment possible.

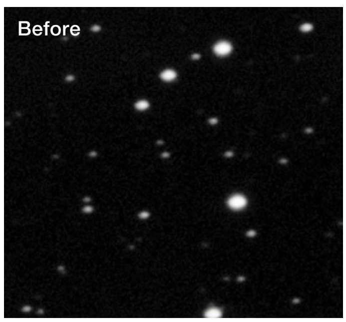
The specialized image-registration program *RegiStar* (**aurigaimaging.com**) also does a great job re-registering lateral chromatic aberration. Again, color-camera users will need to split the color channels first using ***Operations > Split by Color***.

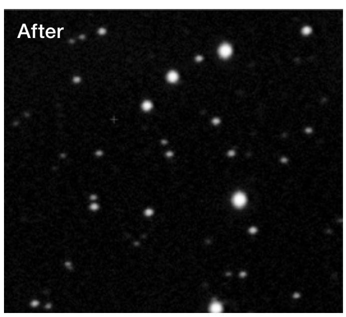
Narrowband astrophotographers can benefit from some star-care actions, too. Because the three narrowband images require aggressively stretching the O III- and S II-filtered images compared to the Hα image, the results produce stars with a strong magenta halo. While some don't mind the appearance, there's a fix to make the color look more natural. Using *PixInsight*, first invert the image, then open the ***SCNR*** tool and select Green in the ***Color to remove*** section and apply the tool. Finally, invert the image back to its original form. The magenta will be gone, and the star colors will be less intense.

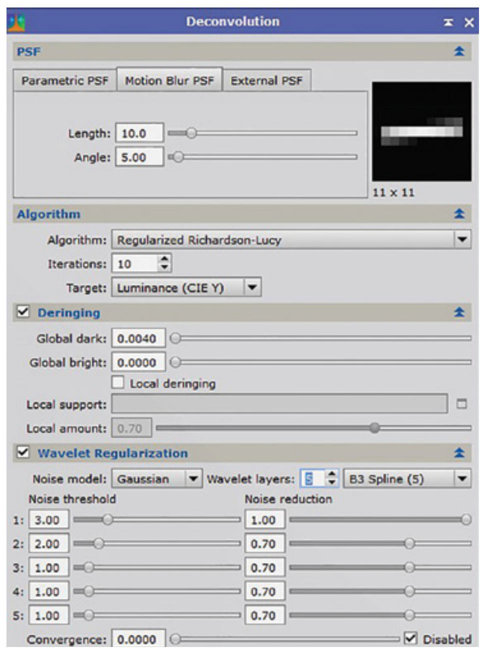
Aim for the Stars

The appearance of stars in our images has a big impact on how we perceive overall quality of a picture. Imperfect stars distract us from the main subject and likely mean that other parts of the image are less than optimally processed. On the other hand, small, round, natural-looking stars can enhance the photo without getting in the way. Even if your stars look great right out of the camera, you can improve them by careful post-processing. Remember, it was probably a sky full of tiny, beautiful pinpricks of light that first enchanted you. See if you can capture some of that magic in your astrophotos by letting the stars shine!

■ Contributing Editor **RON BRECHER** often hosts workshops on deep-sky image processing with *PixInsight*. Visit his website at **astrodoc.ca**.







▶ **STELLAR ROUND-UP** Using the *Motion Blur PSF* tab in *PixInsight*'s *Deconvolution* tool (right) can fix errors like slightly oblong stars.


Get details by visiting InsightCruises.com, emailing info@insightcruises.com, or calling 650-787-5665.
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InsightCruises.com/events/st14
Join us in Northern New Mexico for an annular eclipse October 11–16, 2023.
Based at the Hyatt Regency Tamaya, amid contemporary luxury.
2024's Great Texas Eclipse
InsightCruises.com/events/st15
Enjoy our Great Texas Eclipse celebration set in Austin, Texas April 4–9, 2024.
Based in the 4.5-star Downtown Omni Austin Hotel.
Luxor 2027 • Eclipse of the Century • 3 Options
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1
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SOFITEL WINTER PALACE
(Luxor-based plus cruise option to Cairo)
2
July 28 – August 5, 2027
Aboard the ms HAMEES
(Luxor-based plus cruise option to Cairo)
3
July 27 – August 13, 2027
17-NIGHT NILE RIVER CRUISE
(from Aswan to Cairo)
Aboard the ss MISR
CST# 2065380-40

Sky-Watcher's Evolux 82ED Refractor

We test one of a new series of entry-level apochromatic refractors.

◀ With its optional 0.9× reducer/corrector, the Evolux 82ED yields a 4.3° by 2.8° field on a full-frame sensor. This stack of 20 eight-minute exposures with a Canon EOS Ra camera shows residual chromatic aberration and a lens flare from Deneb just off the right edge of the frame.

Evolux 82ED

U.S. Price: $915

skywatcherusa.com

What We Like

Optics with low chromatic aberration

Excellent corner sharpness with optional reducer/corrector

Extra-long dew shield

What We Don't Like

Defective focuser

Crude camera rotation mechanism

I THINK IT'S FAIR to say that telescopes from Synta's Sky-Watcher brand have helped to democratize the use of apochromatic, or color-free, refractors. Compared to the lofty price of $1,000 per inch (or much more) typical of prestige brands, Sky-Watcher's affordable offerings made apos accessible to more buyers. So, when Sky-Watcher introduces a new series of apos, that's news worth noting.

The Evolux Series

For several years, Sky-Watcher has offered two lines of apo refractors: the entry-level EvoStar series, which features lower-cost doublet lenses, and the premium Esprit series with triplet lenses employing Ohara FPL-53 glass. I reviewed the superb Esprit 100 in the October 2014 issue (page 62). But we haven't seen many new apo designs from Sky-Watcher since.

That is, until now. Its new Evolux series currently includes two models: a 62-mm (2.4-inch) and an 82-mm, both doublets, said to improve upon the long-popular EvoStar series by using newer glass and a new optical design. However, the type of glass employed isn't disclosed, other than being extra-low dispersion (ED). This new design allows the Evolux telescopes to have f/6.45 focal ratios, compared to the photographically slower f/7.5 to f/9 focal ratios of most of the older EvoStar models.

I tested a new Evolux 82ED, on loan from Sky-Watcher USA. The sample sent had obviously been used as it had some cosmetic blemishes. A matching 0.9× reducer/corrector lens was also provided.

▶ The Evolux 82ED is finished in Sky-Watcher's distinctive green accented livery and is shown here equipped for visual use, with its 2-inch back, plus the included Vixen-standard dovetail bar and two finder shoes on the tube cradle.

ALL PHOTOS COURTESY OF AUTHOR

The Evolux 82ED retails for $915, less than the older EvoStar 80ED's current price of $1,080. But the latter is a more complete observing kit that includes an 8×50 finder, a 2-inch star diagonal, and two eyepieces.

The Evolux 82ED is shipped with an aluminum case, a 2-inch visual back, a Vixen-standard dovetail bar, and two mounting shoes for finders or guidescopes, but no other visual accessories. In addition, the reducer/corrector essential for deep-sky imaging is a $385 option. This accessory comes with a camera rotator mechanism and accepts 2-inch (48-mm) filters.

Mechanics

With any apochromatic refractor, especially one intended for photography, two aspects stand out as being most important: the quality of the optics, and its focuser. The focuser in our review sample was initially the Evolux's weak point. It's a 2-inch version with a hybrid rack-and-pinion and Crayford design with an 11:1 dual-speed motion.

Out of the box, the focuser slipped when loaded with the weight of a camera or 2-inch diagonal and eyepiece. The coarse-focus adjustment knob worked without a problem; rather, it was the fine focus that would slip under load as I attempted to rack it inwards. I was able to improve the motion by adjusting the small Allen screws around the focuser and on the shaft of the fine-focus knob. After this fix, the fine motion would grab and move the load in and out with more assurance, though it still slipped at times when the scope was aimed anywhere near the zenith. In addition, tightening the tension knob on the top of the focuser introduced a significant image shift of about 10 arcminutes when focusing.

The focuser does lock down securely, so there wasn't a concern with it slipping during an imaging session. However, despite my efforts, achieving precise focus was more difficult than with any of the other astrographs I've used in recent years, having become accustomed to the ease of the fine-focus knob supplied with many telescopes

▶ The long dew shield retracts fully to store on the 42½-centimeter-long tube. When fully extended, the tube is 58 cm long, an unusual length for an 82-mm-aperture, f/6.45 telescope.

made in the last decade. When alerted to the problem, Sky-Watcher USA sent a new focuser that helped but did not fully eliminate the slippage of the fine focus motion when under load.

Unlike most astrographs on the market today, the Evolux's focuser doesn't rotate. Positioning the focus knobs at the most convenient angle requires rotating the entire optical tube within its clamshell-style tube ring. That's easy enough to do, though not as convenient as rotating just the focuser itself.

The focuser racks out over a range of 66 mm. When used with the reducer/corrector, a DSLR camera reached focus with the focuser racked out to 36 mm. When using the scope visually with a 2-inch star diagonal, all my 2-inch and 1¼-inch Tele Vue and Baader eyepieces reached focus, including dual-barrel models inserted as a 2-inch eyepiece or into a 1¼-inch step-down adapter.

The tube of the 82ED is 42.5 cm long and is equipped with a dew shield that extends 15 cm in front of the lens and can be securely locked into position. This generous length will certainly help ward off dew, without any penalty of increased tube length when the dew shield is retracted. I consider this a great feature.

The tube ring is equipped with two Synta-standard finder shoes, a nice addition that allows both an optical and red dot finder simultaneously, or a finder and a tiny guidescope.

The 2-inch visual back incorporates a brass compression ring and two lock knobs, which can be difficult to adjust as the spacing between the visual back and the body of a 2-inch star diagonal is tight. If the focuser rotated, this wouldn't be a concern, but turning a star diagonal to place the eyepiece at a convenient angle always requires adjusting those two small lock knobs. Little inconveniences like that detracted from the enjoyment of using the telescope in the cold and dark.

When used photographically, the reducer/corrector's camera rotator does allow turning the camera relative to the telescope. But loosening the rotator's three lock screws lets the camera and reducer flop loose, though not to the point of falling off; they remain captive. However, you have to ensure the camera/reducer combination is flush with the rotator when re-tightening the lock bolts, or else the camera won't be square to the scope's optical axis, a situation that will result in distorted star images.

Still, the system works — the camera did maintain focus with no camera tilt after rotation. I also found the telescope maintained its focus well through a night of shooting at freezing temperatures. But the camera rotation seems crude compared to other similarly priced

▼ The dual-speed focuser has a tension adjustment on top and a lock screw on the bottom. The small hex screws indicated helped tighten the fine motion to ease slippage.

telescopes I've tested of late, which have rotators that maintain a solid camera-to-scope connection while still allowing the camera to be turned when needed.

◀ A single exposure with a full-frame sensor (the Canon EOS Ra) taken in twilight shows the level of vignetting when using the reducer/corrector, with the combination offering a fully illuminated field of 36 mm.

Optics

Not having an EvoStar 80ED refractor in hand, I can't say whether the new Evolux 82ED f/6.45 has better color correction than the older f/7.5 model. But I can say that for a doublet ED lens, the color correction of the 82ED is excellent.

In high-magnification star tests, bright stars both in-focus and out-of-focus exhibited very little false color and no obvious blue halos. Star images looked neutral, displaying the star's natural color. Also, once the optics cooled down to the freezing temperatures of my test nights, in-focus Airy disks and extra-focal diffraction patterns looked nearly textbook perfect, free of astigmatism or spherical aberration. This is one sharp little telescope!

It was only with high power on the Moon that some false color showed itself, with the lunar limb tinted pale green outside of focus and pale blue inside of focus (a common experience with doublet apos). But in focus there was no obvious blue or violet fringing along the limb or crater rims. Visually, the 82ED has a level of color correction that will please all but the most discerning apochromatic aficionados.

The tube is well blackened inside but has no annular baffles other than the focuser's drawtube. Even so, I saw little flaring or ghost images from bright light sources positioned just outside the field of a wide-angle eyepiece. When imaging with the reducer/corrector attached, bright stars just outside the frame did introduce flares into the image.

Imaging Performance

Photographically, the 82ED performed very well when used with its matching 0.9× reducer/corrector, which yields a focal length of 477 mm and a focal ratio of f/5.8. Stars were almost perfectly pinpoint out to the very corners of a full-frame (36-mm-wide) sensor. This was superb field flatness — as good as I've seen in any astrographic refractor.

The published specifications promise a fully illuminated field of only 36 mm, a figure I found accurate. Field illumination drops off quickly beyond a 36-mm circle, making the corners of a full-frame (24 × 36 mm) sensor quite dark. A full-frame sensor requires an illuminated image circle at least 44 mm wide to prevent significant vignetting.

By applying flat-field calibration frames, it's certainly possible to make use of the entire field of a 36 × 24-mm sensor when shooting with the 82ED, especially as stars appear sharp to the corners. So, the smaller image circle isn't quite the detriment that the specs might lead you to believe. Or users can simply restrict their imaging to cameras with smaller sensors.

The telescope's less-than-perfect chromatic-aberration correction shows itself in images, with many stars of moderate brightness having blue halos. This is to be expected from a doublet lens.

▲ The shallow depth of the visual back means that the star diagonal's clamping bolts can collide with the star diagonal body and be awkward to reach.

▲ The 82mm ED doublet objective is multi-coated and the interior of the tube blackened, though without any ring baffles or interior ridges to help suppress stray light.

▲ The optional reducer/corrector comes in two parts: the camera rotator, which screws onto the 62-mm threads of the focuser, and the 0.9× field flattener itself, which attaches to the 56-mm threads of the rotator and provides a standard 48-mm thread on the camera side for T-ring adapters and camera nosepieces.

The false color can be reduced or eliminated in processing, though doing so can introduce dark halos around stars.

Recommendations

With a tube weight of only 3.1 kg (6.8 lbs), the Evolux 82-mm is a fine grab-and-go visual scope. It will work well with Sky-Watcher's AZ5 manual, alt-azimuth mount, or its excellent AZ-GTi Go To alt-az mount and lightweight tripod. I tried it with the latter, and the combination was ideal for scooting around the sky.

For an ultra-portable imaging rig, the 82ED would pair nicely with Sky-Watcher's new Star Adventurer GTi equatorial Go To mount (see page 39). Combined with that new mount makes for one of the least expensive setups for deep-sky imaging. The little Evolux 62ED would be even more affordable and portable, making an ideal combination for airline travel.

Photographers may find the residual chromatic aberration and the restricted 36-mm image circle troublesome. Both can be dealt with in processing.

The malfunctioning of the fine focusing knob was a concern. Installing the replacement focuser did alleviate the worst of the slippage, but the fine focus motion still occasionally slipped when racking inward under load and when aimed up high. This shortcoming could be the greatest annoyance to imagers.

■ Contributing Editor **ALAN DYER** is co-author, with Terence Dickinson, of the new fourth edition of *The Backyard Astronomer's Guide*. For more information, see **BackyardAstronomy.com**.

▲ This single exposure of M44, the Beehive Cluster, taken under moonlight with the 0.9× reducer/corrector, shows excellent star images at each corner of a full-frame sensor, with no distortion from astigmatism, coma, or lateral chromatic aberration. The close-up of the center does show blue halos from the Evolux's longitudinal chromatic aberration.

New Life for Old Piers

Two classic mounts combine to make a versatile telescope pedestal.

◀ Larry Myers's Questar telescope sits proudly atop a doubled Criterion pier mount.

IN THE EARLY DAYS of astronomy, pier mounts were de rigueur. Tall piers were great for refractors, putting the eyepiece at a relatively comfortable height. Even big Newtonian reflectors came on piers. The Criterion company put practically every scope it sold on a sturdy, three-legged pier.

Then the Dobsonian revolution came along, and a lot of piers wound up getting stored in the backs of garages, up in attics, or out in the barn.

Questar, on the other hand, made mostly tabletop mounts for its fabulous — and fabulously expensive — line of Maksutov-Cassegrain telescopes. It's rare to find a Questar mounted on anything else.

Oregon ATM Larry Myers recently acquired a 3.5-inch Questar, after realizing that his enthusiasm for hauling out his big scopes had flagged a bit as he aged. But the tabletop mount didn't exactly set him free. And when he tried star-hopping to familiar targets, he quickly realized that he was completely dependent upon a Telrad-style finder. A 95-mm lens shade with a smaller red-dot finder mounted to the scope partially solved that problem, but he still had to get his head right down to tabletop height to use it.

A camera tripod temporarily helped, but one day while at a friend's house, Larry saw a dusty old Criterion pier mount sitting in a corner of his garage. He thought to himself, "Hey, I have one of those mounts collecting dust as well. What can I do with two pier mounts?" So, he asked his friend for the mount and took it home.

Larry says, "Okay, in full disclosure, I have to admit that I love building things (but I can quit any time)." Part of the joy in telescope-making is thinking through the project before you start bending metal, so Larry says, "I sat the two mounts in my living room and just stared at them for a few days." He realized that he preferred standing rather than sitting when observing, which meant a much taller pier than either of the originals. Could he stack the two piers one atop the other without creating a harmonic-vibration tower?

Nothing ventured, nothing gained. So he decided to give it a try.

The first step was to disassemble the 60-year-old mounts. They were badly rusted and very stubborn, but with the help of a lot of penetrating oil, applied

▲ *Top:* Taking apart the Criterion mount was a chore, but persistence eventually paid off. *Bottom:* The two pier sections are joined with an internal coupling that extends several inches into each end.

heat, and a sledgehammer, Larry won.

Then he started cutting. He bandsawed the altitude swivel off one of the right-ascension assemblies, keeping the flat metal part and tossing the polar-axis bearing housing. Then he made a thick-walled coupling to drop into the top of one column and the bottom of the other. Next, he drilled and tapped threads to match the existing leg holes in the top pier and the top holes on the lower pier to the coupling. He was happy to find that the resulting extended pier felt nice and rigid.

Larry then designed a top plate to mount the Questar on. A few phone calls to aluminum suppliers provided sticker shock: $189 for an 8-inch-by-half-inch disk. So, he tried a steel scrap yard, where they sawed off a ¾-inch slab of 8-inch-solid stock for a much more reasonable $27. He then used a lathe

ALL IMAGES COURTESY OF LARRY MYERS

to smooth both faces of the disk and wound up with a ⅝-inch final thickness.

He cut a window in the disk for the Questar's power cord and drilled holes for the screws holding the disk to the salvaged half of the polar-axis flange. He decided to capture the base of the Questar with two button-head cap screws and a removable thumbscrew. Nylon washers and short sections of surgical tubing over the threads prevented the screws from scratching the telescope's base.

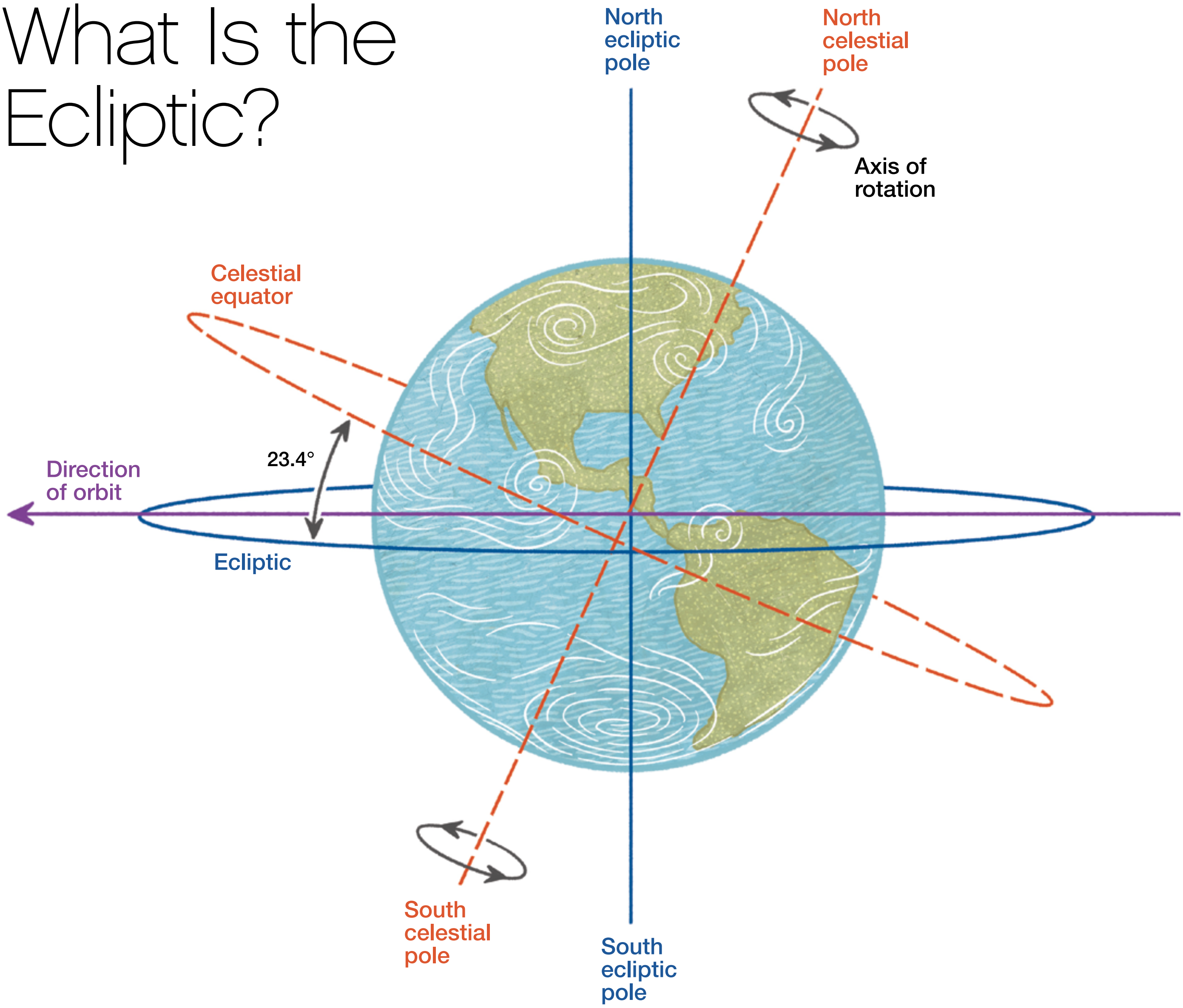
Along the way he added an aluminum block and screw to serve as a fine-tuning adjustment for the polar axis. He took some pains to save the original Criterion label, and he added an eyepiece holder partway down the pier. After testing to make sure everything functioned as intended, he had everything sandblasted and powder-coated.

How well does it work? Larry is very happy with it. Setup time takes less than two minutes, damping time is minimal, and Larry can observe standing up — or sitting down if he uses just one of the two pier sections. Larry figures that will come in useful soon, remarking, "I'm old now, so I will probably use that option more and more when I'm really old!"

■ Contributing Editor **JERRY OLTION** also likes to pier upward.

▲ The Questar telescope mounts to a solid aluminum disk. Polar alignment is adjustable with a fine-tuning bolt.

What Is the Ecliptic?



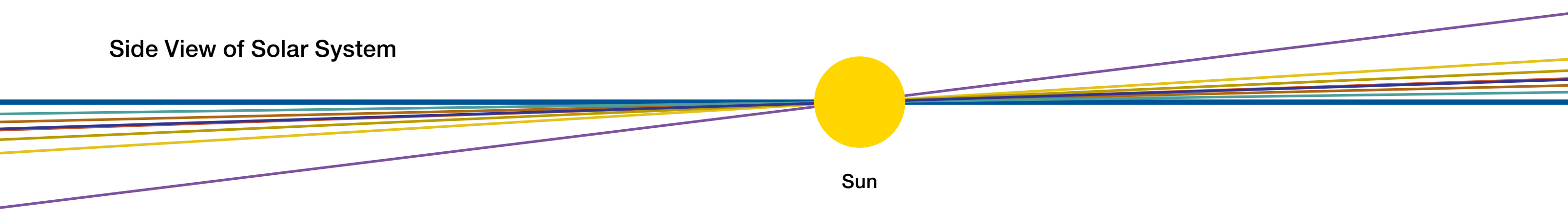
THE ECLIPTIC, SIMPLY PUT, is the plane of Earth's orbit around the Sun. It extends beyond that to include the seven other planets — and, because it's imaginary, actually beyond that into infinity. But for our purposes, picture a flat, round disk with the Sun at the center and all the planets, from Mercury out through Neptune, circling it in roughly the same plane.

I say roughly because the planets don't circle our star on precisely the same orbital plane as Earth (see diagram below). They vary a bit, though only slightly. Uranus varies the least, deviating from the ecliptic by less than a degree. Mercury has the greatest inclination, about 7°. (Pluto's is 17°, but it's officially a dwarf planet so is not included here.) Essentially, all the planets, as well as the asteroid belt between Mars and Jupiter, lie in the same plane.

They do so, astronomers think, because they all coalesced from the

EARTH AND ECLIPTIC: LEAH TISCIONE / S&T; PLANET ORBITS: TERRI DUBÉ / S&T; INCLINATIONS SOURCE: NASA

Side View of Solar System



same *accretion disk* of debris that formed the Sun about 4½ billion years ago.

So why is this plane called the ecliptic? The word comes from the Greek for "fail to appear," and ancient astronomers named it such because it's the place where eclipses happen. A solar eclipse occurs when the Moon passes between Earth and the Sun; a lunar eclipse happens when Earth slips between Sun and Moon. Both only take place when the Moon is on or near that plane of Earth's orbit around the Sun, at two points in the lunar orbit known as *nodes*. When it's off that plane, its shadow misses Earth, and there's no solar eclipse — or Earth's shadow misses the Moon and there's no lunar eclipse.

The Moon isn't always on the plane, and that's because its orbit is inclined about 5° from the ecliptic (see diagram below right). Twice a month on average, the Moon crosses the ecliptic at either an *ascending* or *descending* node. That's when eclipses can occur.

Against the Stars

While the ecliptic is technically the plane of Earth's orbit around the Sun, it might be easier to think of it as the *apparent* path of the Sun and planets around Earth. That's because our senses tell us, even if it isn't in fact true, that our planet is motionless in space while those other bodies revolve around it.

From our earthbound perspective, the Sun arcs overhead from east to west over the course of a day (because of Earth's 24-hour rotation) and slowly creeps from west to east over the course of a year (because of Earth's 365¼-day annual orbit).

The Sun takes one year to (apparently) complete a circuit of the ecliptic, because that's how long it takes Earth to finish one orbit of our star. Each day in that year, the Sun moves eastward slightly less than 1°, a reflection of how far our planet has progressed in its orbit in that 24-hour period.

The other planets, too, travel along the ecliptic. See our monthly ecliptic diagram on page 47 for their positions as of mid-September.

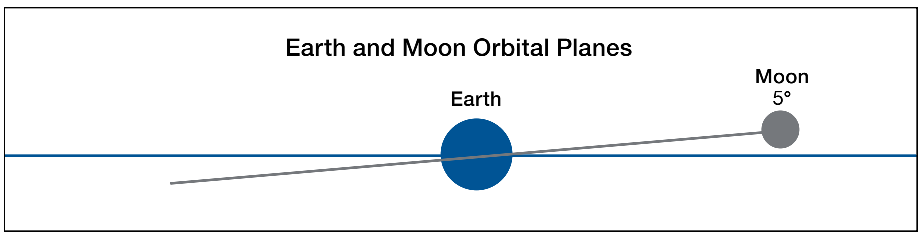
With each passing day, the Sun's position against the background stars changes. Over the course of a year, our star journeys in front of the 12 classic constellations of the ancient zodiac. From January to December, they are Capricornus, Aquarius, Pisces, Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpius, and Sagittarius. (The ecliptic actually crosses the modern boundary of one more constellation — Ophiuchus — making the Serpent Bearer the zodiac's unofficial 13th constellation.)

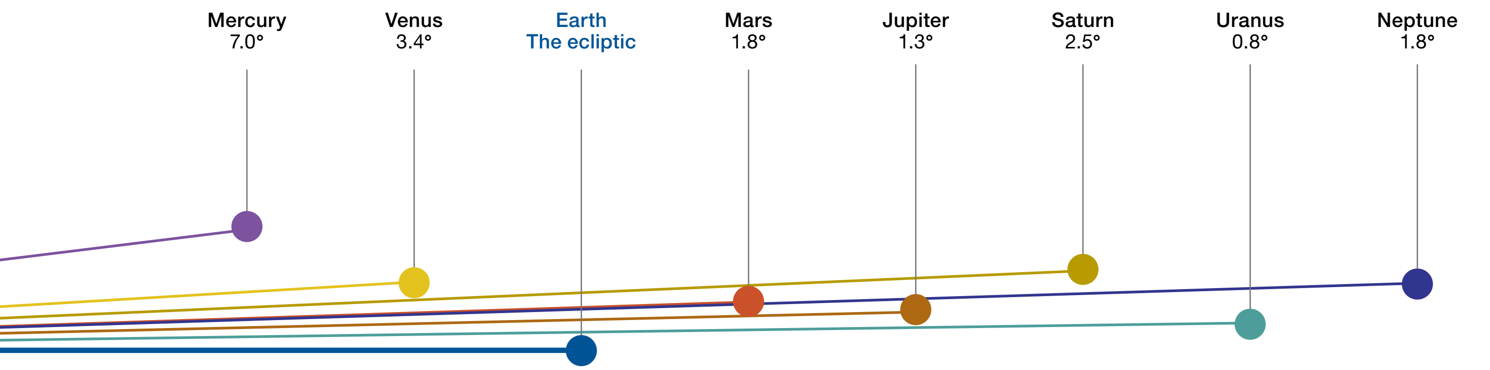
Ecliptic vs Celestial Equator

It's useful to distinguish between the ecliptic and the *celestial equator*. As schoolchildren learn, Earth is tilted on its axis. That is, our planet's rotational axis is not perpendicular to the ecliptic plane but rather inclined to it by about 23.4°. Just as the ecliptic plane extends out in an infinite circle from Earth's orbit around the Sun, the celestial equator extends out in an infinite circle from Earth's equator, which is tilted 23.4° from our planet's orbital plane (see diagram on page 74).

This distinction is helpful to keep in mind because most astronomers today use a coordinate system based on so-called equatorial coordinates rather than on ecliptical coordinates to precisely locate stars and other objects in the sky. The ecliptic diagram on page 47 uses equatorial coordinates, which is why the ecliptic line is wavy rather than straight. ■

▼▶ *Below:* Each planet's line represents its orbit around the Sun. It appears here as a line rather than a circle or oval because we're seeing it edge-on. This allows us to see the degree to which all non-Earth planetary orbits deviate from the ecliptic, or Earth's orbital plane, which appears horizontal below. *Right:* The Moon's orbit inclines from the ecliptic by about 5°.





Orbits not to scale

▷ MINING FOR AN ECLIPSE

Sérgio Conceição

The eclipsed Moon sets during totality as seen from the deserted São Domingos Mine in Portugal on the morning of May 16th. The second bright star to the Moon's left is Antares.

DETAILS: *Canon EOS R6 camera and Canon RF 15-to-35-mm zoom lens. Composite of many 1⁄200- and ¼-second exposures at f/5.6, ISO 200 and ISO 6400.*

▽ LUNAR ECLIPSE TRIO

David Kodama

Aerosols from the eruption of the Hunga Tonga-Hunga Ha'apai underwater volcano caused the lunar eclipse of May 16, 2022, to appear especially dark. This composite image from southern California depicts the Moon 10 minutes before totality, midway through the eclipse, and 10 minutes after totality ended.

DETAILS: *Borg 107FL astrograph and Nikon D850 camera. Composite of three exposures, each 4 seconds long at f/3.9, ISO 64.*

MULTICOLORED MOON

Chirag Upreti

Although clouds mostly impeded the view of May's lunar eclipse from New York City, a transparent patch enabled Chirag Upreti to capture the subtle bands of purple and blue along the edge of Earth's umbral shadow following totality.

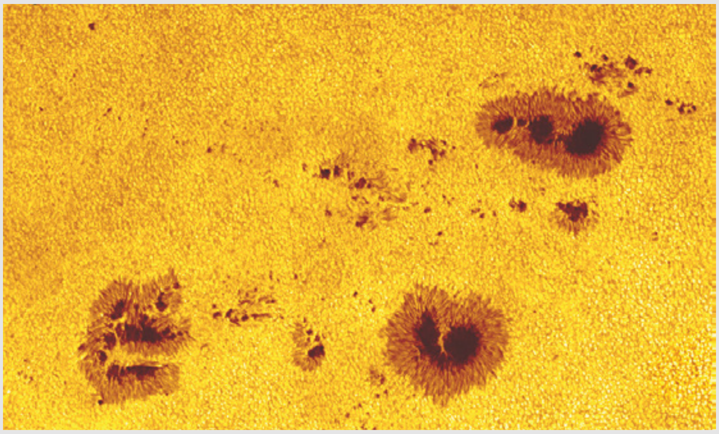
DETAILS: *Sony α7R III camera, 200-to-600-mm zoom lens, and 1.4× teleconverter. Total exposure: ½ second at f/11, ISO 500.*

GALACTIC NEIGHBOR

Kfir Simon

Vibrant, reddish star-forming regions contrast with the bluish glow of young stars in the outer regions of M31, the Andromeda Galaxy. Dark dust lanes appear to spiral towards the galaxy's golden core in this enhanced-color image.

DETAILS: *Celestron 36-cm Rowe-Ackermann Schmidt Astrograph with QHY600 camera. Total exposure: 4 hours through LRGB and Hα filters.*



◁ CHURNING ACTIVITY

Dave Tyler

This high-resolution image of the photosphere captures massive sunspot groups AR2993 (top right) and AR2994 (bottom) surrounded by dozens of smaller spots amidst a sea of brighter granulation.

DETAILS: *Astro-Physics 178-mm triplet APO refractor and ZWO ASI174MM camera. Stack of 300 frames recorded through solar-continuum and infrared-blocking filters recorded on April 21, 2022.*

CELESTIAL PAW PRINT

Kfir Simon

The Cat's Paw Nebula, NGC 6334, in Scorpius is a vast star-forming region containing several bluish bubbles of nebulosity, giving it the appearance of a feline paw print.

DETAILS: *AstroSysteme Austria 16-inch astrograph and Moravian G4-16000 camera. Total exposure: 6½ hours through narrowband and RGB filters.*

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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 24–29
NEBRASKA STAR PARTY
Valentine, NE
nebraskastarparty.org

July 26–31
OREGON STAR PARTY
Indian Trail Spring, OR
oregonstarparty.org

July 26–31
TABLE MOUNTAIN STAR PARTY
Oroville, WA
tmspa.com

July 28–30
ALCON 2022
Albuquerque, NM
alcon2022.org

July 28–31
STELLAFANE CONVENTION
Springfield, VT
stellafane.org

August 18–21
THEBACHA & WOOD BUFFALO DARK SKY FESTIVAL
Fort Smith, NT
tawbas.ca/dark-sky-festival.html

August 20–28
MOUNT KOBAU STAR PARTY
Osoyoos, BC
mksp.ca

August 22–28
MAINE ASTRONOMY RETREAT
Washington, ME
astronomyretreat.com

August 23–28
SASKATCHEWAN SUMMER STAR PARTY
Maple Creek, SK
sssp.saskatoon.rasc.ca

August 24–29
NORTHERN NIGHTS STAR FEST
Palisade, MN
https://is.gd/Northern_Nights2022

August 25–28
STARFEST
Ayton, ON
nyaa.ca/starfest.html

August 25–29
IOWA STAR PARTY
Coon Rapids, IA
iowastarparty.com

August 26–28
NORTHWOODS STARFEST
Fall Creek, WI
cvastro.org/northwoods-starfest

August 26–28
NOVA EAST
Smileys Provincial Park, NS
novaeast.rasc.ca

August 26–30
ALMOST HEAVEN STAR PARTY
Spruce Knob, WV
ahsp.org

September 16–17
ASTRONOMY AT THE BEACH
Island Lake State Recreation Area, MI
glaac.org

• For a more complete listing, visit https://is.gd/star_parties.

A Fireball Over Israel

The author recalls his sighting of a spectacular meteor six decades ago, shortly before he married his wife of 60 years.

IT WAS 60 YEARS AGO this month when I submitted my first article to *Sky & Telescope* (see story at right). As the article relates, while strolling along the Mediterranean just after sunset one day, I saw a huge, brilliant-white flash suddenly streak across the sky, leaving behind a razor-sharp trail. Seconds later, the trail changed color to orange and red due to the setting Sun and then metamorphosed into a zigzag shape. I watched it for about 20 minutes until the gathering darkness ended the show.

Back in my room, I quickly scribbled down some notes and a rough sketch of what I'd seen, then called Israel Radio to describe the event. My audio report was broadcast on the evening news all across the country. The next day I learned from the wide press coverage that people had witnessed the event from as far away as Eilat, a town some 350 km south of where I was in Haifa.

The *Jerusalem Post*, for one, wrote: "Thousands of eyes glanced skyward and hundreds of people ran into the streets throughout the country when a mysterious ball of fire spouting trails of smoke flashed across the sky at 5:45 yesterday evening." Newspaper offices and police stations received "hundreds of telephone calls" from concerned citizens, the paper reported. Some thought it might have been a rocket shot from a neighboring territory, but an expert at Israel's Geological Survey explained to the *Post* that it was "a piece of cosmic material, of iron or stone, attracted by the earth's gravity."

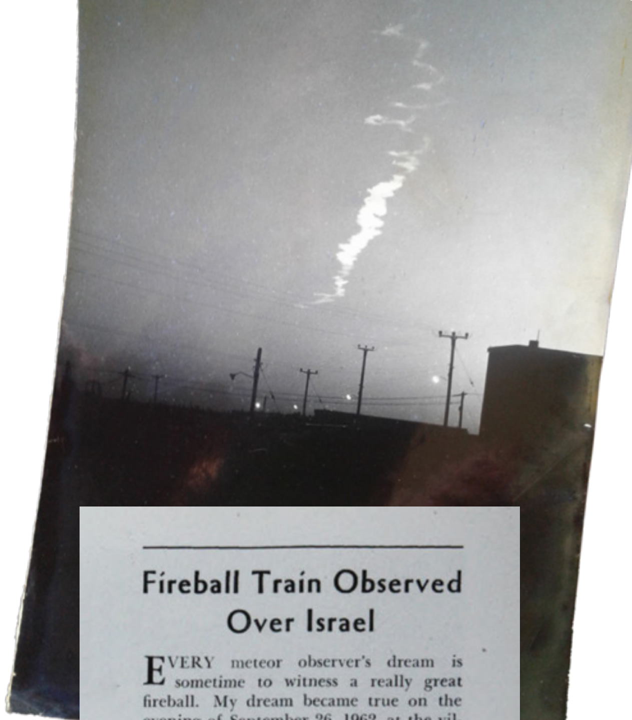
I sent an account of my observation to Israel's Association of Amateur Astronomers, to the American Meteor Society, and to Charles Federer, *S&T*'s editor. Federer wrote back that *S&T* would love to publish the piece, but could I possibly provide a photo?

I didn't have one myself, but providence intervened: A photograph appeared the very next morning in the Tel Aviv daily *Yedioth Ahronoth* (in English, *Latest News*). I contacted the photographer, who kindly sent me a print of his photo, which, as *S&T* later noted, he'd taken with a Rolleiflex camera on Ilford FP3 film. I mailed the photo to Federer, and it appeared on the cover of the July 1963 issue. Inside, adjacent to the Table of Contents on page 3, was my report under my then name Eli Metzger (which I later changed to the Hebrew Maor, meaning "a source of light").

This was my first article to appear in a publication outside Israel — and, I'm glad to report, not the last. Over the years I contributed eight more articles to *S&T* and got to know and work with five of its Editors in Chief.

One last note: As it happens, on the night of the fireball my soon-to-be wife — we were married two weeks later — was on a bus with her mother en route to getting her wedding dress when she heard the radio broadcast. It didn't mention me by name, but she knew instantly it was me. So this month we're celebrating two 60th anniversaries.

ELI MAOR's most recent feature article for the magazine, "1925: An Eclipse Like No Other," ran in the January 2017 issue.



Fireball Train Observed Over Israel

EVERY meteor observer's dream is sometime to witness a really great fireball. My dream became true on the evening of September 26, 1962, at the village where I am a science teacher, about 20 kilometers south of Haifa and three kilometers from the coast. It was about 15 minutes after sunset, and I had gone on a short walk to enjoy a fine, perfectly cloudless evening.

At 15:46 Universal time, I was looking toward the point where the sun had set, when suddenly my attention was caught by a burst of light to my left. Turning, I saw a great drop of brilliant white light descend slowly down the sky, leaving an extremely intense sharp train, whose brightness swiftly spread backward along its length.

I estimated the duration of fall as three seconds, but perhaps it was much less. The fireball first appeared 12 or 18 degrees above the horizon (I could not be sure as I was facing in another direction), and disappeared at four to five degrees. The path was inclined 70 degrees westward to the horizon, and the azimuth of the point of disappearance was 15 degrees west of south, as estimated afterward from Polaris.

This fireball was intermediate in brightness between Venus and the full moon, probably nearer the latter, and its hue resembled the white of burning magnesium ribbon.

The train was at first intensely white, but within seconds it changed into a column of very strongly red and orange clouds, these tints undoubtedly influenced by the sunset. The train thickened and slowly became distorted into zigzags. As a whole, the train did not drift, but remained suspended without movement in the sky.

Slowly fading and becoming white once more, the last scattered clouds of the train could be seen until 16:22 — that is, 36 minutes after the fall. Undoubtedly I could have traced it longer if I had had a field glass.

I informed the press and radio, and my report was broadcast with the 9 p.m. news. From the extensive accounts in the next morning's newspapers, I learned that this phenomenon had been witnessed by many people throughout Israel.

Fortunately, one of these observers was Nathan Sadan, in Beersheeba, about 250 kilometers south of Haifa. I first saw his picture of the train (see front cover) in a newspaper, and he kindly supplied a print for SKY AND TELESCOPE.

ELI METZGER
21 Rosen St.
Ramat-Chen (Tel-Aviv)
Israel

July, 1963, SKY AND TELESCOPE 3

METEOR-TRAIL PHOTO: NATHAN SADAN

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