FIRST EXPOSURE:
Tips for Better Astropics
PAGE 54

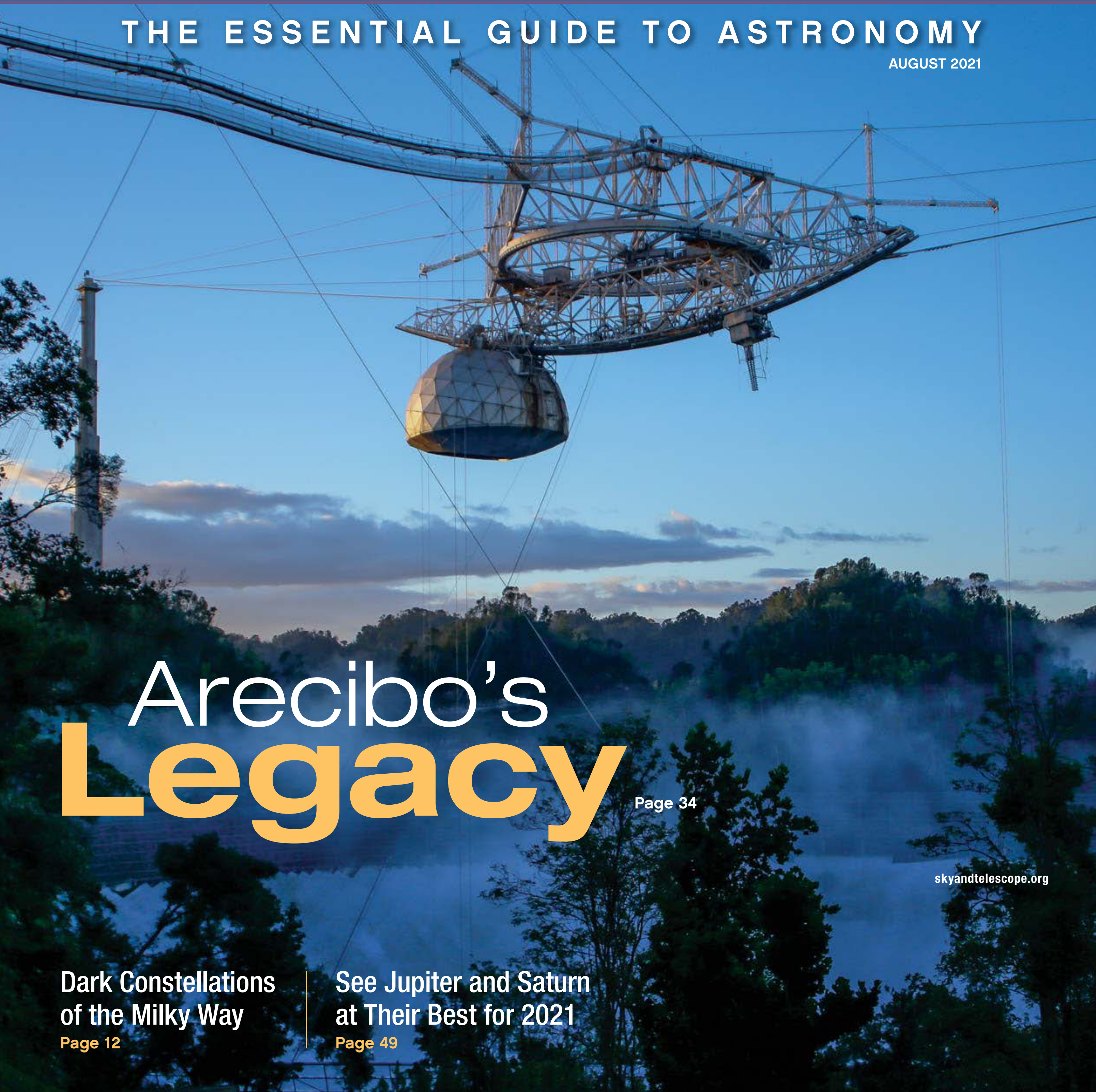
NEBULAE:
Cloud-Hop Through the Galaxy
PAGE 18

EQUIPMENT:
Binocular Buyers' Guide
PAGE 60

SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

AUGUST 2021



Arecibo's Legacy

Page 34

skyandtelescope.org

Dark Constellations of the Milky Way
Page 12

See Jupiter and Saturn at Their Best for 2021
Page 49

CONTENTS

SKY&TELESCOPE
THE ESSENTIAL GUIDE TO ASTRONOMY

August 2021 VOL. 142, NO. 2

12

JESSICA GULLBERG

ON THE COVER

The instrument platform above Arecibo's dish, before collapse

PHOTO: ISRAEL CABRERA

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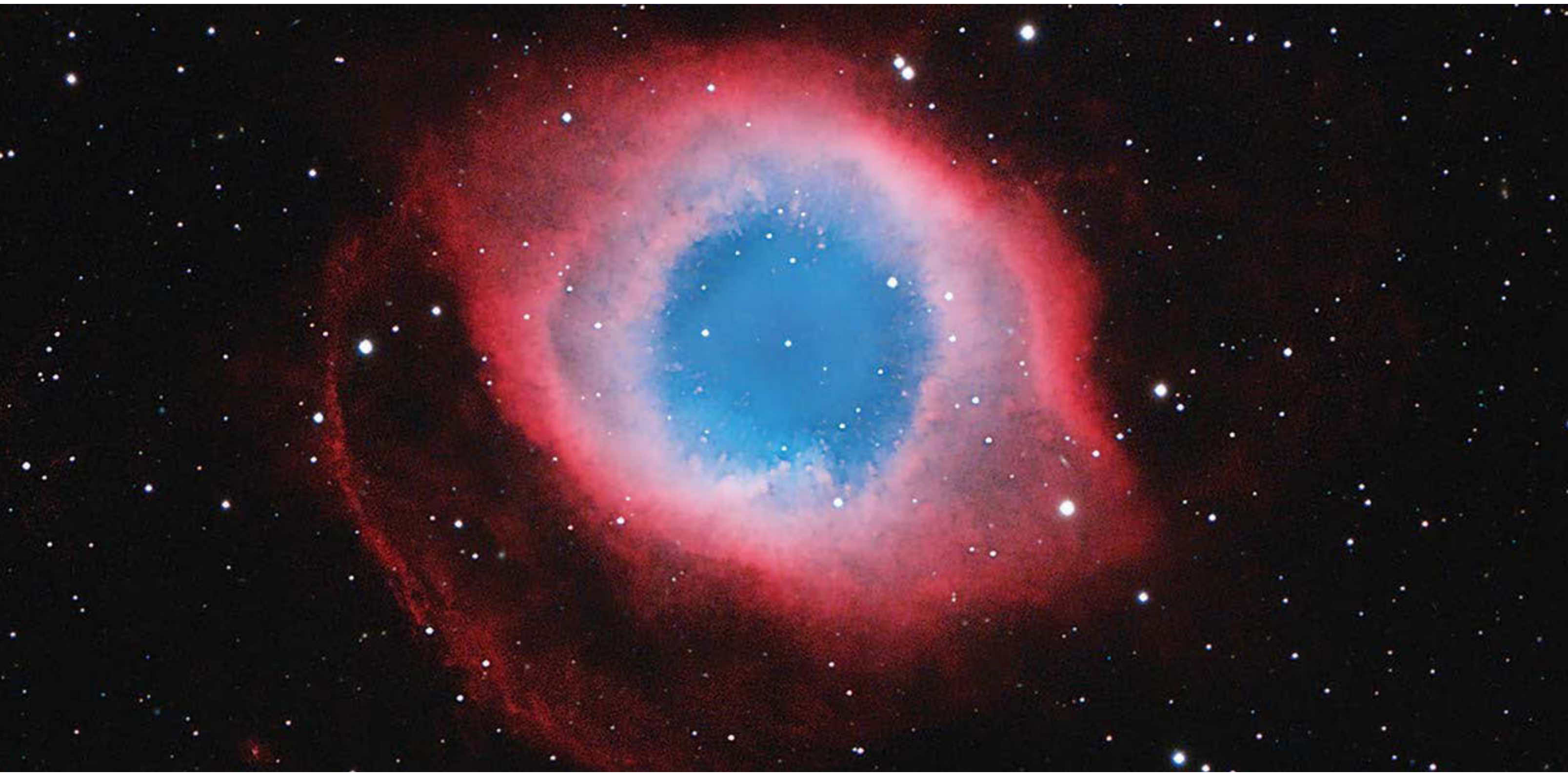

Vantage Points

ASTRONOMY HAS MEANT DIFFERENT THINGS to different peoples, with each society regarding the night sky in its own way. In this issue, we explore contributions that several cultures have made to our collective appreciation and interpretation of the firmament.

As writer Douglas MacDougal describes on page 24, the Babylonians were the first civilization to accurately track and record positions of the planets. They did so on a daily basis, giving rise to *ephemerides* (from the Latin *ephemeris*, diary) — tables that list the positions of celestial objects over time. Today, we compute ephemerides electronically, but their origin lies in calculations inscribed into cuneiform tablets beginning in the 7th century BC.

The Babylonians, and the ancient Greeks who built on their efforts, used stars to outline figures in the sky, many of which we still rely on today in our pantheon of constellations. But as archaeoastronomer Steve Gullberg explains on page 12, indigenous people elsewhere in the world discerned full-bodied figures in the opaque clouds of gas and dust that dot our galaxy. Often these *dark constellations* were culturally significant creatures, such as the llama was to the Inca.

▲ Artist's concept of the Emu and smaller Kangaroo dark constellations

JESSICA GULLBERG, FIGURES: GREGG DINDERMAN / *S&T*

Certain contemporary groups adhere to similar traditions. Aboriginal Australians recognize a vast Emu, with the Coalsack Nebula as its head and its legs stretching all the way to Scorpius. Argentina's Moqoit deem the Milky Way the trunk of a colossal tree, while western Torres Strait Islanders, an oceanic population north of Australia, see it as sediment stirred up by the shovelnose shark.

To many Puerto Ricans, by contrast, astronomy is synonymous with something human-built: Arecibo. As radio astronomer Gerrit Verschuur conveys on page 34, the telescope's collapse last December hit islanders hard. Arecibo had inspired numerous Puerto Ricans to go into science and engineering, many furthering radio astronomy by working and conducting research at the observatory.

All these contributions, together with those from Arabia, India, China, and divers other cultures both modern and ancient, have enriched our study and love of the stars. Without the unique cosmological viewpoints various societies have held over the millennia, astronomy today would be a much drier subject.

In closing, I'd like to laud two of our own contributors. This year's AAS Solar Physics Division Popular Media Award for a journalist went to News Editor Monica Young, while that for a scientist went to Contributing Editor Monica Bobra (for an infographic co-created by artist Nicolle Fuller). For more details, including the role other *S&T* staffers played, see **is.gd/solarawards**.

Peter

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

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

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Van Gogh Vision

Monica Young's News Note "Magnetic Whirlpool" (*S&T:* May 2021, p. 11) contains a remarkable image depicting the complex structure of the magnetic field associated with M51. It's reminiscent of *The Starry Night* by Dutch post-impressionist artist Vincent van Gogh. The eddy-like magnetic field lines portrayed in "Magnetic Whirlpool" closely resemble the bold, swirling brushstrokes of van Gogh's masterpiece. A side-by-side comparison of M51's magnetic streamlines and *The Starry Night* reveals the incredible relationship between science and art.

Frank Ridolfo • Bloomfield, Connecticut

▲ The magnetic streamlines overlaid on this image of M51 *(left)* are suggestive of Vincent van Gogh's famous painting *The Starry Night (right)*.

Advertising the Average Astronomer

Parents at inner-city school star parties often ask, "Why are you doing this?" I'd reply, "So the students can see the rings of Saturn." But the question they are actually asking is, "Why would you, a seemingly 'normal' person, own a telescope? Why would you take the time to set it up and look at the stars?" Most adults don't realize that astronomy is a passion that people can enjoy independently of work. One doesn't have to be a professional to love the night sky.

I've interacted with young people who are spellbound by astronomy. Unfortunately, many of these potential astronomers feel they must curb their enthusiasm or risk ridicule from friends and family. Why would their parents encourage an endeavor that they don't understand? TV shows like *Cosmos* do an excellent job of educating the public. However, Neil deGrasse Tyson isn't your average astronomer. He's a celebrity who helped Superman in *Action Comics* #14. More power to him, but who among us can aspire to that level of success?

Part-time astronomers need to let people know what we're doing. Not everyone has the time to visit a classroom, but nowadays anyone can create a YouTube channel. I know it's hard to risk looking foolish on the internet, but sometimes we have to take a chance.

Gordon Reade
Palo Alto, California

Entranced by the Cosmos

Those of us working in astronomy, whether as amateurs or professionals, get so embroiled in the details that we forget why we love the field. I was attracted by a fascination with the science. But at the same time, I was entranced by the beauty of astronomical objects.

It seems to me that we all owe it to the public to present not just the science of the universe but also its beauty. Not everyone wants to compile a light curve or write computer code, but we can all marvel at the loveliness of the cosmos.

I am particularly thrilled by interstellar nebulae. Recently, I was listening *Symphony Number 5 in D Minor, Opus 47* by Dmitri Shostakovich, which brought to mind images of nebulae. So I put the symphony and images of various nebulae together as a YouTube video: **https://is.gd/BeautyoftheUniverse**.

George Greenstein
Pelham, Massachusetts

Where Have All the Telescopes Gone?

There are millions of commercial and homemade instruments in the U.S. alone, yet, sadly, various surveys indicate that only a small percentage of these are actively used. As their owners have lost interest in using them, many lie in storage in a basement, attic, or garage. I've often felt like famed observer Leslie Peltier when he wrote of such idle scopes in his book *Starlight Nights*, "as they slowly gather the dust of the passing years, it seems that they must wonder just what has become of the hands which once so eagerly pointed them to the skies."

Even the smallest of optics can provide a lifetime of cosmic adventure in wandering the wondrous corridors of creation overhead at night. So if you're among those who've perhaps laid one of your early telescopes to rest and graduated to a larger or more sophisticated instrument, why not dust it off and give it to someone, thereby opening a whole new universe to them? I'm especially thinking here of young people, who in today's chaotic world desperately need to experience that "cosmic perspective" that Carl Sagan so often talked about.

James Mullaney
Lewes, Delaware

Scanning for Biosignatures

"Building a Better Biosignature" by Arwen Rimmer (*S&T:* May 2021, p. 34) speculates about the technology science-fiction characters use to scan for life when encountering a new world. I've been a *Star Trek* fan since day one and never really thought about the scanning technology. I assumed it had something to do with looking for roads, structures, heat signatures, electromagnetic emis-

WHIRLPOOL: SOFIA STREAMLINES: NASA / SOFIA SCIENCE TEAM / A. BORLAFF; BACKGROUND IMAGE: NASA / ESA / S. BECKWITH (STSCI) / HUBBLE HERITAGE TEAM (STSCI / AURA); STARRY NIGHT: MUSEUM OF MODERN ART / WIKIMEDIA COMMONS / PUBLIC DOMAIN sions, and other default indicators. Sure, they'd usually report the oxygen content and occasionally the surface gravity, but those are relatively easy. Until I read this piece, I didn't realize there were so many other chemical clues to consider. Thanks for opening my eyes to the fascinating future of biosignature detection.

Dan Heim
New River, Arizona

The writing in *S&T* is always top-notch, from the News Notes to the feature articles. I'm sure this must have as much to do with the editing as with the quality of the authors' writing. But the article on biosignatures is a cut above, what with its full explanation of every point, anticipating any questions a reader might have, and the distinctive, fun phraseology — not to mention treating data as the plural word it is. I look forward to more articles by Arwen Rimmer.

Joel Marks
Milford, Connecticut

Absorption Line Overload

"How Well Do We Know the Sun?" by Colin Stuart (*S&T:* Apr. 2021, p. 12) states that 67 elements have been identified in the Sun so far. The photograph on page 13 shows a beautiful and extremely detailed solar spectrum. Its caption notes that the dark absorption lines result from the presence of specific elements in the Sun's atmosphere. But the image shows far more than 67 elements. Why are there so many more absorption lines than elements?

James Schwartz
Valrico, Florida

Monica Young replies: *You're right, there are a lot more absorption lines than individual elements. Every element absorbs light at multiple wavelengths due to the many energy levels available to its electrons. Even hydrogen has a number of possible energy levels for its single electron and therefore can absorb several wavelengths of sunlight. Atoms with additional electrons can produce even more absorption lines.*

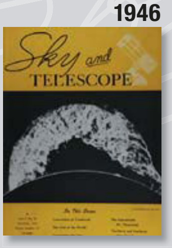
FOR THE RECORD

- The image of Pine Mountain Observatory in "Working With What You Have" (*S&T:* Jun. 2021, p. 54) was a 30-minute exposure shot with a tripod-mounted Canon 80D DSLR set to ISO 200 and a Canon kit lens zoomed to 20 mm and f/6.3.
- The "Selected Jupiter Mutual Satellite Events" tables in the May, June, and July 2021 issues had incorrect values in the "Mag. change" column. The correct ones are May 1: 0.0; 11: 0.7; 20: 0.5; 27: 0.4; June 1: 0.7; 10: 0.1; 18: 0.2; 21: 0.1; 28: 0.0; July 5: 0.0. Events with a change in magnitude of less than 0.3 are difficult to perceive, and those with a value of 0.0 are unobservable and shouldn't have been included.

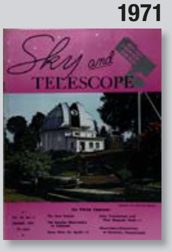
SUBMISSIONS: Write to *Sky & Telescope*, One Alewife Center, Suite 300B, Cambridge, MA 02140, USA or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1946



1971



1996

◖August 1946

UV Frontier "Films developed by Eastman Kodak Company with special fluorescent coatings will be used in spectrographs mounted in the noses of [captured] V-2 rockets. Ultraviolet sunlight, unable to penetrate either our atmosphere or ordinary photographic emulsions, will be recorded when the rockets reach altitudes of about 100 miles. The fluorescent film coating glows when ultraviolet light strikes it, and the glow is recorded on the film."

These early rocket flights, the first "baby steps" into ultraviolet astronomy, successfully recorded the spectral line of singly ionized magnesium at 280 nanometers.

◖August 1971

Shrinking Planet "[T]he mass of the planet Pluto was determined to be about 0.18 that of the earth, in a study by [U. S. Naval Observatory astronomers in 1968]. Their method was to evaluate the size of the perturbations that Pluto's gravitational attraction produces in the orbital motion of Neptune . . .

"This study has now been repeated and refined . . . The mass of Pluto is found to be 0.11 that of the earth . . . If the diameter of Pluto is accepted as 6,400 kilometers, then the mean density of the planet is about 0.88 the earth's. Thus it appears that Pluto may closely resemble Mars in size, mass, and density."

The flaw in all these early determinations was to assume, following Percival Lowell, that Pluto perturbs Neptune noticeably. It doesn't. We now know Pluto has just 0.002 the mass of Earth and about two-thirds the diameter of our own Moon.

◖August 1996

Stardust? "When a backyard observer witnesses a meteor, he or she sees the flaming residue of a piece of cosmic debris usually the size of a pebble. Many more particles are so small . . . that they vaporize unseen in the Earth's atmosphere. Nevertheless, astronomers have used radar to detect the ionized trails of such invisible meteors. One such system is the Advanced Meteor Orbit Radar (AMOR) in New Zealand. Not only can it 'see' the tracks of meteors as faint as 13th magnitude, but it allows astronomers to determine an incoming particle's trajectory and, hence, its orbit. . . .

"[As] Andrew D. Taylor (University of Adelaide) and his colleagues explain . . . about 14 percent of the more than 350,000 meteors AMOR detected traveled at more than 73 kilometers per second — fast enough to escape (or to have entered) the solar system along hyperbolic trajectories. . . .

"[With AMOR, they] hope to identify specific stellar sources of extrasolar dust."

But astronomers have since questioned the extrasolar origin of these tiny particles. The much larger bodies 1I/'Oumuamua (2017) and 2I/Borisov (2019) are our only confirmed visitors from other stars.

MARS

NASA's Ingenuity Helicopter Takes Flight

NASA'S INGENUITY Mars Helicopter flew into the history books of interplanetary aviation on April 19, 2021, when it conducted the first powered flight on another planet. Since then, the helicopter has flown higher, farther, and faster on four additional trips over the course of a month. As of press time, NASA has declared the technology demonstration a success and announced an extended operations phase designed to test the helicopter's capabilities.

The first flight lasted just 39.1 seconds, as the solar-powered helicopter spun its two counter-rotating pairs of rotor blades faster than 2,500 rotations per minute to lift itself into the thin Martian atmosphere. Ingenuity reached a height of 3 meters (10 feet) and hovered briefly before landing back on the surface. The helicopter carried a 13-megapixel color camera, which looks out at the horizon to image terrain, and a 0.5-megapixel black-and-white camera that faces downward for navigation. The Perseverance rover also documented the event from 64.3 meters away. The flight was run autonomously via previously uploaded software, as Mars was more than 15 light-minutes away at the time.

▲ Perseverance's navigation camera captured Ingenuity on its fifth flight, which took it on a one-way trip to a new airfield.

On April 22nd, the helicopter made a second flight, climbing to almost 5 meters before tilting 5°, which enabled the thrust from its rotors to carry it 2 meters sideways. On the third trip the helicopter traveled 50 meters out and back again, and the fourth flight took it on a roundtrip of 266 meters. Ingenuity broke its own speed record on the latter flight, moving at a maximum of 3.5 meters per second (8 mph).

NASA named the airfield that Ingenuity sortied from the Wright Brothers Field in honor of the field that hosted the first controlled, powered flight from Earth near Kitty Hawk, North Carolina. (That historic event was also brief, lasting only 12 seconds.) The International Civil Aviation Organization even bestowed on the field its own airport code: JZRO. Ingenuity also carries a postage stamp-sized swatch of muslin fabric from the original Wright Flyer.

The first flight of the new operations demonstration phase took Ingenuity away from the Wright Brothers Field for good. The helicopter traveled 129 meters downrange to a new site. Before landing, it rose to 10 meters to image the surrounding terrain.

Though Ingenuity was a proof of concept, NASA plans to use powered flight as a main component in future missions, including the nuclear-powered Dragonfly mission that will head to Saturn's largest moon, Titan. In the Mars helicopter's new phase of operations, it will scout, take stereo images, and test other capabilities to prepare future missions for flights in alien skies.

■ DAVID DICKINSON

Find video and audio of the flights at https://is.gd/Ingenuity.

BLACK HOLES

Is the "Unicorn" the Closest Black Hole?

THE INVISIBLE COMPANION to the red giant star V723 Monocerotis in Monoceros, the Unicorn, might be the nearest black hole at 1,500 light-years away. But not everyone is convinced.

Astronomers had previously cataloged the 8.3-magnitude variable star as an eclipsing binary. But when graduate student Tharindu Jayasinghe (Ohio State University) took a closer look at data from the All-Sky Automated Survey, the Kilodegree Extremely Little Telescope, and the Transiting Exoplanet Survey Satellite, he found that a distorted teardrop shape created by gravitational interactions with an even more massive companion could explain the red giant's brightness variations.

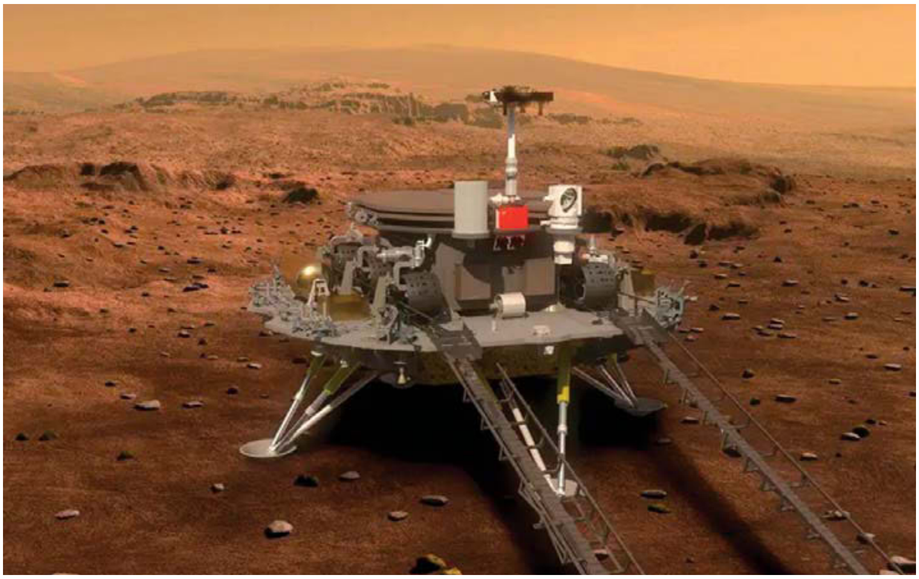
In the June *Monthly Notices of the Royal Astronomical Society*, Jayasinghe's team's estimates put the companion's mass at the equivalent of three Suns. They claim that a single compact body — a black hole — is the most likely explanation. Kento Masuda (Osaka University, Japan) and Teruyuki Hirano (National Institute of Natural Sciences, Japan) arrive at a similar conclusion in an independent analysis, posted on the arXiv preprint server.

However, Edward van den Heuvel (University of Amsterdam) is skepti-

NASA / JPL-CALTECH

SPACE

Firsts for China at Mars and in Low-Earth Orbit



▲ An artist's concept shows the Chinese rover perched atop the landing platform at the southern edge of the plains of Utopia Planitia. It will roll down the ramp to begin exploration.

TOUCHDOWN! On May 14th China's rover, named Zhurong for a mythical god of fire and war, landed at the southern edge of Utopia Planitia on Mars.

As of press time, the China National Space Administration has pronounced the landing successful but has not yet released images of the landing site. China is the fifth nation to attempt a soft landing on Mars and the third to succeed (though the Soviet Union's Mars 3 lander stopped functioning shortly after setting down).

The rover is part of the Tianwen 1 ("questions to heaven" in Chinese) mission, which also includes an orbiter and landing platform that accompanied the rover to the surface. The mission launched in July 2020 (*S&T:* July 2020, p. 22) and arrived in orbit around Mars in February 2021.

The rover entered the Martian atmosphere protected behind a heat shield, before discarding it and deploying a large parachute. Retrorockets slowed it further, and autonomous hazard avoidance guided the spacecraft on final approach. The orbiter served as a communications relay during the landing, and the European Space Agency and Argentina have also assisted in tracking the mission.

Zhurong's primary mission is set for at least 90 sols, or about three months. The solar-powered rover is equipped with six science packages, including a laser spectrometer, a climate weather package, a magnetometer, imagers, and ground-penetrating radar. Besides studying Martian regolith and geology, magnetic fields, and its weather and climate, Zhurong will also search for subsurface water ice. That "ground truth" will put data collected by the Tianwen 1 orbiter into context. The orbiter is designed to operate for at least a Martian year, or 687 days.

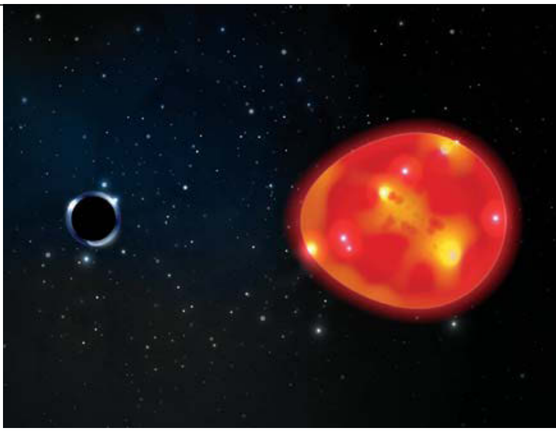
The successful landing closely follows another accomplishment: On April 29th, China launched the first section of its Tiangong ("heavenly palace") space station. The core module, Tianhe ("harmony of the heavens"), is the first of three parts, which together have a nominal lifetime of 10 years. Two other pieces, the Wentian and Mengtian experiment modules, are due to launch by early 2022. Tianhe is already scheduled to accept Tianzhou cargo vehicles and crewed Shenzhou spacecraft in May and June, respectively.

Due to U.S. technology trade restrictions, China has been conspicuously absent from the International Space Station, which has hosted a continuous human presence in space since 2000. It remains unclear whether China plans to maintain a permanent presence on the station, or if crews will rotate out in temporary expeditions.

■ DAVID DICKINSON

---

cal about the purported evidence for "non-interacting" low-mass black holes, in which there's no mass transfer, accretion disk, or X-ray emission to support the claim. Other claims of nearby black holes have not stood the test of time (e.g., *S&T:* Aug. 2020, p. 8). In the case of the "Unicorn," van den Heuvel thinks that what appears to be an invisible black hole could actually be a close pair of low-luminosity stars too faint to see.



▶ One explanation for the light variations from the red giant star V723 Monocerotis is that it has a distorted shape due to the tidal pull of a 3-solar-mass black hole companion, as shown in this artist's concept.

Then again, if V723 Monocerotis does orbit a bona fide black hole, it would be the smallest one found so far, part of a rare class of low-mass black holes. Filling this "mass gap" would shed light on black hole formation.

■ GOVERT SCHILLING

ZHURONG: CNSA; BLACK HOLE: LAUREN FANFER / OHIO STATE UNIVERSITY

NEUTRON STARS

What's Inside Neutron Stars?

SIZE MEASUREMENTS OF two neutron stars have narrowed down what kinds of exotic matter might exist in their extremely dense cores. There, where densities reach roughly twice that of an atomic nucleus, matter might transform, breaking neutrons into their constituent quarks or forming even more exotic particles.

To probe this ultra-dense matter, astronomers measure neutron stars' mass and radius, use these values to calculate how pressure changes with density (a relation known as the *equation of state*), and then compare this to nuclear physicists' predictions.

But measuring their size is tricky. Neutron stars' gravity is so extreme, it bends light leaving the surface like a funhouse mirror, making the objects appear bigger than they are. Anna Watts (University of Amsterdam) and Cole Miller (University of Maryland, College Park) led two independent teams using the Neutron star Interior Composition Explorer (NICER) telescope aboard the International Space Station to see through this light-bending effect.

By analyzing changes in brightness as short as 100 nanoseconds, Watts's and Miller's teams mapped hotspots rotating on the surfaces of two neutron stars, J0030+0451 and J0740+6620, and derived their true size. They published results for J0030 in 2019 and in April, the teams presented new results for J0740 at a virtual meeting of the American Physical Society.

At 1.4 times the mass of the Sun, J0030 barely had enough heft to collapse into a neutron star; meanwhile, J0740's 2.1 solar masses make it the most massive neutron star known. "Our new measurements of J0740 show that even though it's almost 50% more massive than J0030, it's essentially the same size," Watts says. "That challenges some of the more squeezable models of neutron star cores, including versions where the interior is just a sea of quarks."

▶ This animation frame shows an example of the hotspots that whirl around on the surfaces of the pulsars J0030 and J0740.

Yet, even though the observations rule out quark soup cores, they also suggest that the internal pressure is more intense than previously realized, which may rule out simpler neutron cores, too. Some hybrid scenarios incorporating both neutrons and quarks might still work. More exotic particles are still in play, too.

"Our fervent hope is that at least we're able to make a lot of nuclear physicists sweat," Miller says, "because this [result] is not easy to get into their models."

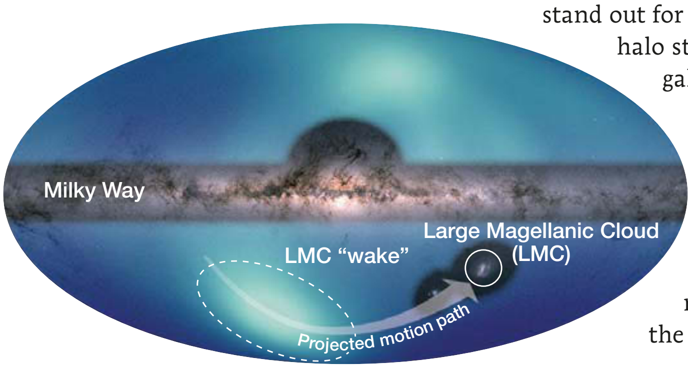
■ MONICA YOUNG

MILKY WAY

A Dark Matter "Wake" in Our Galaxy's Outer Reaches

THE LARGE MAGELLANIC CLOUD (LMC), the Milky Way's biggest satellite, is plowing through — and pulling on — the fog of dark matter that surrounds our galaxy. Sparse stars float like the tips of dark matter icebergs in this galactic ocean. Now, astronomers have definitively detected a pile-up in those stars (and presumably the dark matter, too) that the LMC has left in its wake as it makes its first pass. The results appear in the April 22nd *Nature*.

▼ Images of the Milky Way and the Large Magellanic Cloud are overlaid on a map of the surrounding galactic halo. Shades of blue represent stellar density, with lighter blue regions indicating stellar pileups.



Charlie Conroy (Center for Astrophysics, Harvard & Smithsonian) and colleagues plotted distances and positions for 1,301 giant stars between 200,000 and 330,000 light-years from the galactic center using data from the European Space Agency's Gaia satellite and NASA's Wide-field Infrared Survey Explorer. Two regions on the sky stand out for their thickness of halo stars: one below the galactic plane and one above. To the south, a stellar pile-up extends toward the Large Magellanic Cloud. The slightly less dense region of stars in the north is even larger, spanning a quarter of the sky.

The team compared the observed density of stars to computer simulations tracing the gravitational effects of the Large Magellanic Cloud as it passes around the Milky Way for the first time. Nicolás Garavito-Camargo (University of Arizona) led the work on the simulations, which show that a wake of stars (and dark matter) should trail the satellite as it falls through our galaxy's halo. The expected wake matches the location of the dense region of stars below the plane, though the observed contrast is even stronger than predicted.

Meanwhile, the Milky Way itself should move in response to the massive dwarf, which has a tenth of our galaxy's heft. As the pair's center of mass shifts, a weaker but wider-ranging effect gathers stars (and dark matter) closer together in a large region above the galactic plane.

This result helps astronomers refine their understanding of the complex dark matter halo around our galaxy.

■ MONICA YOUNG

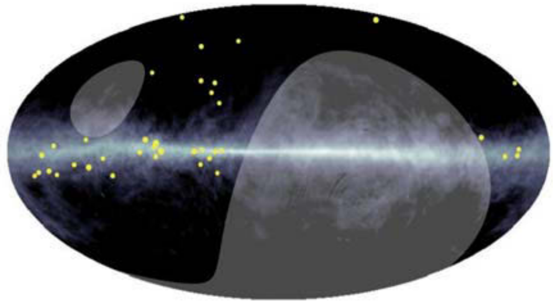
NEUTRON STAR: NASA'S GODDARD SPACE FLIGHT CENTER; MILKY WAY HALO STARS: NASA / ESA / JPL-CALTECH / CONROY ET. AL. 2021

COSMIC RAYS

Tibetan Observatory Sees Galactic PeVatrons

MOVE OVER, CERN. Unknown sources in the Milky Way dubbed "PeVatrons" accelerate protons to energies of a few peta-electron-volts (PeV) — dozens of times higher than the yield of the Large Hadron Collider. Now, data from a high-altitude experiment in Tibet confirm that these very-high-energy accelerators exist inside our galaxy.

Galactic magnetic fields bend the paths of cosmic rays, so they do not "point back" to their origin. But cosmic rays occasionally slam into cosmic microwave background photons, and the ensuing reaction imparts about 10% of the cosmic ray's energy into gamma rays. And unlike charged particles, gamma rays maintain their direction.



▶ The Tibet ASγ Collaboration found dozens of very-high-energy gamma rays (yellow points) concentrated along the Milky Way. (The gray shaded areas are outside the detectors' field of view.)

The recently upgraded, 31-year-old Tibet ASγ experiment registers the secondary particles that rain down when energetic gamma rays smash into Earth's atmosphere. Some 700 scintillators at an altitude of 4,300 meters (14,000 feet) in Tibet detect these air showers, revealing both the energy and direction of the original gamma ray.

Between 2014 and 2017, the Tibet ASγ Collaboration found a few dozen very-high-energy gamma rays not associated with other celestial sources; one of them is the most energetic gamma ray ever detected. They're concentrated along the band of the Milky Way, providing strong evidence for particle accelerators not only within our galaxy but spread over its disk, the team reports in the April 9th *Physical Review Letters*. Exactly what accelerates particles to such high energies remains unknown; possible sources include pulsars and star-forming regions.

■ GOVERT SCHILLING

IN BRIEF

2022 NASA Budget Proposal

The Biden administration has revealed its discretionary funding request for fiscal year 2022, including $10.2 billion for the National Science Foundation and $24.7 billion for NASA. The request represents 20% and 6.3% increases, respectively, relative to the enacted 2021 budget. The NASA budget would, among other things, fund the Artemis initiative to return humans to the Moon, missions to Europa and Titan (expected to launch in 2024 and 2027, respectively), the first-ever sample return from Mars, and the continuation of crewed missions to the International Space Station (ISS). The Artemis program, in particular, would receive $6.9 billion, $325 million more than in FY2021. For now, NASA will continue to rely on SpaceX and Orbital Sciences to bring crew and cargo to the ISS. The FY2022 proposal also continues development of the Nancy Grace Roman Space Telescope, which was threatened with termination in 2020 before being reinstated. The new request would also return NASA and NSF to advancing research in climate science, which took a deep cut under the previous administration (*S&T:* June 2020, p. 12), and increase funding for outreach initiatives. However, the request makes no mention of the Stratospheric Observatory, which the previous administration had also highlighted for termination in 2020.

■ DAVID DICKINSON

See the request at **https://is.gd/FY2022**.

AI Hunt for Quasar Lenses

New applications of machine learning (*S&T:* Dec. 2017, p. 20) have enabled astronomers to discover 12 quadruply lensed quasars. In each case, a foreground galaxy splits the light from a background quasar into four separate images. Astronomers can utilize these beautiful cosmic coincidences to obtain an independent measure of the universe's current expansion rate, a value that astronomers are still debating (*S&T:* June 2019, p. 22). It has taken four decades to find 56 of these rare alignments. Now, a project that subjects data from the European Space Agency's Gaia satellite to multiple machine-learning methods has picked out another dozen in one fell swoop. The team, led by Daniel Stern (JPL-Caltech), used multiple ground-based observatories to confirm the finds; the results will appear in the *Astrophysical Journal*. Not every machine-selected target turned out to be a quadruple lens: Foreground stars sometimes fooled the algorithms, masquerading as one or more distant quasar images. This "ground truth" offers the team a chance to revise their methods before applying them to the newest Gaia data release (*S&T:* Apr. 2021, p. 8). "Machine learning was key to our study, but it is not meant to replace human decisions," explains team member Alberto Krone-Martins (University of California, Irvine). "We continuously train and update the models in an ongoing learning loop, such that humans and the human expertise are an essential part of the loop."

■ MONICA YOUNG

Read more at **https://is.gd/AIquasars**.

Puzzling Far-out Gas Giant

Astronomers have imaged a super-Jupiter circling a young star 360 light-years away in the southern constellation Musca, the Fly. It's on a surprisingly wide orbit, about 115 times farther out than Earth is from the Sun — a distance that defies traditional ideas about planet formation. Alexander Bohn (Leiden University, The Netherlands) and colleagues were using the Spectro-Polarimetric High-contrast Exoplanet Research instrument on the European Southern Observatory's Very Large Telescope in Chile for the Young Suns Exoplanet Survey, directly imaging planets around infant stars, when they discovered the planet YSES 2b. The six-Jupiter-mass planet is still glowing with the heat of its formation in a system just 14 million years old. Astronomers think giant planets usually form closer to their star via a process called *core accretion*. But in the case of YSES 2b, there wouldn't be enough material so far from the star. The planet might instead have formed via *gravitational instability*, but Bohn says computer simulations of this process typically create much more massive brown dwarfs. However, Ken Rice (University of Edinburgh, UK), who was not involved in the study, says smaller masses could be possible. In the study, to appear in *Astronomy & Astrophysics*, the researchers suggest follow-up observations, such as of the planet's atmosphere, could help decide between scenarios.

■ JULIE FREYDLIN

Read more about YSES 2b at **https://is.gd/faroutgasgiant**.

APS; ATOMIC HYDROGEN DISTRIBUTION: HEASARC / LAMBDA / NASA / GFSC

The Milky Way's Dark Constell

Many cultures draw patterns in the sky not with stars but with darkness.

▲ **MILKY WAY** *Left:* This panoramic view of our galaxy's dusty plane combines images taken from Chile and the Canary Islands. *Right:* A different view of our galaxy, done in watercolor. We'll use this version to depict the dark constellations discussed in the piece.

ESO / SERGE BRUNIER

The Milky Way can be rather difficult to see these days, due to light pollution. Many in urban areas don't get a good look at it at all, and it can even lose some of its luster in rural locations. I can't discern much of our galaxy's dusty plane from where I live, but in 2019 I was fortunate enough to attend the Okie-Tex Star Party in Kenton, Oklahoma. This remote area is in the western tip of Oklahoma's panhandle, and its skies are magnificently dark. I was able to gaze upon the beauty of the Milky Way for the first time in quite a while.

People in ancient cultures were lucky, because they could see this wonder regularly. There wasn't much light after dark, and their skies were brilliant with the glow of countless stars when clear of clouds on moonless nights. Shadowlike swaths of dusty interstellar gas, including patches that we today call *dark nebulae* (see page 18), accentuated the beauty.

Because the sky was an integral part of daily experience, it's no surprise that many cultures employed astronomy in a number of ways. The field of *archaeoastronomy* studies how ancient peoples utilized their knowledge of the heavens. They often employed it calendrically for such matters as crop management and planning the dates of religious festivals. Some also engineered impressive visual effects of light and shadow at significant times of the year, such as at the solstices.

Of course, these civilizations also noted patterns in the sky. They imagined the shapes of powerful beings that they saw outlined by groups of stars, intertwined with their mythical cosmologies. The Sumerians and Babylonians, for example, cataloged the constellations of stars they observed and helped create the basis for the zodiac that we know today (*S&T:* Jan. 2018, p. 66). Babylonians used their celestial knowledge to foretell the future for their king and country (see page 24), and the Greeks built upon this with myths about their pantheon of gods.

But some cultures also saw *dark constellations*. Instead of the stick figures that the Babylonians and others drew with stars, dark constellations are shapes formed by the cloudlets

JESSICA GULLBERG

and tendrils of dusty gas in the Milky Way that blocks the light from the millions of stars beyond. These figures typically represent culturally significant animals. We know of examples from across the world, from Indonesia and Australia to the Americas and Africa. Most are in the Southern Hemisphere — perhaps because there, the Milky Way's center and dusty plane dominate the sky in a way they don't in the Northern Hemisphere.

Here, we'll focus on examples from three parts of the world that use the same section of the galaxy in their mythologies, one particularly well-suited for such cosmological imaginings.

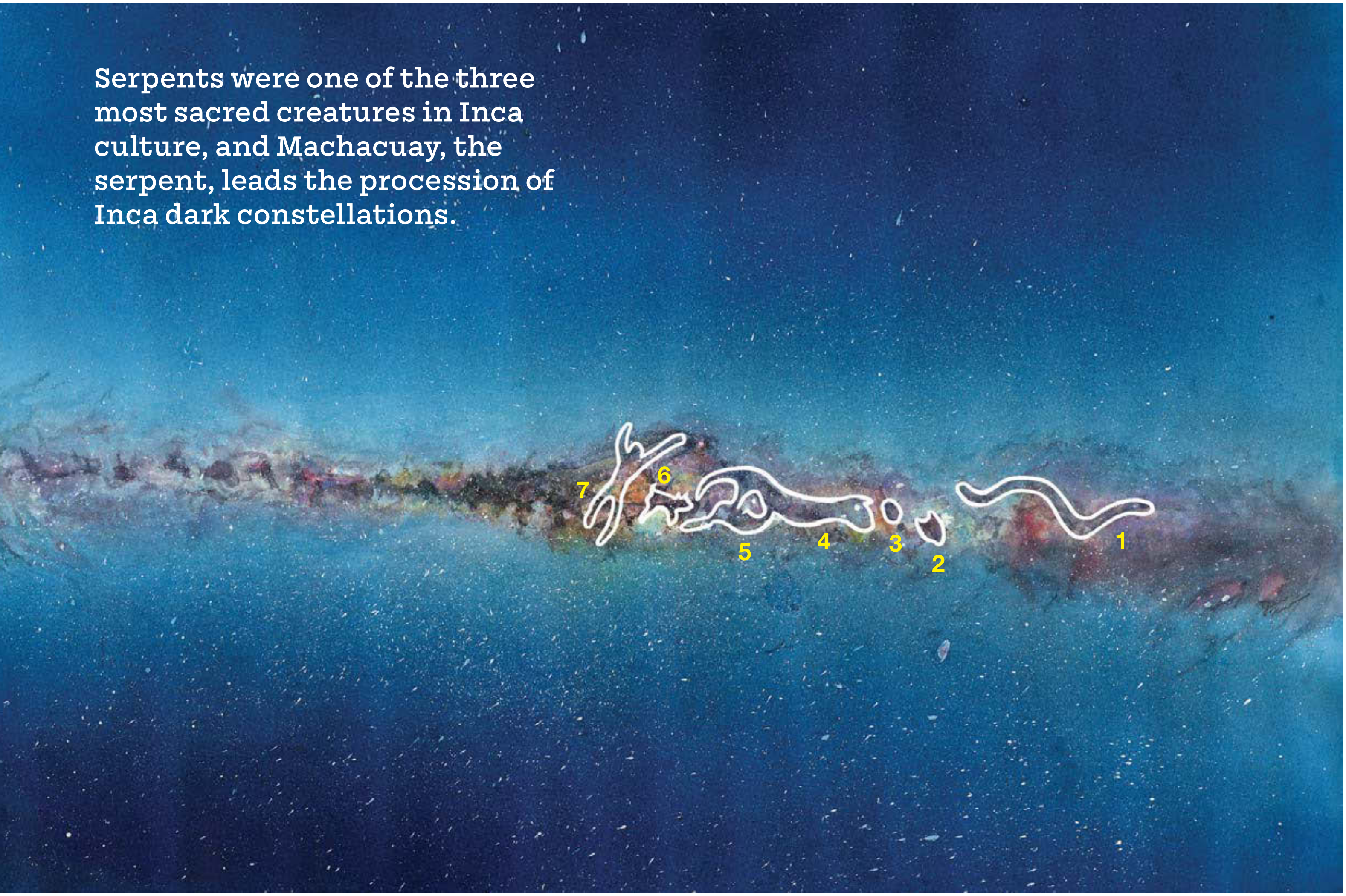
Dark Constellations in the Andes

The Inca Empire, with its capital in Cusco, stretched along the Andes from southern Colombia and Ecuador through Peru to Bolivia, Chile, and Argentina. The empire itself existed from approximately 1438 to 1532, but its people's descendants still live throughout the Andean highlands and speak dialects of Quechua, the Inca language. Much of what we know of Inca history and beliefs comes from the oral traditions these descendants continue to pass on from one generation to the next.

Instead of using the ecliptic as a reference, the Incas depended on the Milky Way to orient their celestial framework.

Instead of using the ecliptic as a reference, the Incas depended on the Milky Way to orient their celestial framework. To them, the Milky Way was a river flowing across the night sky — they believed that the waters of rivers on Earth were drawn into the heavens, traveled across the Milky Way, and then later returned to Earth as rain after a celestial rejuvenation. Our world was thought to float in a cosmic ocean, and when the Milky Way's orientation was properly aligned, water was drawn into the "celestial river."

The Incas saw several cosmologically significant animals in dark patches stretching across roughly 150° of the Milky Way's expanse. Mainly these animals were ones that figured prominently in Andean myth and traditions. The Incas believed many things to have life, sentience, and powerful influence. They thought that the dark animal constellations in the sky were alive and responsible for the procreation of their animal counterparts on Earth.



I was personally introduced to the Incas' dark constellations in 2007 while performing field research at a site called Llactapata, 5 km (3 mi) from Machu Picchu across a great gorge. My team and I had climbed the ridge from the river below and were camping overnight in order to photo-document the June solstice sunrise at Llactapata's Sun Temple. The sky was clear and inky black. I discussed the dark constellations with a local research assistant, Carlos Aranibar, who then took my green laser pointer and gave me an unforgettable tour, outlining each one for me. What I saw is still vivid in my memory, and experiencing this in the land of the Incas is something I will always treasure.

The seven dark constellations Carlos outlined for me comprised a varied

▲ **INCA DARK CONSTELLATIONS** Leading from right to left, we have (1) Machacuay, the Serpent; (2) Hanp'atu, the Toad; (3) Yutu, the Tinamou; (4) Yacana, the mother Llama; (5) Uñallamacha, the Baby Llama; (6) Atoq, the Fox; and (7) Michij runa, the Shepherd.

◀ **INCA AND MOQOIT** In its heyday, the Inca Empire stretched along several thousand kilometers of South America, following the coastline on one side and the Andes on the other. The Moqoit today primarily occupy a much smaller region in northern Argentina.

troupe of animals, including several that play central roles in Inca lore. Serpents, for example, were one of the three most sacred creatures in Inca culture, and Machacuay, the Serpent, leads the procession of Inca dark constellations as it moves across the sky from one horizon to the other.

A smaller dark constellation, Hanp'atu, the Toad, follows closely

INCA DARK CONSTELLATIONS: BACKGROUND: JESSICA GULLBERG, FIGURES: LEAH TISCIONE / S&T; MAP: GREGG DINDERMAN / S&T

The stars Alpha and Beta Centauri are the dogs of Lapilalaxachi, and they chase and bite the Mañic.

▲ **THE MAÑIC** The Moqoit see a huge rhea along the Milky Way, chased there by a hunter to protect humans from the bird.

BACKGROUND: JESSICA GULLBERG, RHEA: LEAH TISCIONE / S&T

behind Machacuay. Toads were thought of as bad omens because they were created by the devil.

Yutu, the Tinamou (a large, ground-dwelling bird), follows Hanp'atu in the Incan Milky Way and is about the same size. In Western astronomy we know this dark area near the Southern Cross as the Coalsack. It features in several cultures' sky mythologies, as we'll see.

Llamas are prominent in many Inca traditions, and Yacana, the Llama, is the most prominent of the Incas' dark constellations. It follows Yutu and is situated between our constellations of Centaurus and Scorpius. The stars Alpha and Beta Centauri are known as Llamacñawin, the eyes of the Llama. Beneath Yacana is a smaller dark constellation called Uñallamacha, a baby llama said to be suckling its mother.

Following Yacana and Uñallamacha is a smaller constellation called Atoq, the Fox. Atoq lies on the ecliptic between the constellations of Scorpius and Sagittarius.

There are two differing ideas about the seventh and last dark constellation. Some say that this was a second Yutu while others maintain it was Michij runa, a shepherd driving the procession. Michij runa is shown here on page 14; a second Yutu would be much smaller, in the approximate location of Michij runa's lower leg.

Dark Constellations in Argentina

Staying in South America and moving southeast, we encounter the Moqoit. The Moqoit, or Mocoví, today live in the southern part of the Gran Chaco region, in northeastern Argentina. Like the Incan people, the Moqoit structure much of their understanding of the heavens around the Milky Way — it essentially forms the axis of their night sky.

The Moqoit also pay great attention to the dark areas of the Milky Way. Their principal constellation is the Mañic. The Moqoit believe each animal species has a master, and the Mañic is the mythical master of South American rheas, which are large flightless birds similar to ostriches.

Moqoit myth talks about the Mañic sheltering in burrows, under the roots of the ombú. The ombú is a tree species native to the grasslands of this region and has a giant, spongy trunk and large canopy. Much like its terrestrial counterpart, the celestial ombú was the world tree looming over the landscape. The Milky Way formed its trunk, connecting the roots in the ground to the canopy in the sky. The celestial tree was where the Mañic would eat humans.

The legend continues with Lapilalaxachi, who was a powerful human ancestor of the Moqoit and whom they identified with the Pleiades. Lapilalaxachi set out to confront the Mañic and pursued it throughout the world. Once treed by Lapilalaxachi, the Mañic climbed the ombú trunk far into the sky. The bird forms a gigantic dark constellation, with its head beginning at the Coalsack and its body stretching some 70° behind to the constellation of Sagittarius. The stars Alpha and Beta Cen are the dogs of Lapilalaxachi, and they chase and bite the Mañic.

The Moqoit also use another part of the Milky Way to construct a figure by combining dark areas with individual stars. This hybrid entity is called the Mapiqo'xoic, or the old algarrobo tree, and is in the part of the sky we know as Sagittarius.

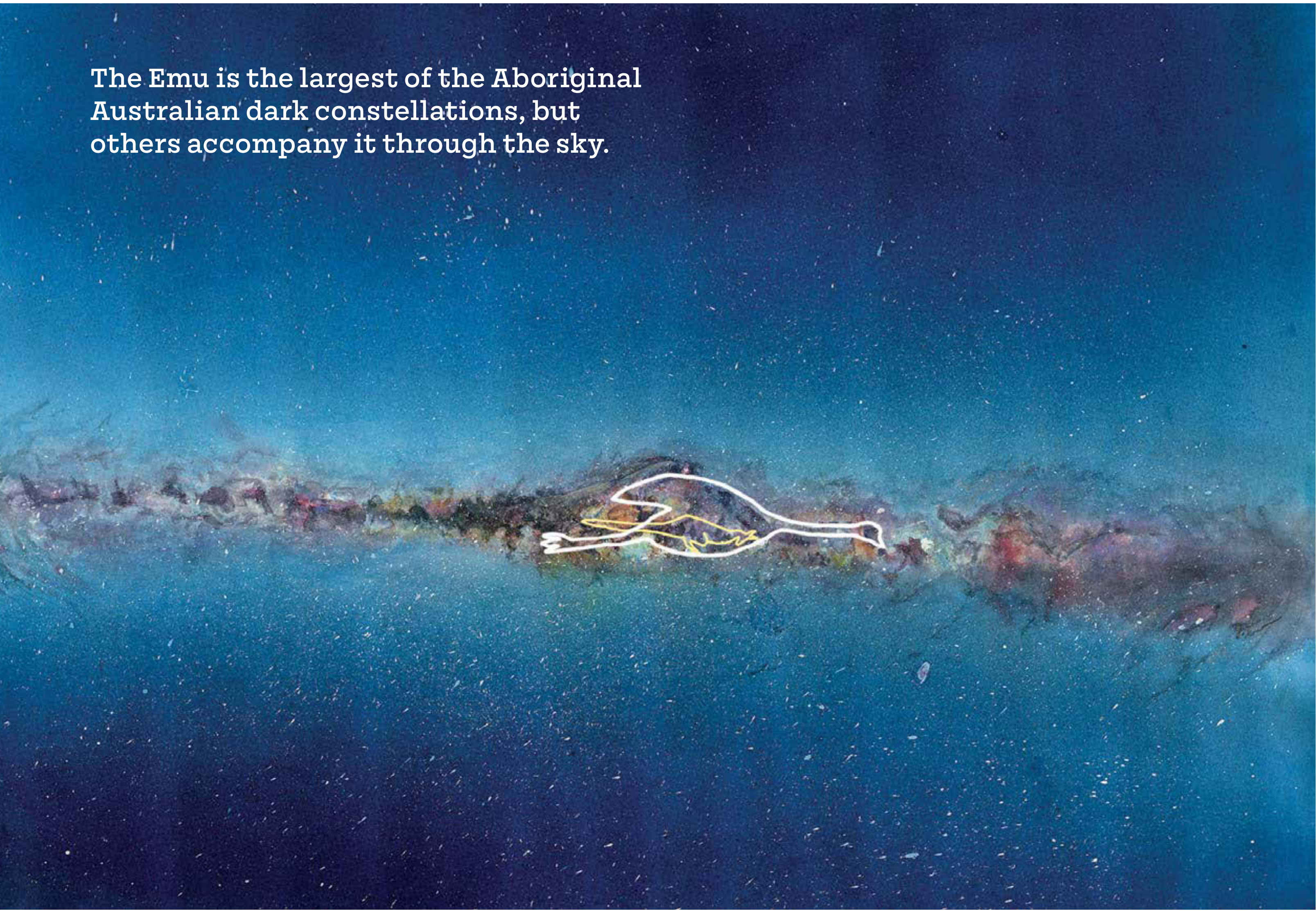
Dark Constellations in Australia

Moving to the continent of Australia, we find several groups who use dark constellations, often paired with a vision of the Milky Way as a celestial river. Some see dark spaces in the Milky Way as water holes or caves, occasionally home to creatures or evil spirits. In Wardaman traditions, for example, the Coalsack represents a dark cave with the evil spirit Utdjungon inside. The myth holds that if humans break traditional law, the spirit will end the world by casting down a fiery star. In Wiradjuri cosmology, meanwhile, a serpent called Wāwi lurks in a dark area between the Southern Cross and the constellation Vela.

Although many picture kangaroos and koalas when thinking of Australian wildlife, one of the continent's most

▼ **THE EMU AND KANGAROO** Several Aboriginal Australian groups see an emu in the sky — it's called Gawarrgay by the Kamilaroi, for example. Overlapping the celestial emu's body is a kangaroo. At other times of the year, these creatures are replaced by crocodiles.

BACKGROUND: JESSICA GULLBERG, FIGURES: GREGG DINDERMAN / S&T



notable land creatures is the emu. Emus are large, flightless birds similar to rheas and ostriches and are found in much of Australia. Aboriginal Australians have long used emu eggs as a source of nutrition, gathering them by luring away the male emus — which incubate the eggs — so as to raid the nests.

Understandably, then, the emu also appears in the Australian sky. The Emu is the best known Aboriginal Australian dark constellation. It appears in the traditions of the Kamilaroi and Euahlayi in northern New South Wales, as well as in other Indigenous cultures across the country. Like the Mañic, the Emu's head begins at the Coalsack, with its body stretching across Centaurus into Scorpius and Sagittarius.

The changing orientations of the Emu over the course of the year have great cultural significance. When the Emu rises in April and May, it depicts a female emu that's pursuing a male emu to mate. In June and July, the Emu has gained considerable altitude and is now a male that's nesting and incubating eggs. This marks the time to gather such eggs on Earth. In August and September the Emu is perpendicular to the horizon, a male rising from the nest when the chicks hatch — corresponding to the end of the emus' incubation period. Aboriginal Australian initiation ceremonies begin at the time of this orientation.

When the celestial Emu sinks low to the horizon in October and November, the head and neck are difficult to see. The visible part along the Milky Way's bulge now portrays an emu sitting in a water hole, displacing water and causing the land to dry in the hot months of the Southern Hemisphere's summer. The Emu then leaves the water holes, which are now dry.

The Emu is the largest of the Aboriginal Australian dark constellations, but others accompany it through the sky. In Kamilaroi and Euahlayi traditions, dark areas in the Milky Way beneath the Emu represent a Kangaroo. Additionally, beginning in September and October, some see dark Crocodiles stretching through Sagittarius, which also mark the time for ceremony.

▲ **ABORIGINAL AUSTRALIANS AND POLYNESIANS** Several groups in Australia and New Zealand trace dark constellations along the Milky Way. Shown here are cultures mentioned in the article.

GREGG DINDERMAN / S&T

Some see dark spaces in the Milky Way as water holes or caves, occasionally home to creatures or evil spirits.

Commonalities

Any part of the Milky Way is magnificent when viewed under clear skies far from light pollution, but as shown by these examples, creatures seen in the Southern Hemisphere tend to cluster in one particular region of the galaxy, where dark areas are especially prominent. Entities envisioned by the Incas, the Moqoit, and the Aboriginal Australians are all located in a section that stretches through Centaurus, Scorpius, and Sagittarius. The Tupi in Brazil also see a rhea in the same part of the Milky Way as the Aboriginal Australians see the Emu and the Moqoit the Mañic. It's quite interesting that several cultures independently saw birdlike creatures with long necks in the same part of the galaxy. (And although the Incas' Llama isn't a bird, it does have a long neck.)

Doubtless due to their geography, these peoples largely drew land animals. But a recurring theme among oceanic cultures is to imagine sea creatures in the sky. Various peoples have viewed the Milky Way as a waterway teeming with living creatures, including celestial sharks: The Torres Strait Islanders of Australia, for example, see in the Milky Way a shovelnose shark kicking up debris from the seafloor, while for the Māori of New Zealand it's a watery home to a shark.

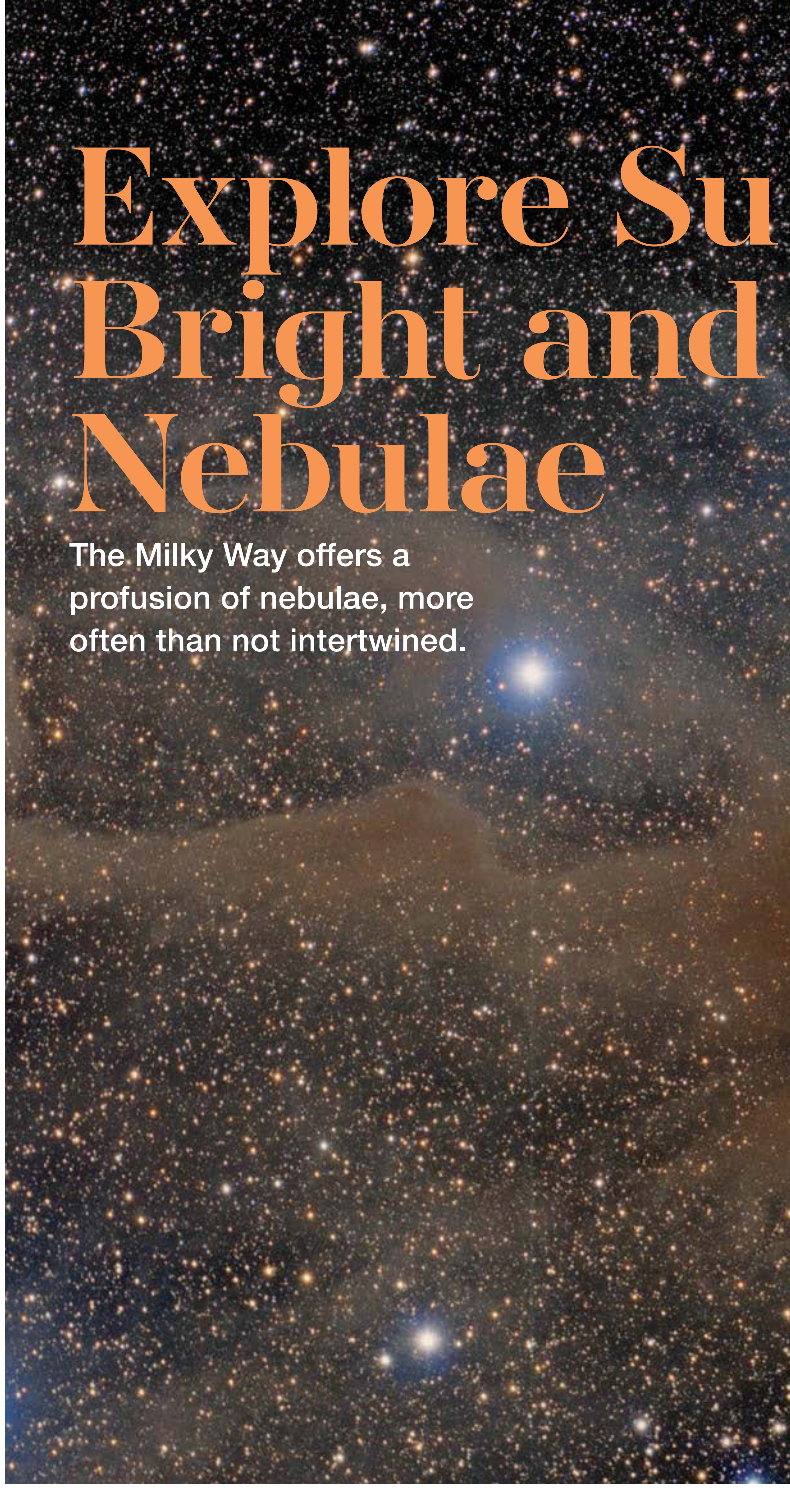
Unsurprisingly, many skygazers have used the stark, mysterious shape of the Coalsack in their celestial stories. Some relate the dark nebula with fish and fishing. The Bugis of Indonesia see the Coalsack as Bembé' é, the Goat, which foretells calm weather when hidden by haze. The Māori even have multiple names for the Coalsack.

But the Milky Way isn't always viewed as a waterway. Others see our galaxy as a road or passageway. Certain Native American cultures perceive the Milky Way as a road to the afterlife, a pathway between worlds taken by departing spirits. And echoing the Moqoit's vision, the Maya thought of the Milky Way as a world tree and an entrance leading to the underworld.

These are only some of the patterns that the world's cultures have recognized in the dark areas created by the gas and dust obscuring our galaxy. The Milky Way has readily captured peoples' attention for millennia, and dark constellations are a fascinating part of cultural astronomy and another great example of how humans throughout history have been influenced by the night sky.

■ **STEVE GULLBERG** is the director for archaeoastronomy at the University of Oklahoma and is the International Astronomical Union's chair for archaeoastronomy and astronomy in culture. His recent book is *Astronomy of the Inca Empire: Use and Significance of the Sun and the Night Sky*. Steve's wife, Jessica, painted the Milky Way used to depict the dark constellations in this article.

 by Richard P. Wilds



Explore Su
Bright and
Nebulae

The Milky Way offers a profusion of nebulae, more often than not intertwined.

FRANK SACKENHEIM

Early observers of nebulae — among them noted American astronomer E. E. Barnard and German astrophotography pioneer Max Wolf — noticed that bright and dark cosmic clouds often cluster together. William Herschel famously referred to the complexity of such objects when he described the Rho Ophiuchi cloud as a “hole in the sky!” He also noted the positional relationship between dark nebulae and rich star clusters that we now refer to as globular clusters. The Rho Ophiuchi region is a well-known example of this juxtaposition, but there are many more. Let’s begin our exploration of collections of nebulae in the summer sky, starting at southern declinations and gradually moving northward.

First Stop: Corona Australis

Head for the boundary between the Southern Crown and Sagittarius, a bit less than 1° west-northwest of Gamma (γ) Coronae Australis. A classic scenario that would have pleased observers of yore greets us: Not only do we find intertwined bright and dark nebulae, but also a nearby globular cluster (NGC 6723) to boot.

German astronomer and geophysicist Johann Friedrich Julius Schmidt discovered **NGC 6726/27** in 1860. The variable star TY Coronae Australis and the young stellar object HD 176386 power these overlapping nebulae, while a double star lurks nearby. A year later, Schmidt identified **NGC 6729**, a variable reflection nebula reminiscent of NGC 6621 (Hubble’s Variable Nebula). The variable binary R Coronae Australis illuminates the northwestern end, while T Coronae Australis occupies the southeastern corner. A high-power eyepiece will bring the double stars in both objects into view. Immediately to the southwest you’ll come to the large and diffuse **IC 4812** (discovered by American astronomer DeLisle Stewart in 1899). A wide-field eyepiece works best for this expansive target.

These reflection nebulae are all on the northwestern edge of a huge pair of dark clouds comprising **SL 39** and **SL 40**. English astronomer Harold Knox-Shaw chronicled his observations of this region in 1916 while he was superintendent of the Khedivial Observatory at Helwan, Egypt. Knox-Shaw encouraged Barnard to focus on dark nebulae, which Barnard famously did, going on to publish a catalog several years later. And yet, curiously, in spite of Knox-Shaw’s urgings, Barnard never covered this particular collection of objects.

Corona Australis

Object	Type	Size/Sep	RA	Dec.
NGC 6726/27	Reflection	9′ × 7′	19^h 01.7^m	–36° 53′
NGC 6729	Emission/ Reflection	1′ × 1′	19^h 01.9^m	–36° 57′
IC 4812	Reflection	10′ × 7′	19^h 01.1^m	–37° 04′
SL 39	Dark	42′ × 42′	19^h 03.8^m	–37° 16′
SL 40	Dark	15′ × 15′	19^h 02.9^m	–37° 07′

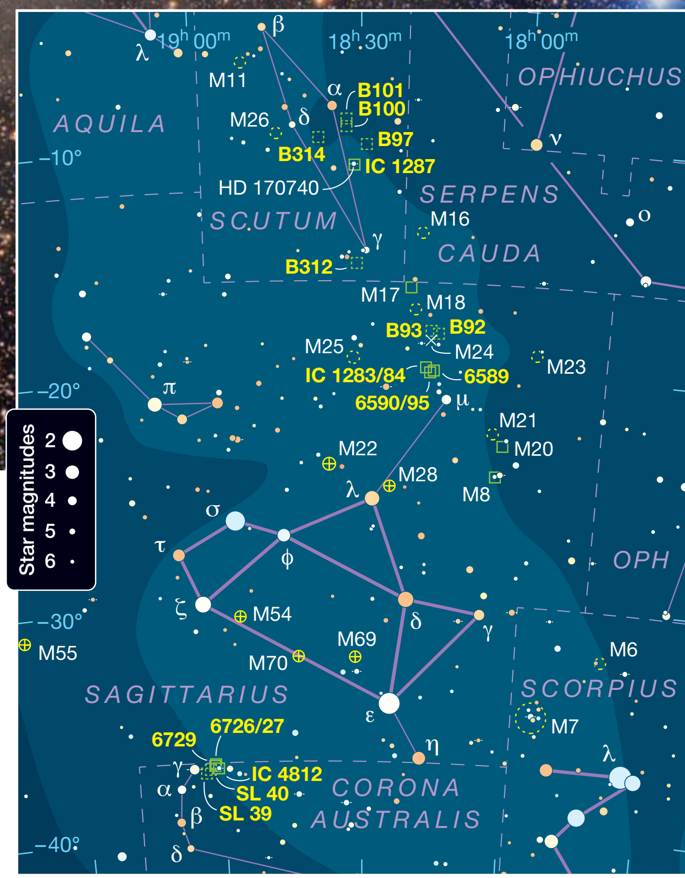
Angular sizes are from recent catalogs. Visually, an object’s size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

Sliding into Sagittarius

Now let’s visit the well-known Small Sagittarius Star Cloud (M24) to find **B92** and **B93**. The richness of the background greatly enhances the visibility of these nebulae and makes B92 one of the easiest dark clouds to observe. It has a lone 11th-magnitude foreground star that’s conspicuous in any telescope under a dark sky, as is the general outline of the nebula itself. However, if your telescope can go down to 15th magnitude (or fainter) the nebula will be more defined. The 8th-magnitude star HD 167411 is just 2′ east of B92, and if you continue east from the star some 10′, you’ll arrive at the bottom end of B93. While also easy to discern, B93 isn’t quite as impressive as B92.

mmer's Dark

HEAVENLY SIGHT This clustering of nebulae in Corona Australis epitomizes the juxtaposition of dark clouds and bright reflection nebulae. The nearby globular cluster NGC 6723 joins NGC 6726/27 and friends, a detail that would have pleased William Herschel no end.



Tracking back to B92 and slewing about ½° southwest into M24 along the more delicate line of B304 brings us to a beautiful star chain that I refer to as the "Dragon's Tail," with 8th-magnitude HD 166982 anchoring it. From B92, swing about 1½° south-southeast to arrive at our next collection of objects: the reflection nebulae **NGC 6589** and **NGC 6590/95** (NGC 6595 is an open cluster at the position of NGC 6590), and the emission nebulae **IC 1283/84**. Though often overlooked, these bright objects are fairly straightforward to view in small telescopes. The underlying dark background provides a nice contrast for these nebulae. Both NGCs are concentrated objects that can take magnification quite well. However, to get a quality view of IC 1283/84, you should use a low-power eyepiece to provide the contrast necessary to bring the bright nebulosity into view against the dark cloud below.

Slewing to Scutum

The best news about **IC 1287** (Barnard also discovered bright objects, this one in 1892) is that it sits just southwest of a wonderful region, the Scutum Star Cloud. A rich-field telescope with a wide-angle eyepiece provides an enchanting view, revealing the massive star cloud and surrounding dark nebulae: **B97**, **B100**, **B101**, and **B314**. We're talking about an area of sky that's about nine square degrees in size. You'll have to slowly sweep your scope across the area multiple times, registering your location between slews by noting markers such as specific stars, star clusters, and even dark nebulae. For example, B100 and B101 are 10′ north of 8th-magnitude star HD 170901 and are 40′ southeast of 4th-magnitude Alpha (α) Scuti.

As you sweep southwest in the star cloud you'll turn up B97. A Mira-type variable star inhabits this nebula: V441 Scuti, which ranges in magnitude from 5.2 to 8.1. Continuing east 1° or so brings you to B314, which sculpts the other side of the star cloud. Circling back south and west returns you to IC 1287. Overall faintness and the presence of 5.7-magnitude HD 170740, which illuminates the nebula, make for a challenging find. Slewing farther south to the border with Sagittarius, we can take in the extensive dark nebula **B312**. It's not hard to locate thanks to the rich star field that fills the region.

Veering to Vulpecula

In order to visit our next targets in the Fox, we'll have to

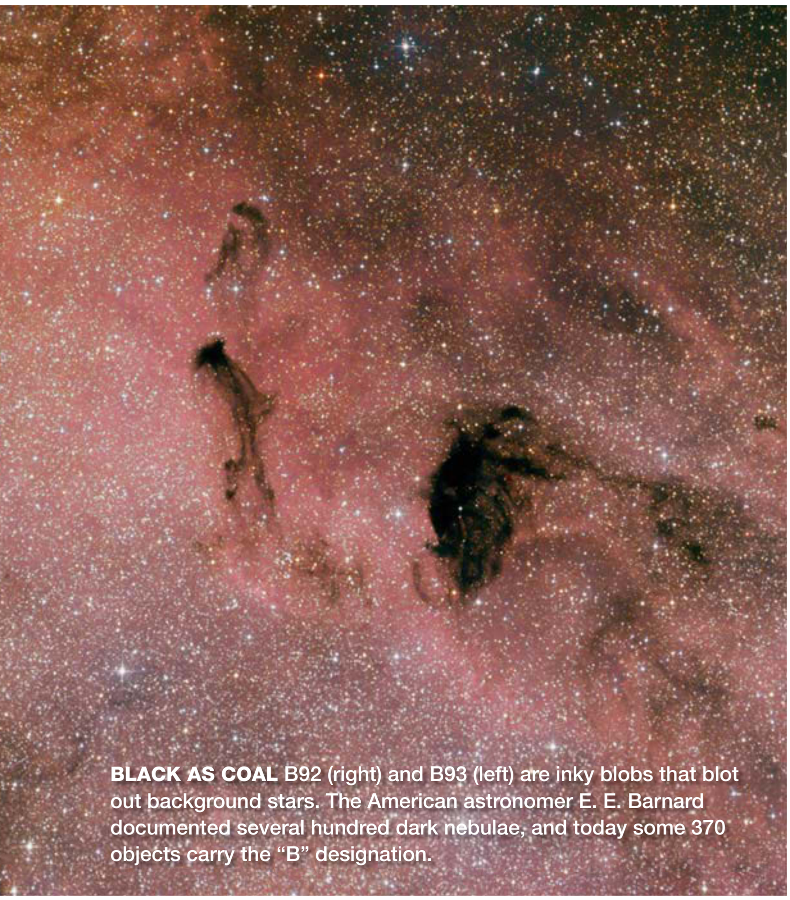
Sagittarius

Object	Type	Size/Sep	RA	Dec.
B92	Dark	15′ × 9′	18^h 15.6^m	–18° 14′
B93	Dark	15′ × 2′	18^h 16.9^m	–18° 04′
NGC 6589	Reflection	5′ × 3′	18^h 16.9^m	–19° 47′
NGC 6590/95	Reflection	4′ × 3′	18^h 17.1^m	–19° 52′
IC 1283/84	Emission/ Reflection	17′ × 15′	18^h 17.6^m	–19° 40′

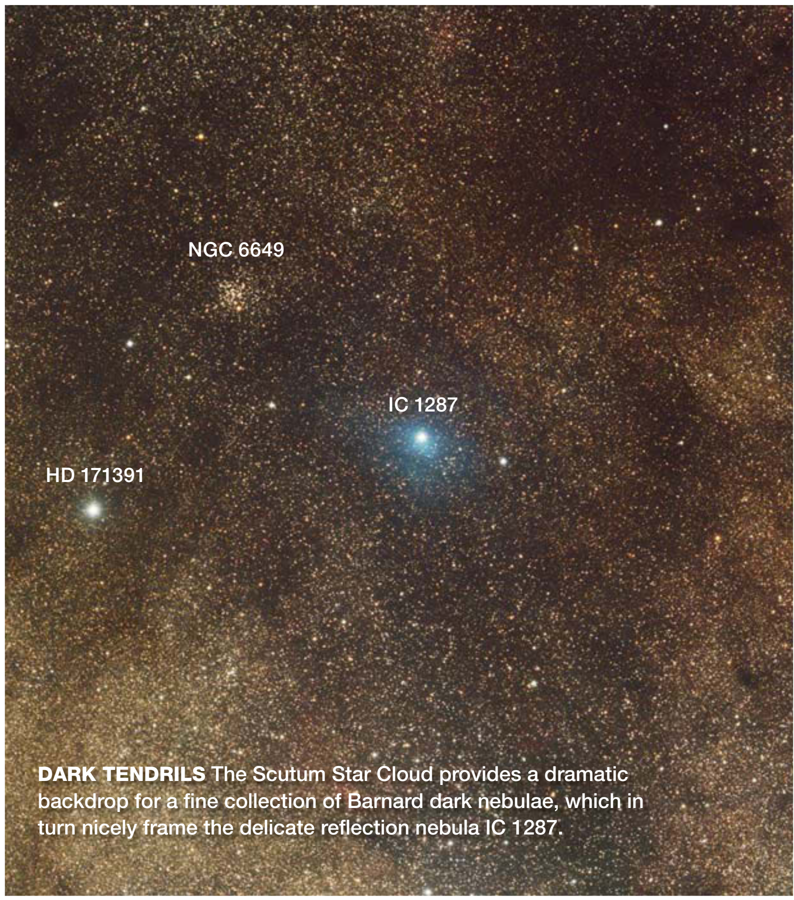
Scutum

Object	Type	Size/Sep	RA	Dec.
IC 1287	Reflection	20′ × 10′	18^h 30.4^m	–10° 48′
B97	Dark	50′ × 50′	18^h 29.1^m	–09° 55′
B100	Dark	16′ × 16′	18^h 32.7^m	–09° 09′
B101	Dark	13′ × 4′	18^h 32.7^m	–08° 49′
B314	Dark	35′ × 25′	18^h 37.1^m	–09° 43′
B312	Dark	100′ × 30′	18^h 32.2^m	–15° 35′

KONSTANTIN VON POSCHINGER / CCDGUIDE.COM (2)



BLACK AS COAL B92 (right) and B93 (left) are inky blobs that blot out background stars. The American astronomer E. E. Barnard documented several hundred dark nebulae, and today some 370 objects carry the "B" designation.



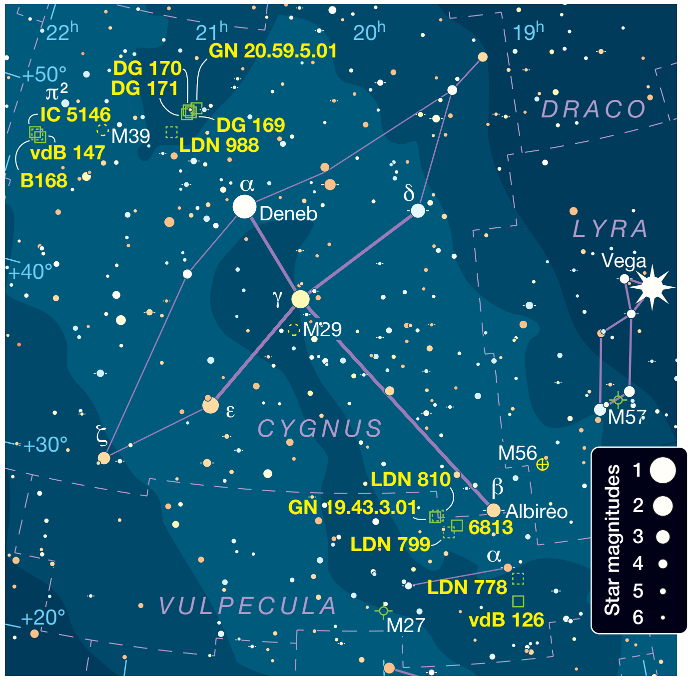
DARK TENDRILS The Scutum Star Cloud provides a dramatic backdrop for a fine collection of Barnard dark nebulae, which in turn nicely frame the delicate reflection nebula IC 1287.

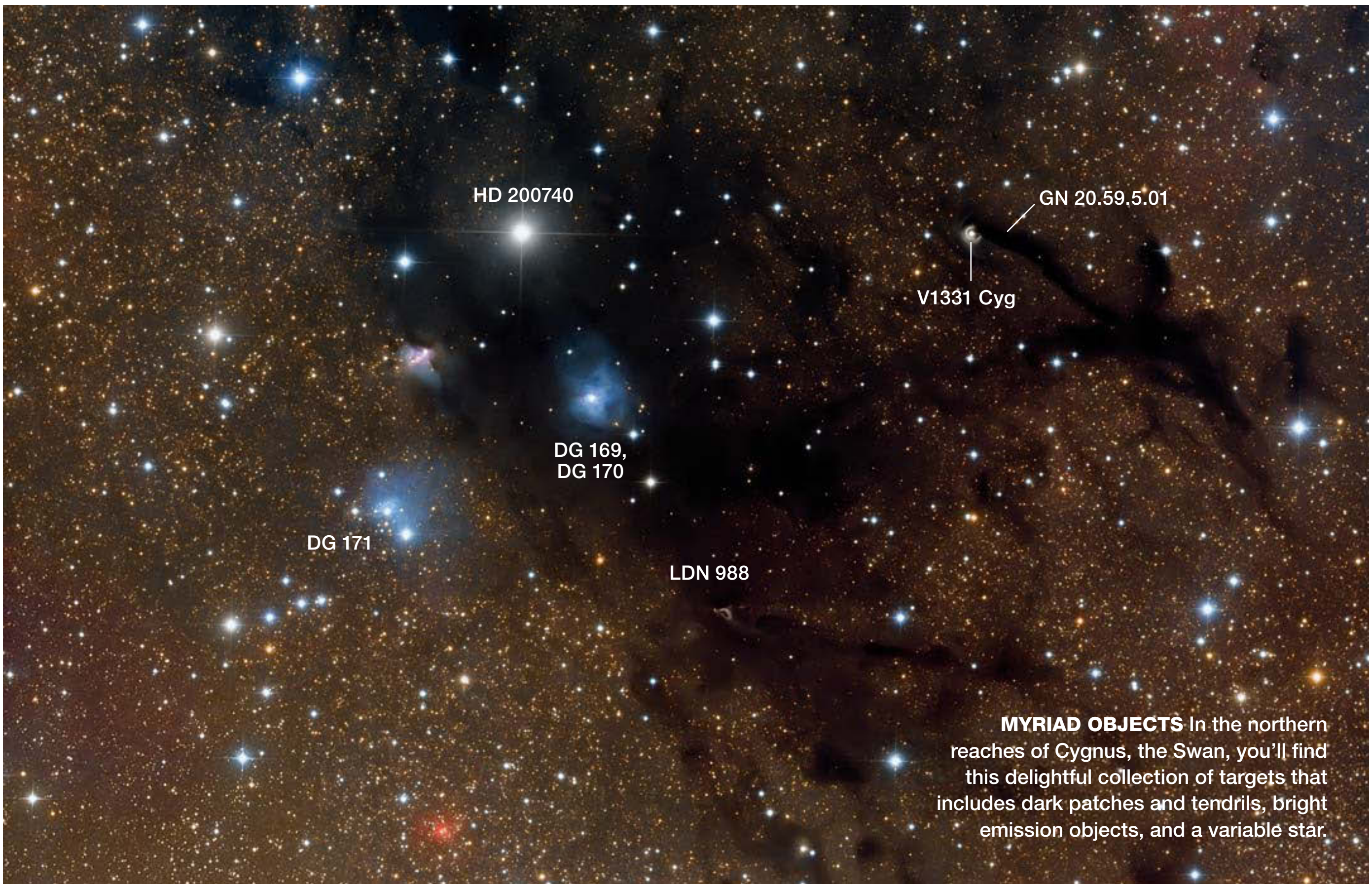
jump off from Beta (β) Cygni, or Albireo, and slew 2° east-southeast to reach **NGC 6813**. This emission nebula shimmers around a 13th-magnitude star and is between two orange 9th-magnitude stars (HD 338691 and HD 338692), situated much closer to the westernmost of the pair. If you next slide some ½° southeast, you'll come upon **LDN 799**, as well as about 10 other dark nebulae within the field. Heading 4° southwest you can also view **LDN 778** with the reflection nebula **vdB 126** a little more than 1° to its south. However, one dark nebula that I particularly enjoyed observing was **LDN 810**. You can detect this dark cloud quite readily by noting how the background changes, despite the numerous bright field stars.

Somewhat counterintuitively, perhaps, dark nebulae can also guide you to faint emission or reflection nebulae, if they're in the same field of view. Navigating to LDN 810 leads you to the difficult reflection nebula **GN 19.43.3.01**, which normally wouldn't rate inclusion on many a list. This is the one object discussed here that I wouldn't propose for

Vulpecula

Object	Type	Size/Sep	RA	Dec.
NGC 6813	Emission	3′ × 2′	$19^h 40.4^m$	+27° 18′
LDN 799	Dark	10′ × 10′	$19^h 42.6^m$	+26° 57′
LDN 778	Dark	—	$19^h 26.5^m$	+23° 59′
vdB 126	Reflection	7′ × 5′	$19^h 26.2^m$	+22° 43′
LDN 810	Dark	—	$19^h 45.4^m$	+27° 51′
GN 19.43.3.01	Reflection	—	$19^h 45.6^m$	+27° 51′





MYRIAD OBJECTS In the northern reaches of Cygnus, the Swan, you'll find this delightful collection of targets that includes dark patches and tendrils, bright emission objects, and a variable star.

JOSEF PÖPSEL / STEFAN BINNEWIES / FRANK SACKENHEIM / CAPELLA OBSERVATORY small telescopes because it's quite difficult to differentiate the nebula from the many faint stars found close to its center.

Cruising Into Cygnus

Heading north to the other end of the Swan and moving about 6° north-northeast from Deneb, or Alpha Cygni, we find a nice chain of three 6th-magnitude stars (HD 199611, HD 199955, and HD 200740) that leads us to a curious group of bright and dark nebulae. Some 6′ southwest of HD 200740 is the comet-shaped **DG 170** with its variable star V1982 Cygni — the most interesting bright nebula in this group (also similar to Hubble's Variable Nebula as well as NGC 6729 that we met above). DG 170 takes high power well, and observers might note changes over time. Around 8′ south-southwest of HD 200740 you'll find **DG 169**, another nice, bright nebula. Larger and less well-defined, **DG 171** is about 7′ south-southeast of DG 170 and is fainter than the other two.

Find your way back to HD 200740 and slew about 20′ due west to the tip of a well-defined, fingerlike dark lane. Here you'll find the curious object V1331 Cygni wrapped in the nebulosity of **GN 20.59.5.01**. Associated with the DG targets is **LDN 988**, informally known as the Pincushion for all the bright nebulae and Herbig-Haro objects seemingly sticking out of it. A 12-inch or larger scope could bring some of these into view. LDN 988 is also part of a larger complex of dark clouds that includes the Northern Coalsack — one of the more easily observed naked-eye dark areas along the Milky Way. (See page 12 for its southern counterpart, the Coalsack Nebula.)

Locate Pi^2 (π^2) Cygni in the northeastern reaches of the Swan and from there slide about 2⅓° southeast to the beautiful field of **IC 5146**. British astronomer and reverend Thomas Henry Espinell Compton Espin discovered this object, which is better known as the Cocoon Nebula. IC 5146 is involved with **B168**, which is a ragged dark lane with a number of darker "ponds" alongside it. Look for this structure snaking into the Cocoon from the west. The combined bright and dark nebulosities of IC 5146 and B168 are reminiscent of the Trifid Nebula (M20) in Sagittarius and NGC 1579 in Perseus (also known as the Northern Trifid). A second bright nebula in the same field is often overlooked due to its well-known neighbor. Look 9′ west-southwest of the Cocoon to find **vdB 147** centered on a 10th-magnitude star on the southern edge of B168 — the star illuminates a portion of the dark nebula.

Sailing into Cepheus

William Herschel discovered **NGC 7129** in 1794 and cata-

Cygnus

Object	Type	Size/Sep	RA	Dec.
DG 170	Reflection	—	$21^h\ 03.9^m$	+50° 15′
DG 169	Reflection	1.5′ × 1.5′	$21^h\ 03.1^m$	+50° 13′
DG 171	Reflection	—	$21^h\ 04.1^m$	+50° 07′
GN 20.59.5.01	Reflection	—	$21^h\ 01.2^m$	+50° 22′
LDN 988	Dark	—	$21^h\ 08.7^m$	+48° 57′
IC 5146	Emission	10′ × 10′	$21^h\ 53.4^m$	+47° 16′
B168	Dark	100′ × 10′	$21^h\ 53.3^m$	+47° 16′
vdB 147	Reflection	—	$21^h\ 52.6^m$	+47° 14′

RIVER OF BLACKNESS The dark lane B168 feeds into the bright emission nebula IC 5146, fondly known as the Cocoon. Can you spot vdB 147 southwest of the Cocoon that illuminates part of B168?

KONSTANTIN VON POSCHINGER / CCDGUIDE.COM

WONDERFUL WISPINESS NGC 7129 is an ethereal reflection nebula in Cepheus tangled with the dark lanes of LDN 1179 and LDN 1182. The fuzzy blobs above it are NGC 7133.

THE GHOST NEBULA The dark cloud LDN 1177 provides the smoky framework for the reflection nebula vdB 141. Can you see why this nebula is nicknamed the Ghost?

loged it as the 75th object in his list of planetary nebulae. Today, however, it's classified as a reflection nebula. Similar to NGC 1931 in Auriga, this accessible object contains four bright stars along with two fainter ones and will easily take quite a bit of magnification. The northeastern section of NGC 7129 is brightest and is tightly intertwined with the dark nebula **LDN 1179**, which also dents it in places. **LDN 1182** is involved more on the outer fringes of the bright nebula. About 10′ northeast of NGC 7129 you'll come across the smaller and fainter **NGC 7133**.

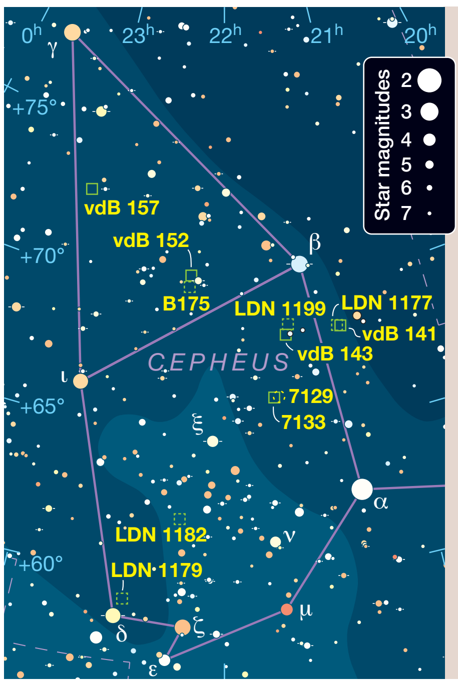
Moving some 5° northeast of NGC 7129 brings you to our final set of objects, highlighted by the bright reflection nebula **vdB 152**, which is surrounded by the dark nebula **B175**. A 9th-magnitude star illuminates vdB 152, and the nebula fades as it stretches some 20′ northward and gradually merges into B175. Another 4½° northeast from there you'll find the easy bright nebula **vdB 157**, which may be an unrelated object. Let's wrap up our tour by slewing 2½° south-southwest from Beta Cephei to find **vdB 141** with **LDN 1177**. Moving the same distance south-southeast from Beta Cephei takes you to **vdB 143** and **LDN 1199**.

The bright and dark summer nebulae we've visited on this tour can — and should — be enjoyed for their own beauty. However, they are most appealing when you consider their complexity: how dark nebulae can define star clouds or how a reflection nebula is just the illuminated part of a dark cloud.

■ **RICHARD P. WILDS** enjoys observing and writing about all manner of bright and dark nebulae from his home in upstate New York.

Cepheus

Object	Type	Size/Sep	RA	Dec.
NGC 7129	Reflection	7′ × 7′	21^h 42.9^m	+66° 06′
LDN 1179	Dark	3′ × 3′	22^h 27.3^m	+59° 02′
LDN 1182	Dark	4′ × 4′	22^h 13.1^m	+61° 55′
NGC 7133	Reflection	3′ × 3′	21^h 43.8^m	+66° 08′
vdB 152	Reflection	4′ × 3′	22^h 13.6^m	+70° 18′
B175	Dark	60′ × 60′	22^h 14.0^m	+69° 54′
vdB 157	Reflection	—	23^h 02.3^m	+72° 44′
vdB 141	Reflection	—	21^h 16.4^m	+68° 16′
LDN 1177	Dark	4′ × 2′	21^h 17.6^m	+68° 18′
vdB 143	Reflection	7′ × 6′	21^h 37.1^m	+68° 12′
LDN 1199	Dark	29′ × 29′	21^h 35.9^m	+68° 33′



Catalogs Galore

The letters that preface the names of the objects discussed here indicate which catalog they're listed in. The familiar "NGC" and "IC" prefixes refer to the historic *New General Catalogue of Nebulae and Clusters of Stars* compiled in 1888 and its supplements, the *Index Catalogues*, published in 1895 and 1908. Others include:

Dark nebulae

B: Barnard's groundbreaking work

LDN: Beverly Lynds's expansion of Barnard's catalog

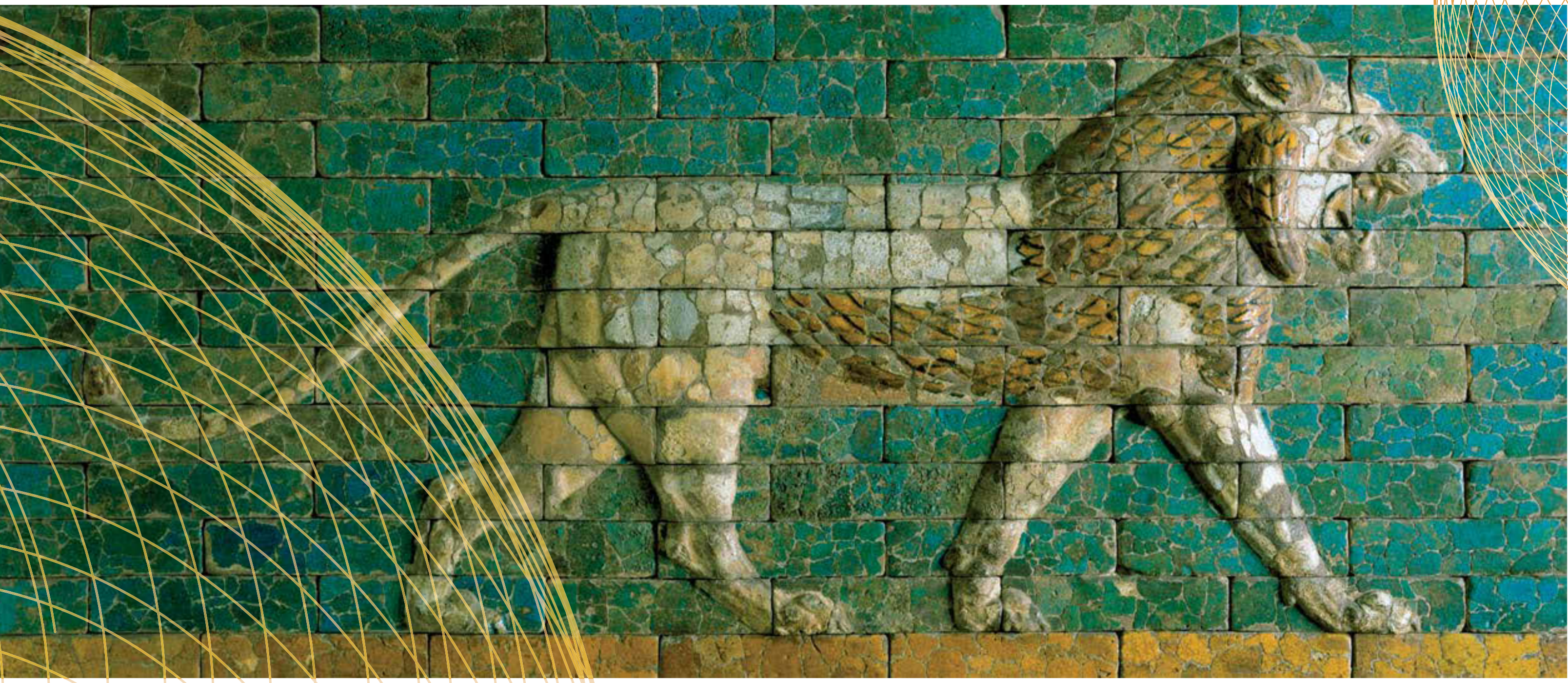
SL: the work of Aage Sandqvist and K. P. Lindroos (and collaborators)

Bright nebulae

DG: Von J. Dorschner and Jena J. Gurtler's catalog published in 1963

vdB: Sidney van den Bergh's work published in 1966

NGC 7129: JOSEF PÖPSEL / STEFAN BINNEWIES / CAPELLA OBSERVATORY; VDB 141: MASIL IMAGING TEAM



Alas, Babylon! When Mars Draws Near . . .

Mesopotamian astronomers pioneered astronomical computing.

Whenever Mars reaches opposition, as it did so brilliantly last October, my thoughts turn to Babylon. Why Babylon? Because incredibly precise accounting of planetary positions started with the Babylonians — indeed, computational astronomy itself originated with them.

Babylonian astronomers consistently tracked and recorded the positions of Mars and the other naked-eye planets from about the mid-7th century BC and kept it up for another half millennium. These records are inscribed on about 1,000 clay tablets currently held mainly in the British Museum in London. The Babylonians also developed mathematical methods that allowed them to predict planetary positions and create ephemerides, even correcting for variable orbital motion. Their saros cycle of the Moon appears on the famed Antikythera Mechanism, discovered on an ancient shipwreck.

A Synodic Clock

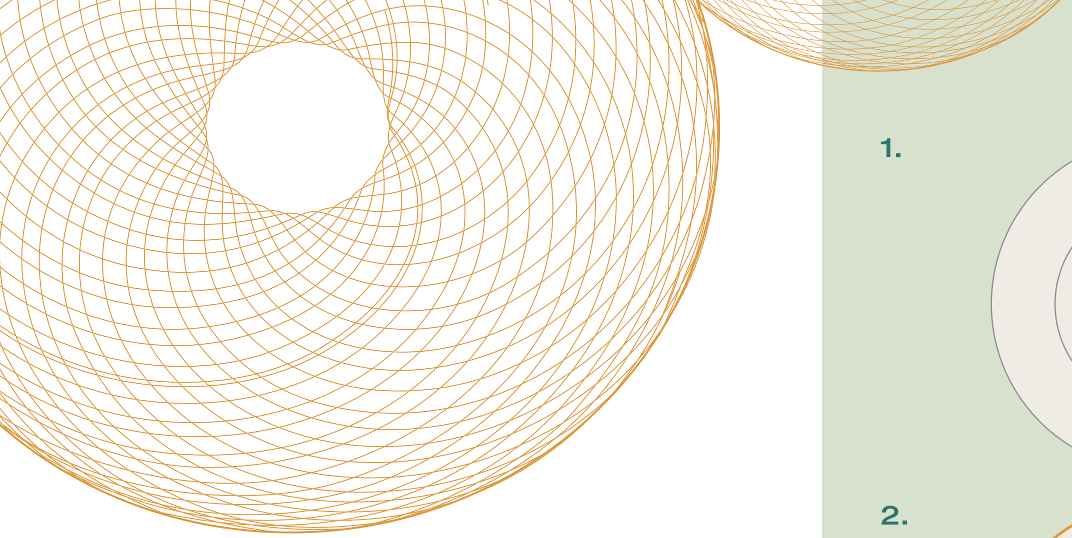
The Babylonians tracked Mars oppositions over many centuries. Such alignments of the Sun, Earth, and Mars occur about every 2 years and 50 days — a span of time known as

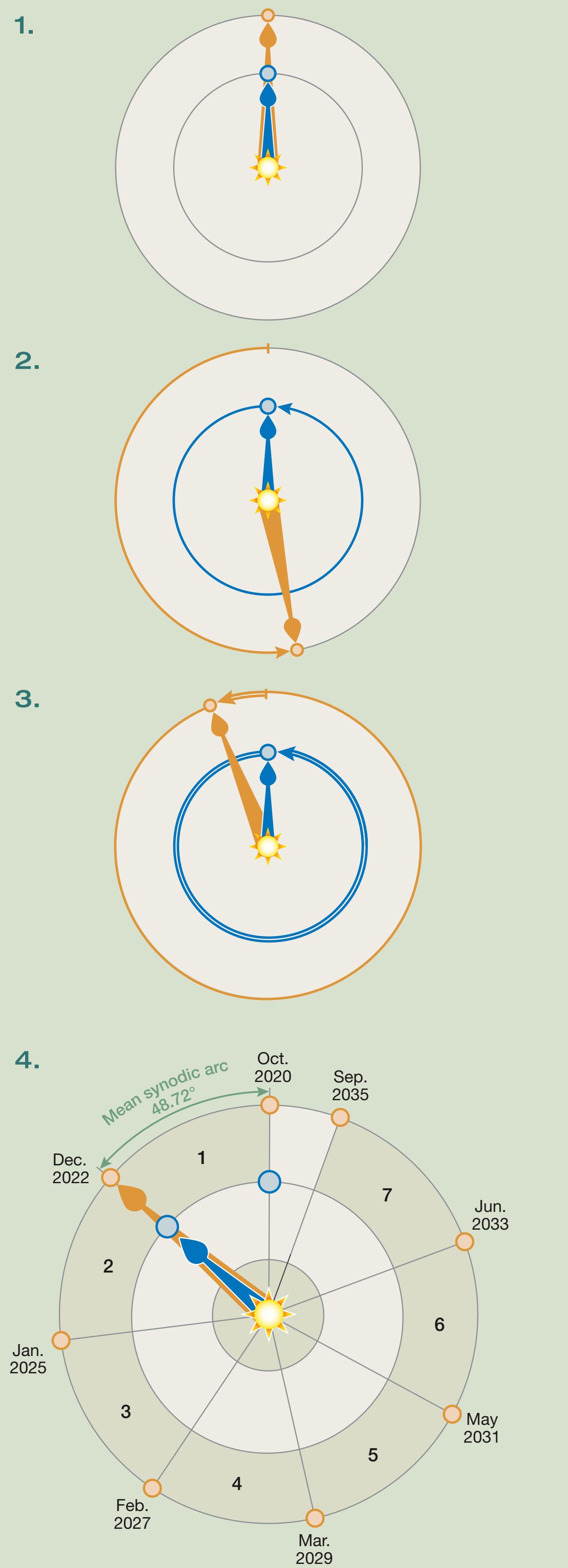
▲ **GUARDIAN BEAST** The pacing lion is an iconic symbol of Babylon and its once-flourishing, vibrant culture. This relief is from the famous processional way leading into the city from Babylon's Ishtar gate.

THE MET / FLETCHER FUND, 1931

Mars's *synodic period* or *synodic cycle*. The intricacies of the synodic cycle can best be explained by imagining a unique clock. Its two hands represent the movements of Earth and Mars in their counterclockwise orbits (assuming uniform circular motion for each). The shorter hand moves with the mean speed of Earth around the Sun, completing a revolution in 365¼ days. The longer hand represents Mars, which takes about 687 days to complete an orbit. The Sun is at the center of the clock where the hands are anchored, and the clock's face is the plane of the ecliptic. Whenever the hands are lined up with each other, we have an opposition.

If Mars were standing still, Earth would simply pass it every year and its synodic cycle (the time between oppositions) would be 365¼ days. If Mars were going half the speed of Earth, the synodic cycle would be exactly two Earth years. And in either scenario Mars would appear to return to the same place in the sky — the same ecliptic longitude, in the same constellation — at each opposition. But, of course,





that's not what really happens. Mars takes about 1.88 Earth years for one orbit, so one Earth year later — when our planet has returned to the location of the most recent opposition — the Mars hand on our clock has advanced about halfway around the clock face from that position. After two complete Earth circuits, our faster-moving planet has almost caught up to Mars but needs another one-seventh of a revolution before the clock hands line up once again.

This extra fraction causes Mars to shift about one-seventh the way around the ecliptic from the previous opposition — slightly more than one-and-a-half zodiacal constellations. The actual fraction, which the Babylonians calculated with remarkable accuracy, is 1/7.3888 — about 48.72° along the ecliptic. In the lingo of Babylonian scholarship, that arc is called the *mean synodic arc* for the planet Mars.

The mean synodic arc can be seen on the accompanying diagram at bottom right. Mars was at opposition in Pisces in October 2020, when the clock hands most recently lined up together. Since then, the Mars hand has continued to revolve (counterclockwise) at the leisurely mean pace of 0.524° per day. At the end of one synodic period Mars will have gone around one full circle of the ecliptic plus an additional 48.72°, to arrive one arc to the left. In the meantime, the Earth hand will have completed two full revolutions plus an additional 48.72° to meet up with Mars for the December 2022 opposition.

That extra 48.72° wedge carries Mars from Pisces into Taurus for the 2022 opposition. The same clockwork applies to each opposition, arc after arc — like slices from a pizza pie. A complete pizza contains seven of these slices, with about a

ORBITAL PATTERN: DOUGLAS MACDOUGAL; CLOCK DIAGRAMS: GREGG DINDERMAN / S&T

▶ **ORBITAL TIME** This series of imaginary clocks illustrates the counterclockwise orbital motions of Mars and Earth. The short clock hand represents Earth, which completes one rotation in 365¼ days. The long hand represents Mars, which takes 687 days to circle the Sun once. **1.** Mars is at opposition and the clock hands overlap. **2.** After one year, the Earth has made a complete trip around the Sun and has returned to the 12 o'clock position, while Mars has traveled more than half an orbit. **3.** After two years, Earth has returned to 12 o'clock a second time, while Mars has advanced slightly past that point. **4.** To catch up to Mars for another opposition, Earth must travel slightly less than one-seventh of an additional orbit (48.72°), a span referred to as Mars's "mean synodic arc."

third of a slice left over. However, it's worth noting that these arc sizes are *mean* values. Because the planets' orbits are ellipses, not circles, the actual values will differ, sometimes substantially. Yet in the long run, by definition, the mean works pretty well.

The Babylonians were keenly interested in knowing how many complete sets of synodic arcs (those full slices plus the leftover bit) would be required for Mars to return to exactly the same place in the sky. There were good reasons for this preoccupation.

In Mesopotamian cosmology, the will of the gods determined planetary appearances in the sky. The positions of the planets among the stars served as omens of good or bad earthly events, varying according to the ominous influences inherent in each planet. Venus and Jupiter were beneficent; Mars and Saturn were malefic; Mercury was ambivalent. It was vital to know when a planet would return to the same place in the sky to correlate this occurrence with important events, such as a flood, a failed harvest, an important birth or death, or war.

For an astonishing six centuries, Babylonian astronomers meticulously inscribed their observations in cuneiform characters on tablets. These so-called Astronomical Diaries accounted for planetary synodic phenomena along with the mundane fluctuations of daily life of Mesopotamia, such as commodity prices, the weather, or the ever-changing level of the Euphrates River.

◀ **WRITTEN IN STONE** Shown here is a cuneiform *procedure text* for the planet Jupiter. Procedure texts are the rulebooks that describe how to calculate ephemerides with astronomical information recorded on other tablets. Analysis of Jupiter's well-represented procedure texts gave scholars confidence that their interpretations of the Mars texts were correct.

The Goal-Year Periods

Babylonian astronomers had succeeded in discovering the synodic returns of the planets with impressive accuracy. Modern scholars call these planetary returns *Goal-Year periods*.

For the outer planets, the Goal-Year periods are those exceedingly rare oppositions when a planet returns to (very nearly) the same place in the sky as it was at a prior opposition. For the exacting Babylonians, there were only two oppositions of Mars in a century that fit the bill, occurring at intervals of 47 years (after 22 synodic cycles) and 79 years (37 synodic cycles). The 79-year period, for example, means that Mars will reach opposition in 2099 very close to where it was during its October 2020 opposition. Just *how close* is the question.

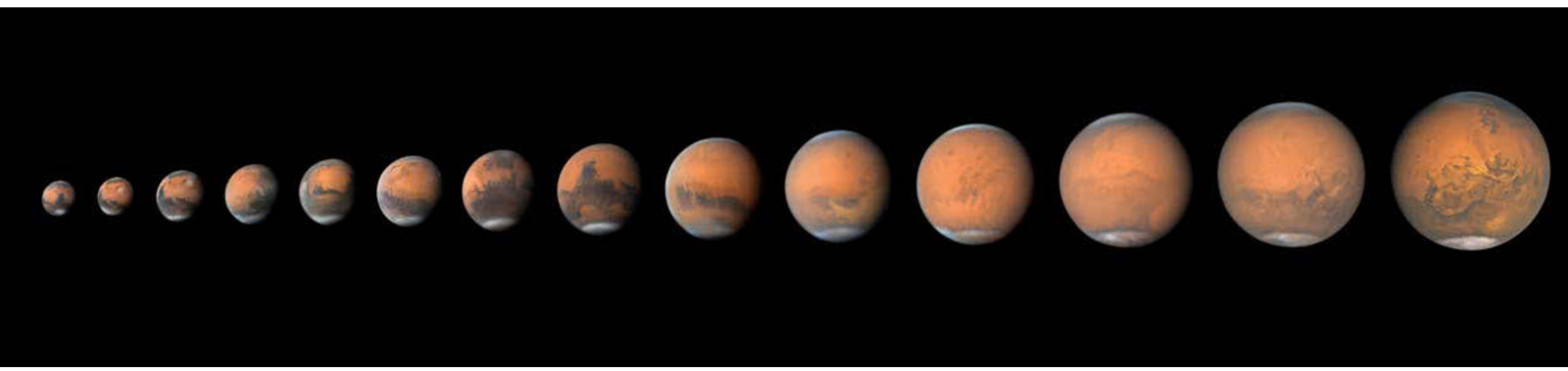
Babylonian stargazers tracked the planets in their courses by noting when they passed certain stellar waypoints along the zodiac known as *normal stars*. They incised ephemerides on spreadsheet-like clay tablets known as the Astronomical Cuneiform Texts (ACT). Some of the centuries-long synodic recurrences found in the ACT turned out to be even more accurate than the shorter Goal-Year periods — Babylonian astronomers, for example, discovered that Mars completes 133 synodic cycles in 284 years. How did they accomplish this impressive computational feat?

Modeling Martian Recurrence Periods

To find out, I experimented with a simple computer model I created to see if the Babylonian Goal-Year periods for Mars were at least plausibly correct from a purely mathematical perspective. I took Mars as my case study because of its recent opposition, its prognostic significance to the Babylonians, and my own enduring fascination with the planet.

Using a home computer and simple mathematical software, I simulated Mars's synodic cycles over 100- and 500-year periods. The program searched for oppositions

▼ **COMING AND GOING** The 2018 Mars apparition is displayed with this superb image sequence from March 2018 through January 2019. Over that span the Martian disk grew from a diameter of 6.7″ to a maximum of 24.3″ during its late-July close approach.



CUNEIFORM TABLET: THE TRUSTEES OF THE BRITISH MUSEUM; MARS IMAGE SEQUENCE: DAMIAN PEACH / CHILESCOPE within a few days of being exact recurrences. As you may have guessed, finding an *exact* recurrence period for Mars isn't possible for the same reason that an irrational number cannot be reduced to a simple fraction. But it is possible to find recurrence periods that are as close as we desire to any chosen margin of error.

Using only the length of the year and the Martian synodic period (779.94 days) as inputs, the program found the same Goal-Year periods as the Babylonian astronomers: 22 cycles in 47 years, and 37 cycles in 79 years. But as we'll see, there's an error lurking here that we haven't yet quantified. In other words, the hands of our imaginary two-planet clock line up, but not exactly. And it's the "not exactly" part that is of particular interest.

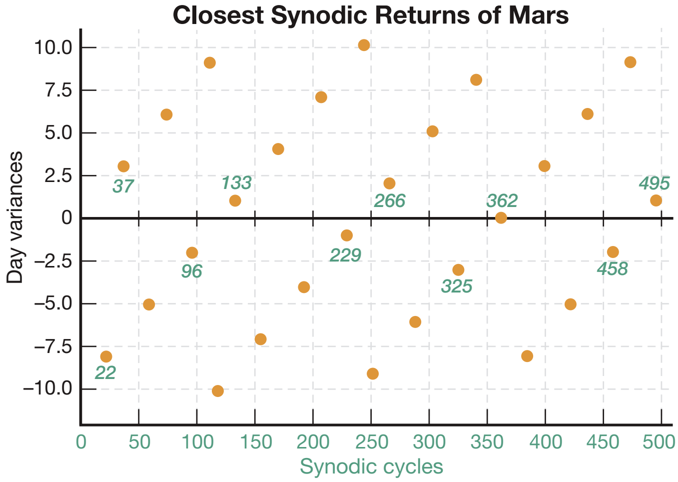
Using Errors to Good Advantage

The Babylonians knew their Goal-Year periods weren't exact, but did they know by how much they were off? Scholars suspect they reckoned their errors to refine their predictions far into the future. Let's see how this might have worked.

My program found that the *mean deviations*, or errors in the Goal-Year periods for Mars, are –8.07 days (early) over 22 cycles in 47 years, and +3.03 days (late) over 37 cycles spanning 79 years. This means that Mars shows up at the same place in the zodiac more than a week early after 47 years, and a little more than 3 days late after 79 years. So, though neither estimate is dead-on, the 79-year return is the more accurate of the two.

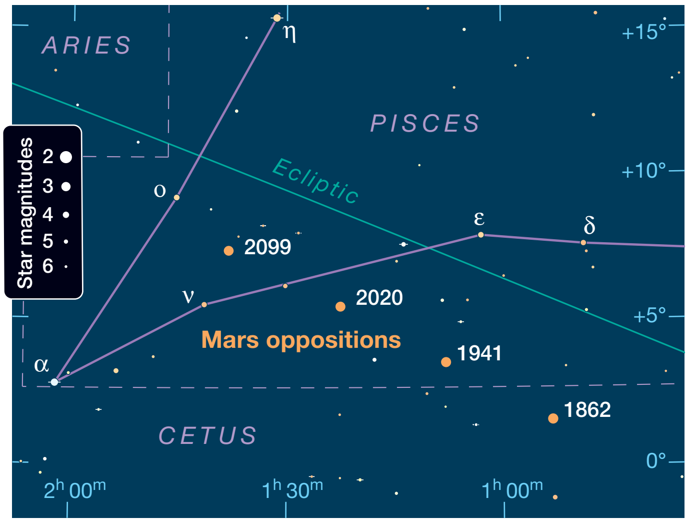
Now here's the fun part. Scholars have surmised that the Babylonians combined several Goal-Year cycles to cancel out these errors and gain predictive accuracy that spans *centuries*. I tested this with the error values churned out by the program. For example, if the Babylonians knew about the errors mentioned above, they could have mapped out a 133-cycle return (284 years) this way: 22 + 37 + 37 + 37 = 133 synodic cycles. Totting up the numbers we see the cumulative error for 133 synodic cycles amounts to about 1 day across almost three centuries: –8 + 3 + 3 + 3 = +1 day.

The error from the first 22-cycle run becomes the starting line for the 37-cycle run, and so on. The plus and minus errors aggregate, and can amplify or cancel, depending on the combinations chosen. From a mathematical point of

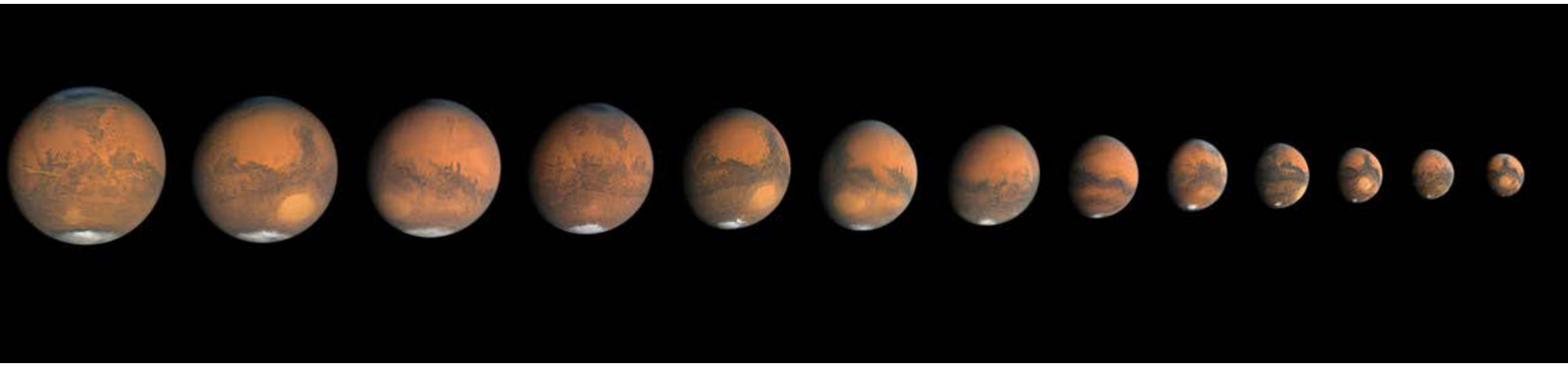


SYNODIC RETURN GRAPH: DOUGLAS MACDOUGAL

▲ **SYNODIC SCHEDULE** This chart displays 500 years of synodic cycles in which recurrences occur within 10 days of Mars's same-place opposition arrival. The synodic cycles appear along the *x*-axis, and the day variances are shown along the *y*-axis. Day variances below the *x*-axis mean Mars arrives early relative to the start of the sequence, while those above the line indicate a late arrival.



▲ **79-YEAR MARS OPPOSITIONS** As described in the article, Mars returns to the same region of sky for oppositions at 79-year intervals. This chart shows the planet for the three most recent occurrences and extends the trend into the future to capture the next Pisces opposition in 2099.



view, the result is completely expected given the nature of periodic motion.

Refining our search to errors of within about two days of exact recurrence, we identify some other close instances in the long haul that illustrate the method:

Synodic Cycle Variances

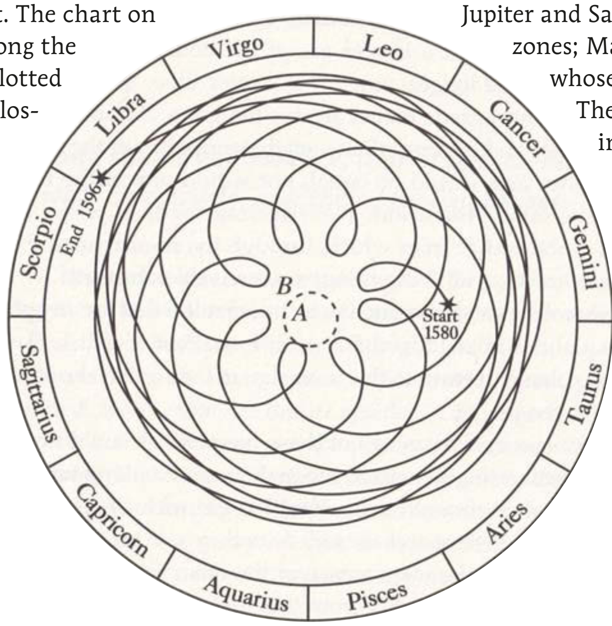
Number of cycles	Interval (years)	Variance (days)
96	205	–2.01
133	284	+1.02
229	489	–0.99
362	773	+0.03

Glancing at the table above, you doubtless noticed intriguing possibilities for combining cycles. Take one 96-cycle and add it to one 133-cycle and you get a 229-cycle period accurate to about 1 day. Add another 133 and you arrive at 362 with negligible error over 773 years.

Plotting the Closest Synodic Recurrences

Curious about the patterns of these periodic phenomena, I went ahead about 500 years in the computer program — beyond the known range of the extrapolated Babylonian Goal-Year periods — and charted the sequences that fall within the range of 10 days ahead or behind schedule of Mars's same-place opposition point. The chart on page 27 shows the day variances along the *y*-axis, and the synodic cycles are plotted on the *x*-axis. The numbered dots closest to zero are the best passages of the planet, that is, those closest to the same place in the sky where Mars was at the start of any chosen observation series. Begin exploring the chart by looking for the 22- and 37-cycle returns and identifying their variances. You can spot the main 133-cycle return and use some mental math to estimate how other combinations above and below the horizontal axis might cancel out.

I found (not surprisingly) that longer-term results are the most sensitive to slight changes in the initial assumptions. We don't know whether the Babylonians were aware of this, but they appear to have settled on the 133-cycle (284-year) recurrence period as good enough for their larger ambitions.



▲ **KEPLER'S MARS** This is a modern rendering of Johannes Kepler's epic, hand-calculated drawing of the path of Mars from his 1609 *Astronomia Nova*, "on the assumption that the earth stands still, as Ptolemy and Brahe would have it." Kepler incorporated 16 years of Tycho Brahe's observational data (from 1580 to 1596) to make this diagram. The number-oriented Babylonians were observing and calculating Martian paths 2,000 years before Kepler.

According to Otto Neugebauer, the pioneering 20th-century translator and scholar of ancient mathematics, the Mars-related tablets explicitly show the 47- and 79-year Goal-Year periods, revealing a precise period for Mars as a linear combination of one 47-year set (22 synodic cycles) combined with three 79-year periods (each containing 37 synodic cycles) for a total of 284 years. Similarly, the Babylonians found exact periods for Jupiter and for Saturn. These results appear to have functioned as baseline parameters for the creation of long-term ephemerides.

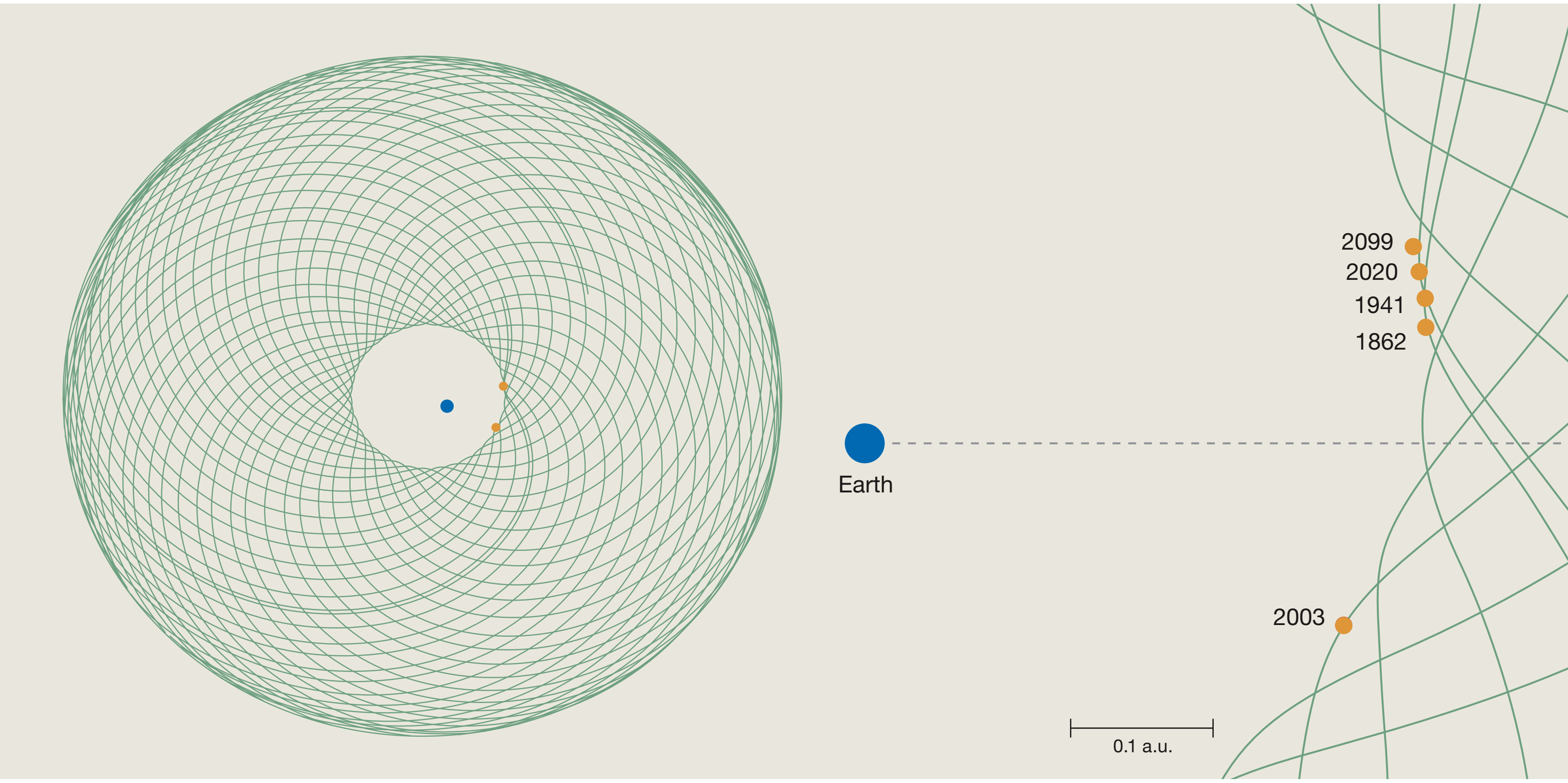
By combining sets of Goal Years to cancel errors, the Babylonians could thus leapfrog far into the future beyond actual observation to derive long-term synodic recurrence periods. For Mars, they could confidently predict that 133 synodic arcs will fit in 151 Martian orbits over the course of 284 Earth years. There's a satisfying symmetry here: 133 complete synodic arcs comprise 6,480°, which happens to be 18 whole revolutions around the 360° ecliptic.

The first full-fledged Babylonian astronomical ephemeris appeared probably in the 3rd century BC — a milestone in their evolving planetary theory. Planetary motion along elliptical orbits is nonuniform, so creating an ephemeris is a bigger challenge than forecasting synodic returns. Yet the Babylonians exhibited remarkable cleverness here, too. They used exact periods as mean parameters for the planets, which they could then augment or diminish with a small correction according to the planet's place (and thus, speed) in its orbit.

They created speed zones. Of the outer planets, sluggish Jupiter and Saturn each required only two speed zones; Mars, the perennial problem child whose orbit is most elliptical, needed six. The speed adjustments for Mars were in simple ratios for the six 60° zones of the zodiac, a sequence that Dutch astronomer and Babylonian expert Teije de Jong called "a miracle of numerical elegance that continues to baffle me."

Mathematical Time Travel

To look at the path of Mars in a modern context, I loaded into my long-suffering laptop 80 years of orbital data from 1940 to 2020, drawn from the NASA/JPL Horizons online database. The result is a complex image resembling the top view of a woven Japanese basket. Johannes Kepler's epochal graph of Mars's path in his 1609 *Astronomia Nova*, using 16 years of Tycho Brahe's data, inspired the diagram. Kepler imagined



▲ **80 YEARS OF MARS** *Left:* This diagram illustrates the orbital path of Mars from a geocentric frame of reference and was plotted using 80 years of data (1940–2020) drawn from the NASA/JPL Horizons online database. Earth is the blue dot at center. The upper orange dot is Mars at its 2020 opposition, and the lower orange dot shows Mars at its historically close 2003 opposition. *Right:* This zoomed-in view plots Mars's positions at the 79-year (37-synodic cycle) oppositions in 1862, 1941, 2020, and 2099. Included for reference is Mars at its remarkably close 2003 opposition. The direction of the vernal equinox is indicated by the dashed line. (The planet disks are not plotted to scale.)

their perpetuation: "These motions, continued farther, would become unintelligibly intricate, for the continuation is boundless, never returning to its previous path."

To see what application of a Goal-Year period specifically means today, I again took as an example the 37-cycle/79-year period, anchored on the October 13, 2020, opposition of Mars. Here are the 79-year oppositions before and after that date:

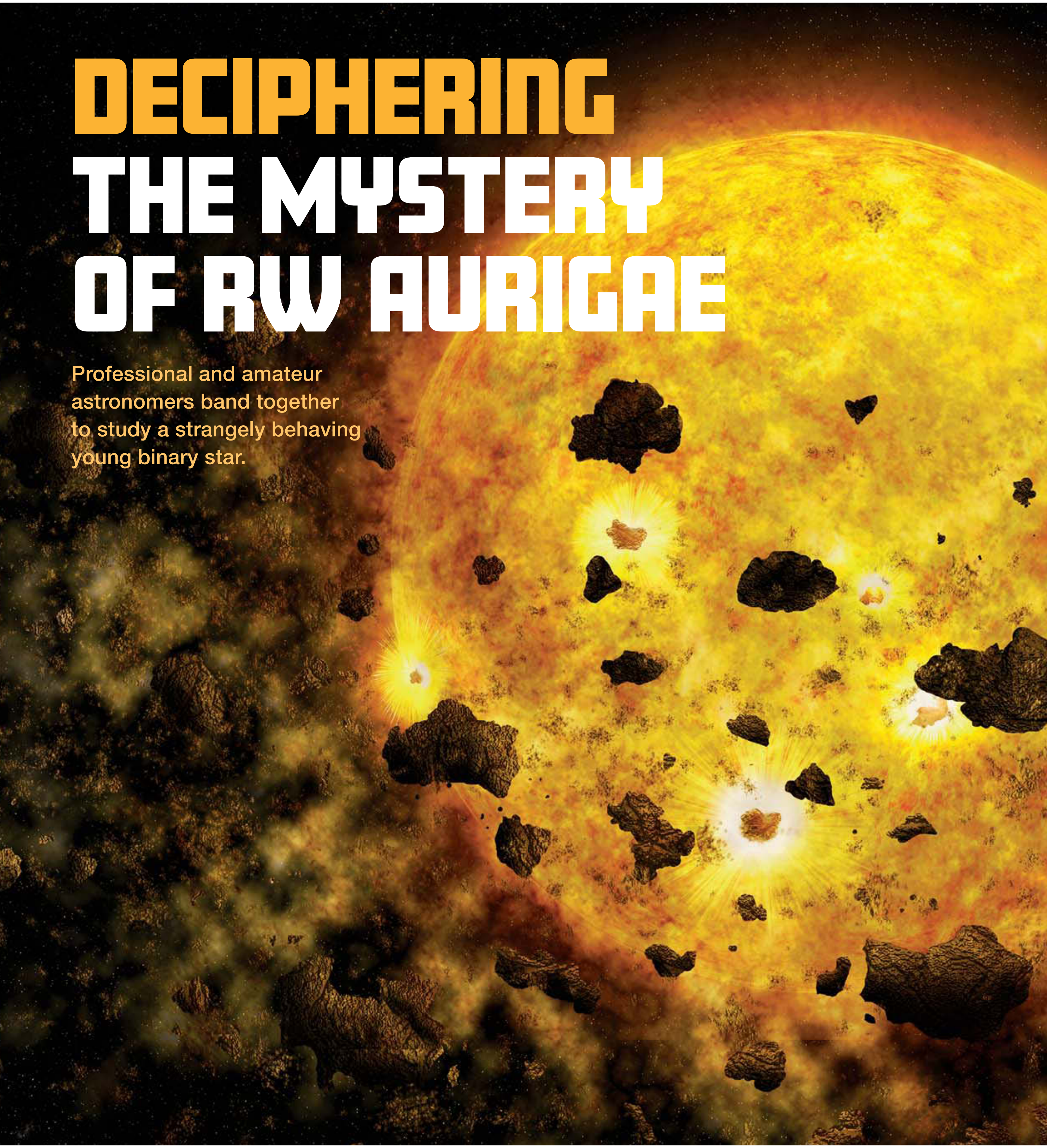
79-Year Mars Oppositions

Year	Date	Constellation	Ecliptic long.
1862	October 5	Cetus	14.31°
1941	October 10	Pisces	17.49°
2020	October 13	Pisces	20.69°
2099	October 18	Pisces	23.76°

As you can see, all are October oppositions in Pisces (except for the 1862 opposition, which occurred in Cetus near the border with Pisces) and are separated by about 3° of ecliptic longitude at each successive opposition. That's a remarkably close grouping and attests to the accuracy of the 79-year period. The 79-year positions differ from perfect alignment with each other because, as we saw, the Babylonian cycle itself is not perfect and because predicted positions are based on mean motions. My accompanying computer-generated simulation of Mars at each of the ecliptic longitudes highlights their closeness. Now your grandkids will know where to look when the October 2099 opposition comes around!

It's incredible to think that with nothing other than keen eyesight, diligence, and exceptional ingenuity, Babylonian astronomers were able to achieve such accurate predictions. With modern mathematical tools we can, in effect, get into their minds and test their thinking. Whether for the purpose of gaining a better understanding of ancient astronomy, simulating plausible scenarios, testing scholarly hypotheses, or creating marvelous teaching tools, nothing beats the power of simple mathematics to explore and enrich the stories of astronomy's long history.

■ **DOUGLAS MACDOUGAL** writes about the history of astronomy and mathematics from his home in Portland, Oregon, and is the author of *Newton's Gravity: An Introductory Guide to the Mechanics of the Universe* (Springer, 2012). He fondly remembers decades ago coaxing his first comet-orbit calculation into a reluctant and overwhelmed Apple IIe computer. You can visit his website and blog at **www.douglasmacdougal.com**.



DECIPHERING THE MYSTERY OF RW AURIGAE

Professional and amateur astronomers band together to study a strangely behaving young binary star.

ROCKY DEBRIS? This artist's concept shows planetesimal debris falling onto the star RW Aurigae A. Such destruction is one of two main scenarios explaining the star's strange drops in brightness.

NASA / CXC / M. WEISS

The path to becoming an orderly planetary system is a messy one. As young stars collapse onto the main sequence, dust grains in orbit around them begin their long journey toward planethood, racing to cling together and collect gas before furious stellar winds whisk it away. Magnetic fields ensnare ionized gas and siphon it onto the star's surface, causing hotspots that blaze in X-rays. Nearby stars can complicate matters, swinging by and warping the disk.

All this warping, siphoning, collecting, and collapsing has created plenty of work for amateur and professional astronomers alike, who have been observing and modeling the behavior of pre-main-sequence stars for decades. Pre-main-sequence stars can vary in brightness on timescales from minutes to years and at essentially all wavelengths, but the reasons for these variations aren't always known. This is the case for RW Aurigae, a binary of young (about 10 million years old) T Tauri stars in the throes of formation. Typically, RW Aurigae varies over long time scales, punctuated by short brightness dips every few decades. But since 2010, RW Aurigae has been dimming for months at a time every few years, unlike anything recorded for the system before.

To make sense of RW Aurigae's erratic behavior, H. Moritz Günther (Massachusetts Institute of Technology) combined the skills of professional and amateur astronomers to shed new light on this strange binary pair — and potentially catch planet formation in action.

A Combination of Skills

Amateur astronomers from the American Association of Variable Star Observers (AAVSO), an international nonprofit that has coordinated tens of millions of variable star observations to date, have been keeping tabs on RW Aurigae for more than a century. Their records start with measurements from Norwegian observer Sigurd Enebo in 1906. As Günther searched the AAVSO archive for photometry of RW Aurigae, he noticed that many of the measurements he was interested in came from an observer with the initials "DUBF." The initials belonged to Franky Dubois, a 69-year-old retired textile worker and prolific observer in Belgium.

"After about 53 years, astronomy has become one of the principal goals of my life," Dubois says. "Thirty-nine years ago, I started daily observations of the Sun. Today, I still determine five relative sunspot numbers in my observatory at home each day, with an average of 253 observations on a yearly basis."

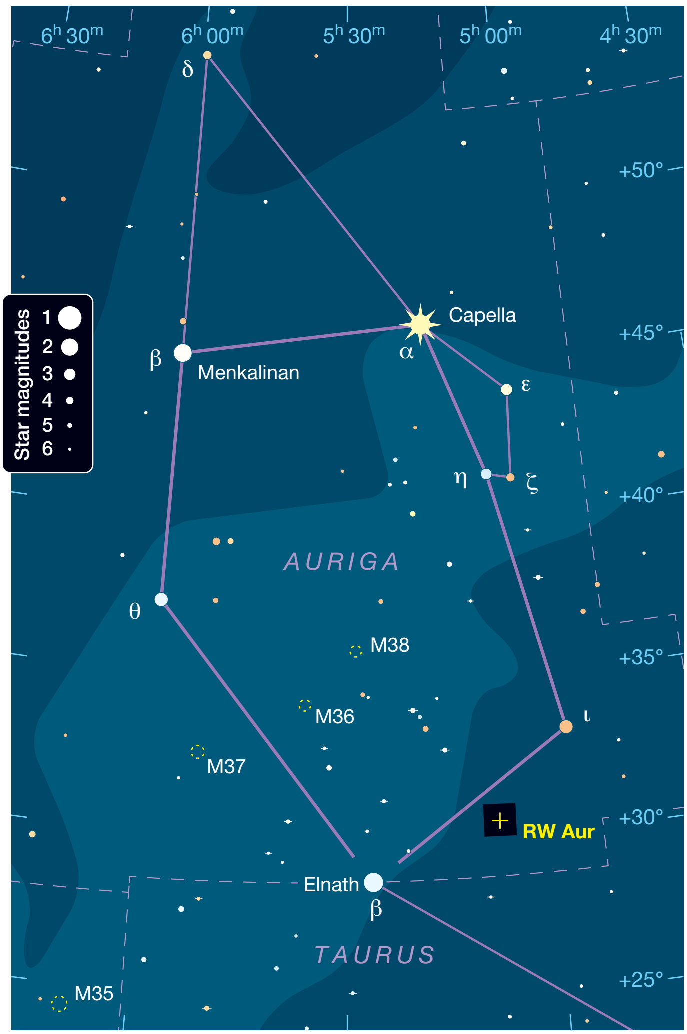
Günther reached out to Dubois to invite him to collaborate and learned that he was part of a team affiliated with AstroLAB IRIS, a public observatory in Ypres, Belgium. Using the 0.7-meter New Multi-Purpose Telescope — the largest amateur telescope in northern France and the Benelux region (Belgium, the Netherlands, and Luxembourg) — Dubois and others orchestrate an average of 93 observing sessions a year, with a peak of 125 sessions in 2018.

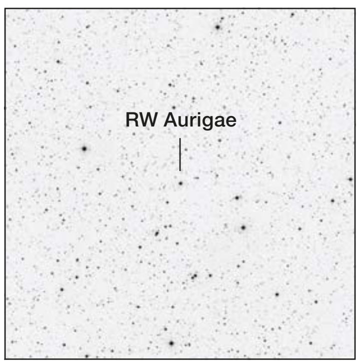
"Each member of the team has his own responsibility, and my responsibility is to collect as many observations as possible," says Dubois. His teammates Ludwig Logie and Steve Rau maintain the telescope while Siegfried Vanaverbeke, a physicist by training, analyzes the data.

In 2014, the team began a program of variable star observations in order to collaborate with professional astronomers. Altogether, the group has provided data and analysis to 27 scientific publications.

Chandra Sheds (X-Ray) Light on the Matter

The decades of ground-based observations of RW Aurigae have given astronomers hints as to the underlying causes of this system's behavior, but the visual-wavelength data don't tell the whole story — especially because the binary pair isn't resolved in the AAVSO observations. To learn more, the team and their collaborators collected X-ray data, which can give insight into the material between us and the star as well as the conditions very close to the star. (Much of the X-ray emission from a young star comes from gas accreting onto the star from its surrounding disk or from the hot, tenuous corona.)





▲ **RW AURIGAE** This binary sits on the southern edge of Auriga, the Charioteer. Its brightness usually varies from about magnitude 9 to 12.5. The star won't be well placed for evening observing for a few months yet; to see it in summer, you'll need to rise well before dawn.

IMAGE: POSS-II / STScI / CALTECH / PALOMAR OBSERVATORY; CHART: GREGG DINDERMAN / S&T

"I think the synergy between space telescopes and ground-based telescopes is the part of the work that is new and is a real breakthrough," says Vanaverbeke.

The team analyzed data from the Chandra X-ray Observatory taken in 2013, 2015, and twice in 2017. The secondary star, RW Aurigae B, was fairly consistent over the years: The flux rose and fell, but the overall shape of its spectrum remained the same. Not so for the primary, RW Aurigae A. In 2013, when the system's visual brightness was about average, the star's coronal X-ray emission peaked around 1 keV (rather low-energy, or "soft," for X-rays). But in subsequent observations, when the optical emission was dim, the soft X-ray emission that was so prominent in 2013 practically vanished. This suggests that there was a huge increase in the amount of material between the star and the telescope — jumping by a factor of 70 in 2015 and by a factor of a few hundred in 2017.

In 2017, things got weirder: The star's X-ray emission shifted to higher energies, and a new feature shot up. Previous observations of RW Aurigae A showed an emission line at 6.7 keV, arising from iron atoms stripped of all but two electrons. The 2017 observations were instead dominated by an emission line at a slightly lower energy (6.63 keV), indicating that it came from cooler iron than the 6.7-keV line.

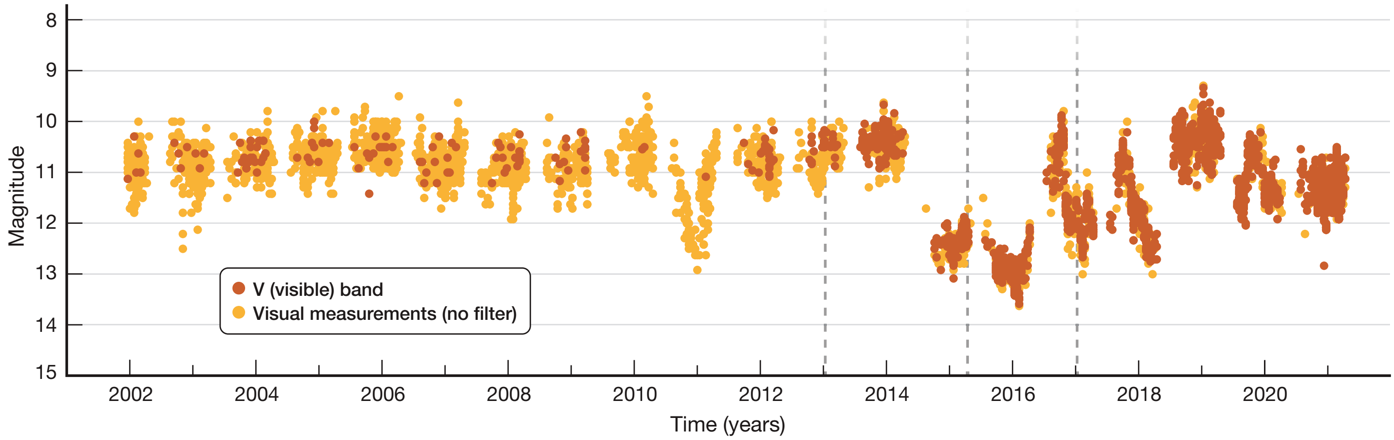
"Cooler iron should emit very few X-rays, so in order to get that much iron emission from this cooler iron you need to have a lot of it," Günther says. The team estimates that the iron abundance in RW Aurigae A's corona is an order of magnitude higher than it is in the Sun. "And then you start questioning where that iron comes from. It essentially must have fallen into the star, because it wasn't there before and stars don't have large reservoirs of iron that suddenly come out without affecting the rest of the spectrum."

So the amount of material around RW Aurigae A has rocketed up by one or two orders of magnitude, and its corona is suddenly rich in iron. What's behind this bizarre behavior?

Planetesimals or Pressure Traps?

One possibility is that in the chaos of formation, collisions between planets growing around RW Aurigae A generated enormous clouds of debris. This dust could be responsible for absorbing the soft X-ray emission that's missing in the later observations and, if it's iron-rich, could cause the enhanced iron in the corona as well.

In this scenario, two planets or planetesimals may have collided in 2011, producing a large brightness dip seen by observers. The fragments from that crash could have collided again around 2015, causing another dimming



▲ **STRANGE BEHAVIOR** RW Aurigae varied sporadically until late 2010, when it began an unusual drop. The system's brightness then plummeted in 2014, as shown by these data collected by various AAVSO observers. Vertical lines mark when the team acquired X-ray observations from the two stars (the two 2017 observations were only two days apart and are combined into a single line).

GREGG DINDERMAN / *S&T*, SOURCES: AAVSO AND GÜNTHER ET AL. / *ASTRONOMICAL JOURNAL* 2018

episode. If by 2017 those planetary fragments had fallen onto the star, that could explain the huge jump in iron emission.

There's another possibility, though. Protoplanetary disks often have striking patterns of bright and dark rings. The most tantalizing explanation for this tree-ring pattern is that baby planets collect gas and dust as they orbit their parent star, carving out dark lanes in the bright disk. But rings can also form thanks to *pressure traps*, high-pressure regions that can collect dust and prevent it from accreting onto the star. Pressure traps can form where gas in the disk freezes or the disk is too dense for the star's radiation to ionize it strongly. (To make matters more complicated, there's also evidence that coalescing planets can cause pressure traps to arise.)

If dust piles up in a pressure trap, it could reach the density implied by the X-ray observations. A gravitational nudge from the close passage of RW Aurigae B could disrupt the pressure trap and send the dust on a collision course with the star. This might explain both the increase in the density and the increase in iron emission, if the dust is iron rich.

Both explanations are exciting. We have indirect evidence of planetesimals accreting onto a star from observations of white dwarfs, but this could be our first opportunity to see it happening in real time. Conversely, if a pressure trap is the cause, then this system could help us better understand the role these traps play in planet formation and accretion. But how do we tell which scenario is actually playing out?

Looking Ahead

Unsurprisingly, it's likely to be challenging. "We don't have enough resolution to see occultations by the planetesimals," says Vanaverbeke. "The amplitude of the occultations would be very small — that would not be observable, I think. So right now, really choosing between accretion of protoplanets and ejection and accretion of dust that is inside the disk and shepherded by tidal accretion will probably have to be because we see chemical differences."

Those chemical differences — things like new elements or ionization levels appearing in the data — might be discernible when the dimming episodes end and RW Aurigae returns to a "normal" state. If the absorbing material around RW Aurigae A disperses, the soft X-ray emission that was all but absent in the 2015 and 2017 observations will shine through once again. That could mean that other chemical species might make an appearance, hopefully clarifying the situation. Seeing those chemical markers "could tell you something about the composition of those grains, and then you can go to a planetary scientist and say, 'I found silicon, iron, and magnesium in a ratio of one to one to one, does it look like a planetary core or not?'" says Günther.

The time scales for the two possibilities might be different as well. In the pressure-trap scenario, the dust grains are separated by size, and grains of different sizes should take different amounts of time to fall onto the star. This could mean that the star is just beginning to accrete the material caught in the pressure trap, and RW Aurigae A's accretion rate might increase over time. On the other hand, in the planetesimal-collision scenario, there might be a wide range of grain sizes that all fall onto the star at the same time.

It's not quite that cut-and-dry, though; as always, protoplanetary disks are complicated. Fragments of planets left over after a collision might themselves undergo collisions, resulting in smaller pieces on orbits of varying eccentricity, which would muddy the calculation. Turbulence and magnetic fields — the two things most likely to keep modelers up at night — have the potential to play a complicating role in either scenario.

Günther, Dubois, and Vanaverbeke plan to keep an eye on the system to see how long it takes to go back to normal — if that ever happens. "RW Aurigae has surprised us so often, it's entirely possible that something unexpected happens," Günther says. "And I don't know what happens after that!"

■ **KERRY HENSLEY** is a planetary scientist and science writer based in Boston.

 by Gerrit Verschuur

Arecibo's Legacy

The tragic loss of the iconic radio telescope abruptly ended more than a half century of science and inspiration.

▲ **BEFORE THE FALL** This panorama from the visitor center's observation deck shows the telescope's instrument platform (with Gregorian dome), two of the three suspension towers, and part of the dish, all surrounded by the Puerto Rican jungle.

ANGEL TRUJILLO / GETTY IMAGES

Disasters such as earthquakes and hurricanes are common in Puerto Rico. Only about 180 by 60 kilometers (110 by 40 miles) in extent, the small island lies 1,600 kilometers southeast of Miami, far from any major landmass. The Atlantic Ocean beats against its northern shores, and the placid Caribbean strokes its southern coast. Despite the dangers, Puerto Rico is a popular tourist destination and home to 3.2 million U.S. citizens, a resilient and diverse population long proud of the world-famous 305-meter (1,000-ft) radio telescope at Arecibo Observatory.

But at 7 a.m. on December 1, 2020, their resilience was severely tested. At that moment the support cables above the dish snapped, and the 900-ton antenna platform suspended above the dish plummeted into it in a mangled mass of steel. The crash triggered a nearby seismograph accustomed to recording small (and some not so small) earthquakes from the collision between tectonic plates in the region.

Senior telescope operator Israel Cabrera was a witness. "I do not have the right words to explain my pain when the platform collapsed," he recalls. "Just to hear the cable threads ripping like gun shots and see the platform coming down — it was a lot to take." He and other staff members watching all started to cry. They had dreaded this moment. "I feel this loss in [a] very emotional way," says Cabrera. "Now, just looking every time I come to work, I can see the ghost of the platform, but it is not there anymore."

Planetary scientist Edgard Rivera-Valentín (Lunar and Planetary Institute) was born in Puerto Rico and had been an integral part of the observatory scientific staff. He emphasizes that the loss isn't merely scientific. "It is cultural. Over the past 57 years, the telescope has woven itself into the Puerto Rican culture and has become a symbol of science and excellence in Puerto Rico. A symbol of our hopes and dreams to improve, to grow, and to achieve. A symbol of inspiration. So, you can imagine the angst I and my island felt witnessing its collapse."

The observatory is located south of the city of Arecibo, some 80 km west of San Juan. When my wife and I worked there as astronomers, it used to take us 35 minutes from our residence to navigate the winding road and the 167 bends in its last few miles. After you received a friendly greeting at the guard gate, you entered what might have been one of coziest spots on Earth to do your work. Nestled in a narrow valley between 30-m-high, densely vegetated cliffs, sturdy concrete and cinder-block buildings housed telescope operations, electronics, administration, staff scientists, visiting scientist quarters, and a cafeteria. Although the dish itself hid behind the foliage, from the control room windows you could see the enormous antenna platform suspended only about 240 m away, as if hovering in midair. At night the jungle came alive with the cacophony of coqui tree frogs calling to one another

among the background sounds of countless other creatures.

What was it like to observe with this awesome structure? Consider the scene in late July 2020, when, following a precautionary shutdown due to Tropical Storm Isaias, the planetary radar team fired up the radio transmitter and nursed their receiver and computers back to life, just in time to catch the passage of the potentially hazardous asteroid known as 2020 NK_1. Within hours the researchers calculated its orbit and concluded that at its closest approach this century, in 2043, this asteroid will pass harmlessly at a distance of 2.5 million miles. That meant scientists could remove it from the list of potential future impactors managed by NASA's Center for Near-Earth Object studies.

"It is very exciting to have a successful observing run like this," says observatory scientist Flaviane Venditti as she recalls her experience. "We felt that what we did was meaningful."

But now the meaning has gone. After she woke up and heard the news on that fateful day in December, her brain didn't register it for several hours. "I was in a mix of denial and shock. It was only hours later when a minute of silence was requested during a virtual call with more than 100 Arecibo users and friends that it really hit me. The telescope had died. That was when I went from denial to mourning."

ARECIBO OBSERVATORY / NASA / NSF

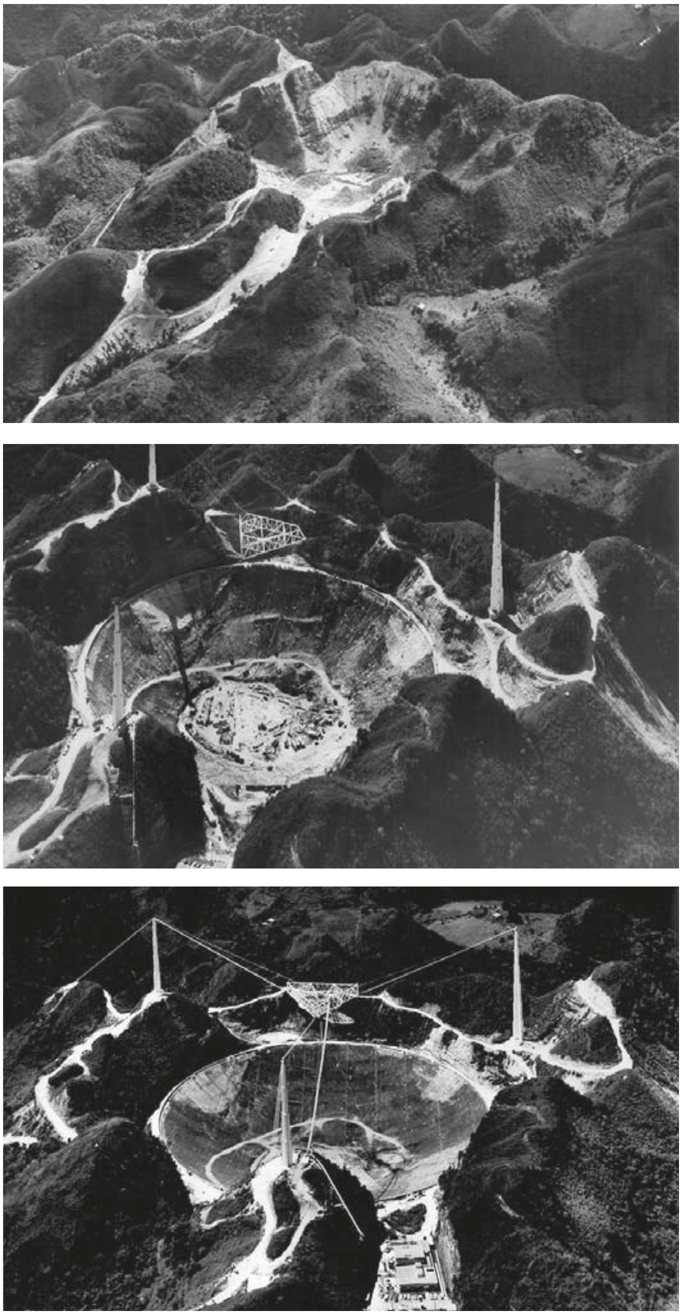
▲ **NO THREAT** Arecibo observations at the end of July 2020 enabled astronomers to confirm that the asteroid 2020 NK_1 will not strike Earth for at least the next 200 years. The object is several hundred meters across.

From Pulsars to Asteroids

Engineers completed construction of Arecibo's great dish in 1963. Originally, defense agencies funded the observatory, but after only a few years the National Science Foundation (NSF) became its steward, joining with NASA in the 1970s to undertake a massive upgrade. A second overhaul in the 1990s smoothed the dish's nearly 40,000 aluminum surface panels to 2-mm accuracy, enabling it to observe at frequencies as high as 10 GHz. Although the dish itself was immobile, astronomers could point at different parts of the sky by moving the instruments on the overhead platform into different positions, thereby catching radio waves reflected off the dish from the target.

The 30-meter-wide Gregorian dome was added to the instrument platform in the second upgrade. It essentially converted the dish from its spherical shape into a paraboloid, focusing the radio waves from space to a single point instead of them coming to a focus along a sequence of points in a line. The upgrade also enabled astronomers to smoothly change between receivers at different frequencies: Mounted on a turntable inside the dome, the desired receiver could be moved to the focal point and brought into action at the flick of a switch. This instrument platform is what plunged into the dish, ending more than a half century of science.

Arecibo leaves an amazing scientific legacy — arguably, no large radio telescope in the world can match its list of key discoveries. Over the decades, astronomers utilized its radar instruments to measure the rotation of Mercury (3 rotations for every 2 orbits of the Sun) and to find that the rotation of Venus beneath its cloudtops is retrograde, spinning backwards compared to its orbit. In 1968, observers used the big dish to measure the frequency of the Crab Nebula pulsar (33 milliseconds — significantly shorter than other pulsars found at the time), and in 1974 Richard Hulse and Joseph Taylor discovered the first-ever binary pulsar. Careful monitoring of the binary's ticking demonstrated the two dead stars were slowly spiraling toward each other at the rate predicted if the system were emitting gravitational waves, then still only hypothetical. That discovery earned the pair a Nobel Prize in 1993, an honor with which no other large, single-dish radio telescope has ever been associated.



▲ **CONSTRUCTING A MEGADISH** To build Arecibo Observatory, crews blasted out a pre-existing valley in the Puerto Rican landscape to be the right shape (*top*, December 1960), raised the towers and instrument platform (*center*, November 1962), and suspended a 305-m dish below it (*bottom*, August 1963).

ARECIBO OBSERVATORY / NAIC / NSF (3)

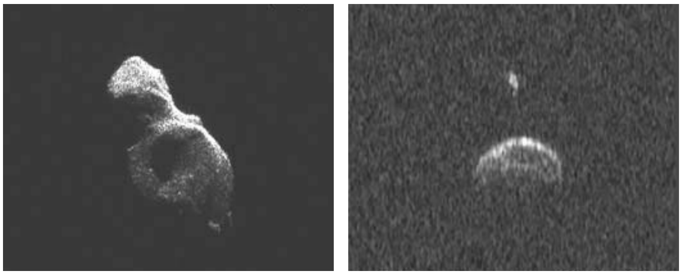
Pulsars continued to play a key role at Arecibo. In 1992 Aleksander Wolszczan and Dale Frail discovered the first planets orbiting a distant star, but that star is a rapidly spinning ball of neutrons — a millisecond pulsar that completes a rotation every 6.2 milliseconds. Dozens of millisecond pulsars, chattering at thousands of times per second, provide very accurate clocks. Before the telescope's collapse, astronomers used it as part of a cooperative project known as the North American Nanohertz Observatory for Gravitational Waves (NANOGrav), monitoring about 80 pulsars on a regular basis using a handful of radio facilities across North America. The NANOGrav team seeks small changes in pulse arrival times that would indicate that Earth is being buffeted by gravitational waves created by pairs of distant supermassive black holes orbiting each other (*S&T:* Jan. 2019, p. 22). Based on how this cosmic surf affects pulsars' signals, astronomers should be able to determine the direction of the waves' arrival.

Early in 2021, the collaboration announced the first hints of a detection of a sea of waves — the *gravitational-wave background* (*S&T:* May 2021, p. 8). But if the team can't confirm the hints using the additional 2.5 years of unpublished data the researchers already have in hand, the loss of Arecibo may delay the work by a couple of years.

Another field hurt by Arecibo's fall is the study of near-Earth objects (NEOs). "Powerful planetary radar systems are very rare," says former observatory scientist Anne Virkki, who headed the planetary radar group until 2021. "The only other active planetary radar in the U.S. is at the Goldstone Deep Space Communications Complex, and it's at least 15 times less sensitive [than Arecibo was] due to its dish size and transmitter power."

Scheduling is also an issue. When a new near-Earth asteroid is detected, it generally wafts past us in a few days. Telescope operators must adapt schedules quickly to catch the object. But Goldstone is in high demand, used as it is for spacecraft communications throughout the solar system. "Their scheduling for asteroid observations is not as flexible as it was at Arecibo," Virkki says.

NEO scientists worry that without the Puerto Rican dish, we are more vulnerable to the inevitable impact of a near-Earth asteroid. In 2019, Arecibo successfully observed more than 120 of these objects, says observatory scientist Sean Marshall, who gives his job description as "defending the planet." In 2020, he and his colleagues withstood earthquakes and tropical storms to observe 58 more, operat-



▲ **NEAR-EARTH ASTEROIDS** These radar images reveal the odd shape of 2014 HQ_{124} *(left)* and the binary 2016 AZ_8 *(right)*. Both 2014 HQ_{124} and 2016 AZ_8's primary member are a few hundred meters wide.

ing through the end of July. "It was exciting to see resolved images of objects that no one had ever seen in detail before," he says.

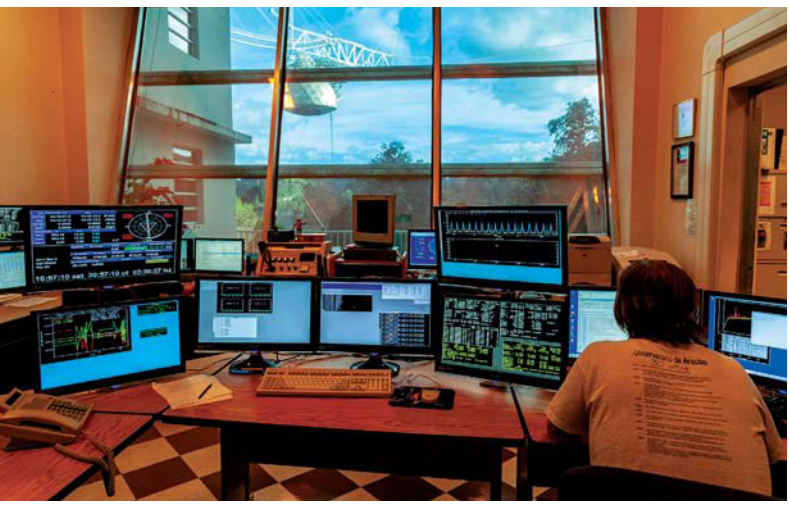
Guarding against the asteroid danger requires knowing as much as possible about objects' orbits and sizes, which requires the mighty radar capability embodied at Arecibo. Now, there is nothing to replace it.

Icon and Inspiration

Puerto Ricans rally in the face of adversity. Following Hurricane Irma in early September 2017, when trees had fallen across the only road along the coast, locals soon went to work clearing the debris with chain saws or machetes they happened to have in their pickups.

About two weeks later, Hurricane Maria devastated the island. The eye of the storm passed right over the observatory and the city of Arecibo. A half dozen colleagues and I sheltered on site either in the sturdy visiting-scientists building or in offices, together with several dogs and two children. Winds of about 190 kph (120 mph) broke the anemometer on the giant antenna platform and snapped a 70-ft-long antenna, which fell into the dish.

2014 HQ_{124}: NASA / JPL / ARECIBO OBSERVATORY; 2016 AZ_8: ARECIBO OBSERVATORY / NASA / NSF; OBSERVATION ROOM: ALAN DYER; TIMELINE: TERRI DUBÉ / S&T



▲ **ROOM WITH A VIEW** From the control room, astronomers and students could look out and see the telescope's instrument platform hanging above the dish.

Arecibo's History at a Glance

Telescope History

1963 Arecibo Ionospheric Observatory completed

1969 National Science Foundation assumes operations from Department of Defense

1974 Installation of planetary radar transmitter, high-precision surface reflector

1997 Gregorian dome installed

2004 Installation of new feed array, enabling pulsar and galactic studies

2006 NSF advisory panel recommends closure. NASA steps in to help

2011 SRI International takes over management for 5-year term

2016 NSF asks astronomy community for funding help

2017 Hurricane Maria knocks part of line feed antenna into the dish

2018 Univ. of Central Florida takes over management

2020 Suspension cables break over several months, platform collapses

Notable Science

1965 Establishes Mercury's rotation rate

1968 Determines period and location of newly discovered Crab Nebula pulsar

1974 Discovers first pulsar in a binary system. Further observations provide first indirect evidence of gravitational waves

1980 First radar echoes off an Earth-crossing asteroid, 1862 Apollo

Radar maps of Venus suggest young surface

1982 Discovers the first millisecond pulsar, PSR 1937+21

1989 Radar image of first peanut-shaped "contact binary" asteroid, 4769 Castalia

1992 Discovers first exoplanets, around pulsar B1257+12

Helps discover ice in shadowed polar craters on Mercury

2003 Provides radar evidence for hydrocarbon lakes on Saturn's moon Titan

2006 First Doppler radar images of a comet nucleus, Comet Catalina (P/2005 JQ5)

2007 First measurement of the YORP effect, the change in an asteroid's spin due to uneven absorption and emission of sunlight

Detection of prebiotic molecules in the galaxy Arp 220

NANOGrav founded to monitor pulsars for signs of passing gravitational waves

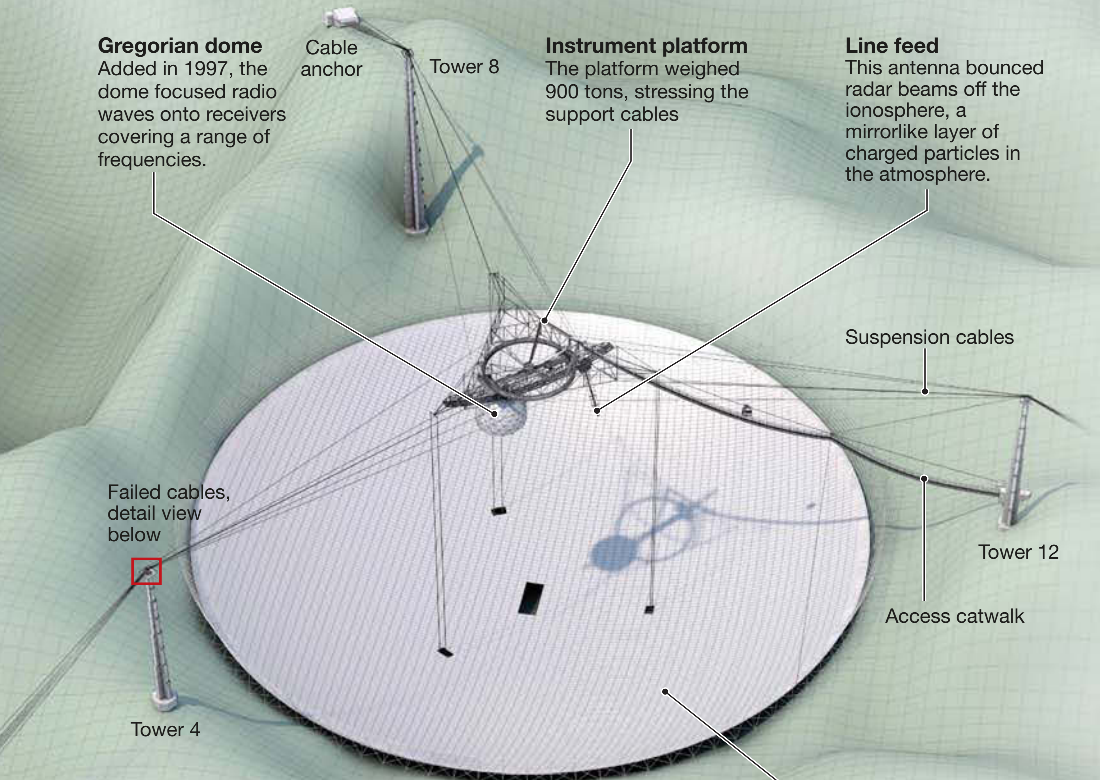
2011 Detects radio flares from a cool brown dwarf, 2MASS J1047+21

2016 Discovers first repeating fast radio burst

2021 NANOGrav announces hint of gravitational-wave background

The Arecibo Telescope

Built into the hills of Puerto Rico, the Arecibo Observatory was a force in radio astronomy for 57 years. But its design left it vulnerable to a harsh tropical climate.

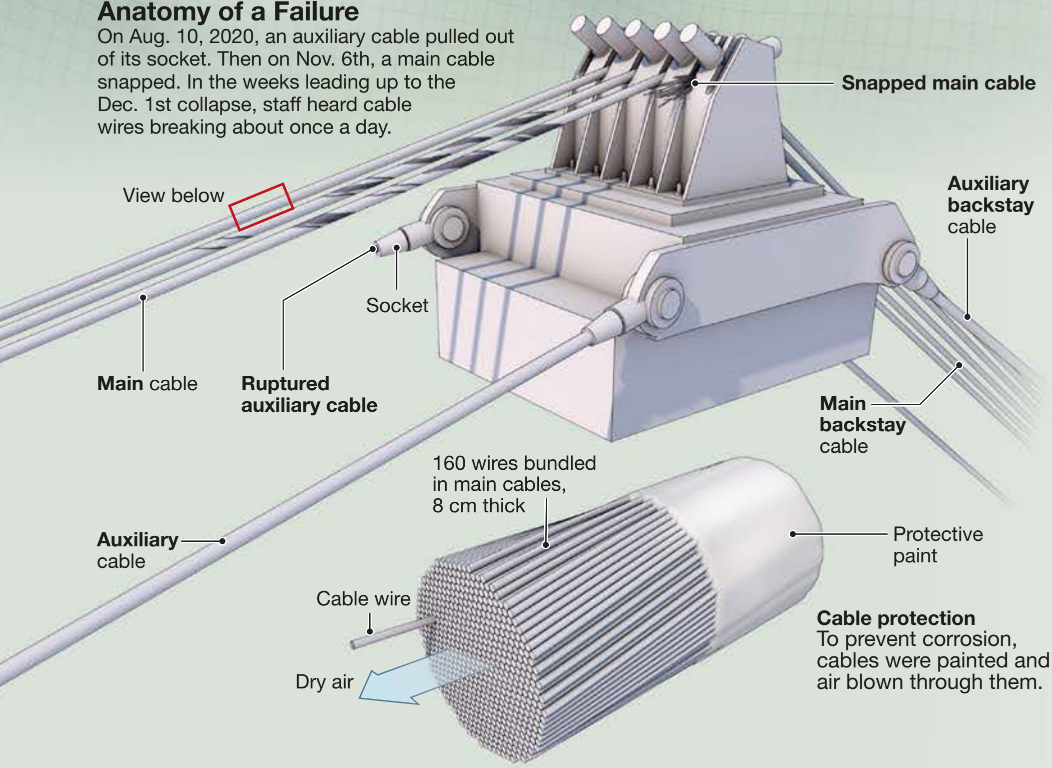


Karst terrain
Arecibo was built in a sinkhole in a Swiss-cheese landscape of soft limestone rocks. The sinkhole supported the reflector dish and protected it from radio interference.

Reflector dish
A 1974 upgrade replaced a wire mesh with more than 38,000 aluminum panels.

Anatomy of a Failure

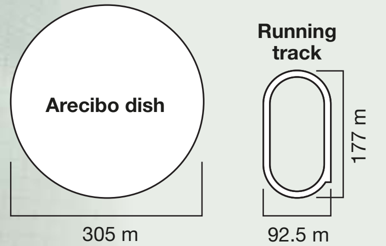
On Aug. 10, 2020, an auxiliary cable pulled out of its socket. Then on Nov. 6th, a main cable snapped. In the weeks leading up to the Dec. 1st collapse, staff heard cable wires breaking about once a day.



Cable protection
To prevent corrosion, cables were painted and air blown through them.

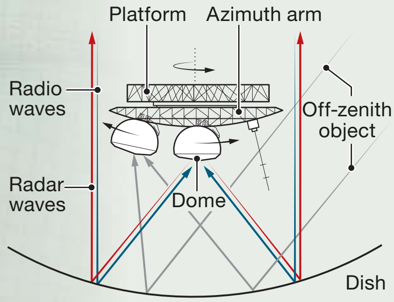
Big Eye on the Sky

Arecibo was the world's largest radio dish until it was surpassed in 2016 by a radio telescope in China (*S&T:* Feb. 2017, p. 26). Size offers sensitivity to faint objects.



How Arecibo Worked

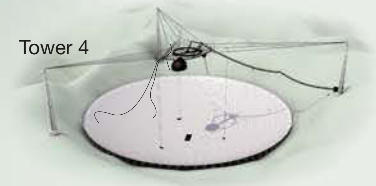
Radio astronomy
Arecibo's spherical dish allowed it to see objects that aren't directly overhead; the telescope "pointed" by moving receivers on the platform.



Radar astronomy
In radar mode, the dish turned emitted waves into a collimated beam. The dish caught reflections from targets in the upper atmosphere or solar system.

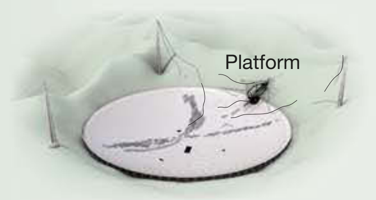
Stages of the Fall

1. After two cables connected to Tower 4 broke, the remaining four shouldered extra loads.



2. On Dec. 1, 2020, those four cables snapped within seconds of each other.

3. The platform crashed through the dish and onto the hillside.



Within days, observatory maintenance crews radiated out with heavy equipment to clear area roads of debris. Occasionally a FEMA helicopter landed at the observatory with food and water, and staff quickly loaded up cars and headed out along the byways to distribute the supplies to the community. Locals who lived close to the observatory made daily pilgrimages to draw the delicious water from a tap by the guard gate, pumped from a well on site. We kept the pump running with an emergency diesel generator, and just when fuel threatened to run out, a tanker truck accompanied by a protective police escort arrived to save the day.

But the dish disaster has a very different impact than storms like these do. While the collapse of the telescope did not cost lives, it cannot be quickly rebuilt, and the careers and livelihoods of most of the staff and scientists will never return to normal. Some members of the Arecibo scientific family still can't bring themselves to watch videos of the collapse, even months later. As Christopher Salter, the head of Arecibo's radio astronomy group, puts it, "If a relative of yours were to be run down in a car accident, would you be able to watch a video recording of the event?"

Nor is the observatory's inspirational role in the community something easily replaced. The visitor center (which survived) lured tens of thousands of tourists every year. At the center, hundreds of teachers from all over the island attended workshops in space sciences, biology, chemistry, and nanotechnology. An additional 15,000 students visited the observatory annually, either for day-long visits or to attend the Arecibo Observatory Space Academy for an intense 18-week research program for highly qualified pre-college students in Puerto Rico. Students made the weekly trek from all over the island to attend. In 2020 the observatory also initiated a Girls Educating Girls program, funded though NASA's Puerto Rico Space Grant Consortium, to increase diversity in STEM fields.

Participants in all these programs had an unparalleled close-up view of the antenna platform through their class windows. Luisa Zambrano-Marin (University of Granada, Spain), who is working on her PhD in asteroid studies, recalls the magical times she experienced with students in the summer programs. "You could see in their eyes the impact, the power this telescope had, the meaning and symbolism this structure had. Scientists have come and gone, so have administrators, but locals have always been the literal operators."

Visits to the huge dish changed students' lives. "We had a field trip to the observatory in 2016," says young researcher Marcos Jusino-Maldonado (University of Puerto Rico, Arecibo), "and I decided right then that I would pursue a career in astrobiology, astronomy, and planetary science." Those opportunities are now gone. "Careers in the space sciences are sadly underdeveloped in Puerto Rico," he says. "The observatory was a beacon of hope — perhaps it was possible to work in these fields in our home island. I believe that without the observatory, many local prospective space scientists will not get the motivation and support to reach their potential."

Arecibo's collapse elicited sadness, frustration and some-

BEFORE AND AFTER *Top:* This image of the 305-m Arecibo Telescope shows the dish unharmed, its instrument platform suspended with tables from three towers, called Tower 4, 8, and 12. The visitor center is at Tower 12 (right). The cables of Tower 4 (left) are the ones that snapped on Dec. 1, 2020. *Middle:* When the platform fell, it tore holes in the dish and expanded a gash from earlier in 2020. The series at left shows *(from top to bottom)* the damage as seen from the center of the dish; the destroyed instrument platform and Gregorian dome, seen from the walkway circling the dish; and the dish's underside, which shelters its own ecosystem.

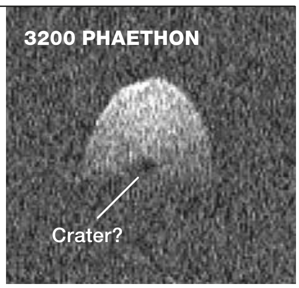
BEFORE: IMAGE COURTESY OF THE ARECIBO OBSERVATORY, A FACILITY OF THE NSF; AFTER: RICARDO ARDUENGO / AFP VIA GETTY IMAGES; CLOSEUPS: MICHELLE NEGRON / NSF (3) times anger, says Héctor Arce (Yale University), who was born and raised in Puerto Rico. “So many people were proud of Arecibo Observatory. Even non-scientists were proud of this huge and impressive structure, knowing it was maintained and cared for by Puerto Ricans.” Arce was one of many inspired to go into science and engineering because of the facility. “Some saw the observatory as a place they could work in Puerto Rico if they decided to go into astronomy or aeronomy. Others were inspired to go into science because they had visited the telescope or had participated in one of their many education programs. The impressive structure was inspiring at many levels.”

Rivera-Valentín agrees. “The Arecibo Observatory is a testament to the social impact science and its facilities can have. This social contract, in my personal opinion, makes us responsible to Puerto Rico. In looking forward to the future after this tragedy, I would hope we take the example of inspiration Arecibo gave us and build the next-generation radar telescope in Puerto Rico.”

The Future

But what are the chances of building a replacement? At the virtual meeting of the American Astronomical Society in January, the director of the NSF’s Division of Astronomical Sciences assured us that Arecibo Observatory would not close. Still, it remains unclear whether the NSF, perhaps in conjunction with NASA, might yet rehabilitate the big dish and its radar and radio astronomy capabilities.

ASTEROID SUCCESS The happy planetary radar group celebrates the acquisition of radio echoes from asteroid 3200 Phaethon in December 2017. This near-Earth Apollo asteroid is 6.25 km (3.9 mi) across and fortunately poses no threat to Earth. Its debris creates the annual Geminid meteor shower in Earth’s skies.



There is also lingering doubt and even resentment about NSF’s commitment to support Arecibo. The demise of the telescope on that fateful day did not happen suddenly; it came after multiple cable failures and several years of inadequate funding, as the agency grappled with a flat astronomy budget and burgeoning commitments (see timeline, page 37). As one observatory staff member lamented, “Personally, I’m very disappointed that not enough was done to prevent the collapse when the cables began to show signs of deterioration. Changing the cables a few years ago could have saved the telescope. An investment in maintaining and upgrading it would have been much more cost-effective than building a new one.”

What would it take to carry out a reconstruction? The collapse of the 300-ft radio telescope at Green Bank in 1988 presents a sobering parallel. That event occurred in the home territory of Senator Robert Byrd, soon to become Chairman of the Senate Appropriations Committee in Congress. From the start, he insisted that the dish be replaced as soon as possible, and that he would find the money to fund it — which he did. But although the Puerto Rican government has pledged \$8 million toward cleanup and replacement planning, the island has no equivalent politician to conjure up the several hundred million dollars needed to rebuild the telescope in whatever form may be decided upon.

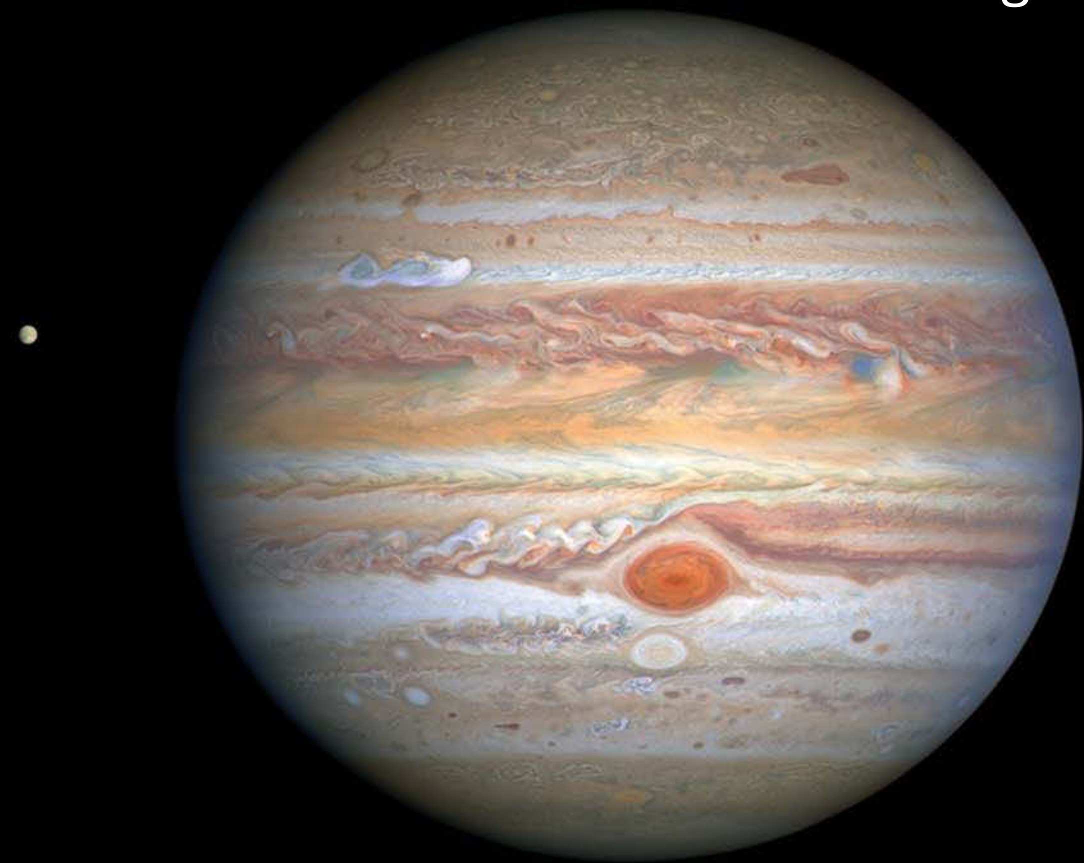
The future is thus uncertain. But it is not necessarily dire. A great deal of infrastructure related to the functioning of a large radio observatory still exists at the site. The control room equipment, back-end receivers and computers, and trained staff — all locals — can be drawn upon again. In addition, as Zambrano-Marin reminded me, the radio frequency protections for the Arecibo site, crucial for radio astronomy and ionospheric studies, are still in place. Usually, it takes decades to build such resources and train the staff. Construction of the instrument itself takes just a few years.

The desire to build the Next Generation Arecibo Telescope (NGAT) is strong. More than 2,000 interested parties with worldwide support have already endorsed the outline of its science and technical goals. As this document wends its way through bureaucratic layers on the mainland, it will hopefully stimulate plans to rebuild. If the money materializes, NGAT will make a profound contribution not just to planetary survival and radio astronomy in general, but also to a generation of scientists waiting to happen.

Seasoned radio astronomer and author **GERRIT VERSCHUUR** was astronomer emeritus at Arecibo from 2015 to 2018. He’s married to astronomer Joan Schmelz (Universities Space Research Association), who served as Arecibo’s deputy director during the same years. Their hearts go out to all the staff who made the observatory such a success and who have lost so much.

Read the Next Generation Arecibo Telescope proposal: naic.edu/ao/ngat.

3200 PHAETHON: ARECIBO OBSERVATORY / NASA / NSF; OBSERVERS: COURTESY OF ANNE VIRKKI



1–2 **ALL NIGHT:** Magnificent Saturn arrives at opposition (see page 49).

2 **MORNING:** While you're admiring the ringed planet, look to the east-northeast to see the waning crescent Moon rise, shepherded into the dawn sky by the Pleiades and the Hyades (go to page 46 for details).

3 **DAWN:** A little less than 6° separates the Moon from Aldebaran. Look high in the east to spot this duo.

6 **DAWN:** A razor-thin lunar crescent hangs some 5° right of Pollux above the east-northeastern horizon.

10 **DUSK:** Look toward the west at sunset to see the waxing crescent Moon and Venus 5½° apart.

11–12 **ALL NIGHT:** The Perseid meteor shower reaches maximum; the waxing crescent Moon won't interfere with viewing. The Perseids are a notoriously long event, and you may see meteors any time after mid-July and well into the second half of August (page 48 has more information).

16 **DUSK:** The Moon, a day past first quarter, is in Scorpius, a little more than 4° separating it from the Scorpion's heart, Antares.

19 **ALL NIGHT:** Majestic Jupiter arrives at opposition (see page 49). The gas giant anchors the eastern end of a line around 30° long with the Moon at the western end and Saturn in between.

20 **DUSK:** The Moon and Saturn, only about 4½° apart, grace the southeastern horizon after sunset.

21 **DUSK:** The almost-full Moon and Jupiter rise in tandem in the east-southeast, around 5° separating the pair.

22 **EVENING:** The Moon, now full, has teased itself away from the gas giants, and the trio are arranged in a pleasing arc above the southeastern horizon.

30 **DAWN:** High in the east, the last-quarter Moon is some 5° from Aldebaran, while the Pleiades above right complete this pretty tableau.
— DIANA HANNIKAINEN

▲ Jupiter, along with its entourage of moons, arrives at opposition this month. The Hubble Space Telescope image above shows Europa on the planet's left.
NASA / ESA / A. SIMON (GODDARD SPACE FLIGHT CENTER) / M. H. WONG (UNIVERSITY OF CALIFORNIA, BERKELEY) / THE OPAL TEAM

Lunar Almanac
Northern Hemisphere Sky Chart

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

NASA / LRO

MOON PHASES

SUN	MON	TUE	WED	THU	FRI	SAT
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

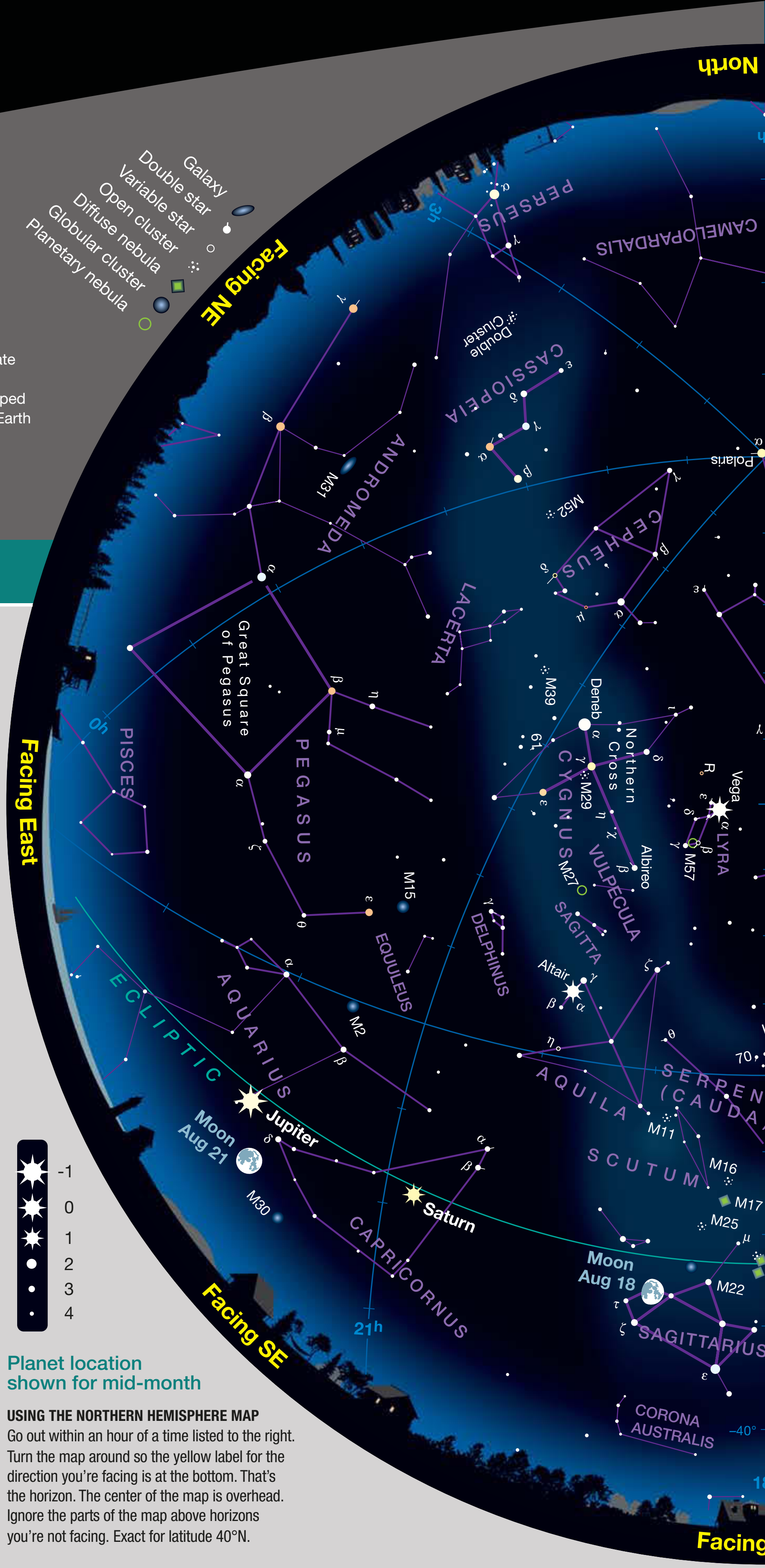
NEW MOON	**FIRST QUARTER**
August 8	August 15
13:50 UT	15:20 UT
FULL MOON	**LAST QUARTER**
August 22	August 30
12:02 UT	07:13 UT

DISTANCES

Apogee	August 2, 08^h UT
404,409 km	Diameter 29′ 33″
Perigee	August 17, 09^h UT
369,125 km	Diameter 32′ 22″
Apogee	August 30, 02^h UT
404,098 km	Diameter 29′ 34″

FAVORABLE LIBRATIONS

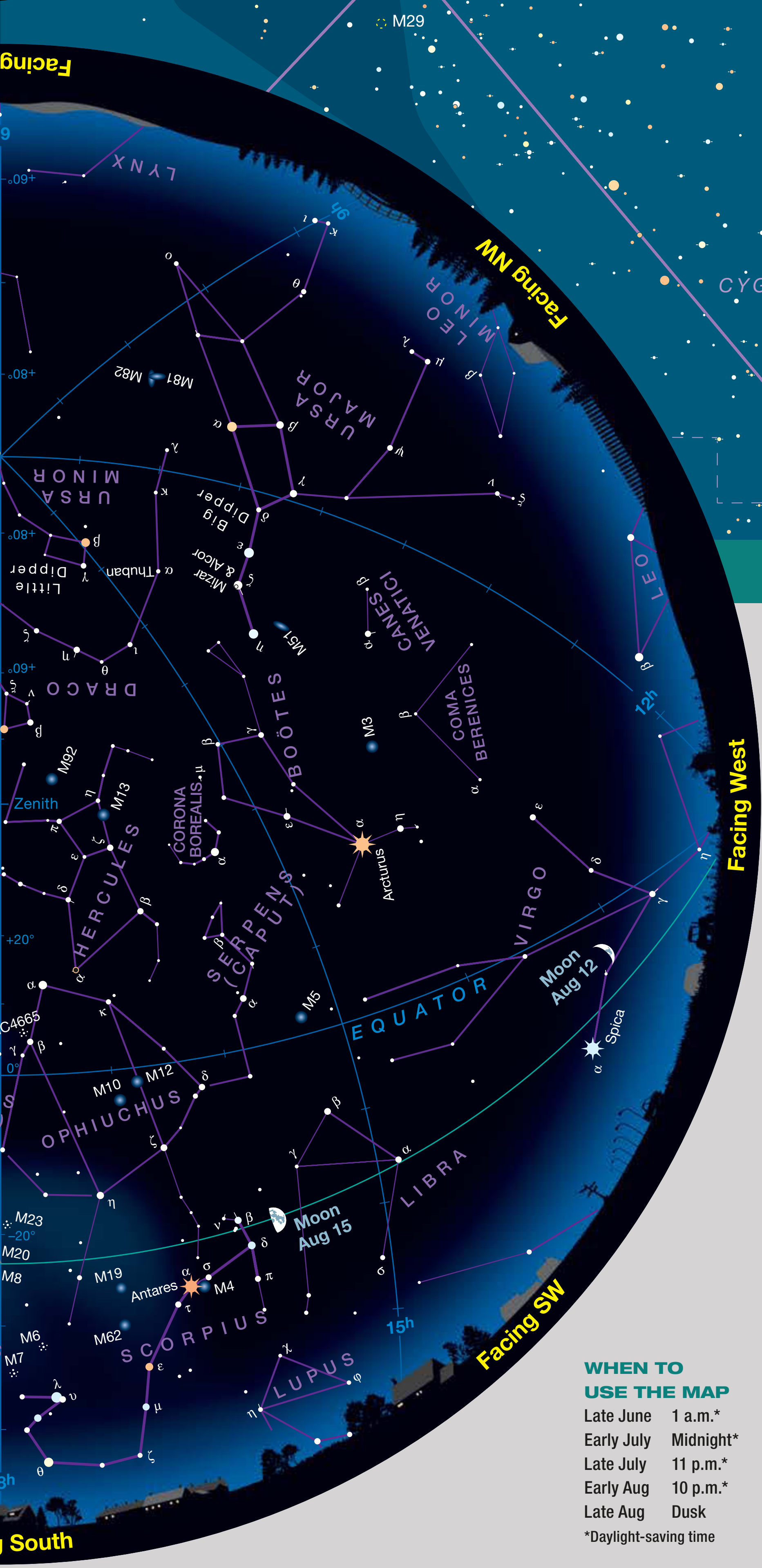
• Piazzi Crater	August 4
• Hayn Crater	August 19
• Compton Crater	August 21
• Boss F Crater	August 22

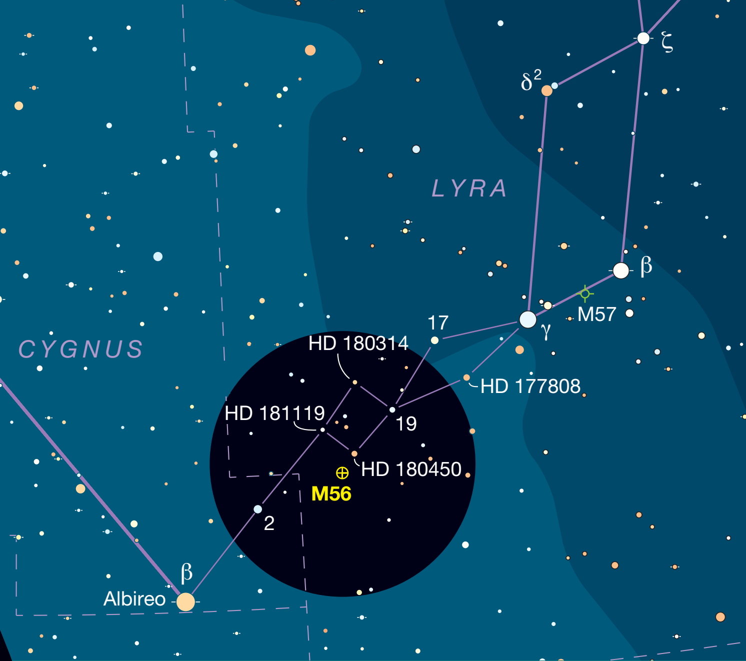


Planet location shown for mid-month

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.





WHEN TO USE THE MAP

Late June	1 a.m.*
Early July	Midnight*
Late July	11 p.m.*
Early Aug	10 p.m.*
Late Aug	Dusk

*Daylight-saving time

Binocular Highlight by Mathew Wedel

Lost in Space

Do certain celestial objects bedevil you? You know where they are, you go looking, and you end up flopping around uselessly before giving up and rechecking your charts. One such object for me is **M56**, a globular cluster in the constellation Lyra, the Lyre. You'd think it would be an easy catch: The cluster lies on a line between Sulafat, or Gamma (γ) Lyrae, and Albireo, or Beta (β) Cygni, a little closer to Albireo than to Sulafat. But I've wasted so much time fumbling for it that I finally worked out a star-hop to get me there quickly.

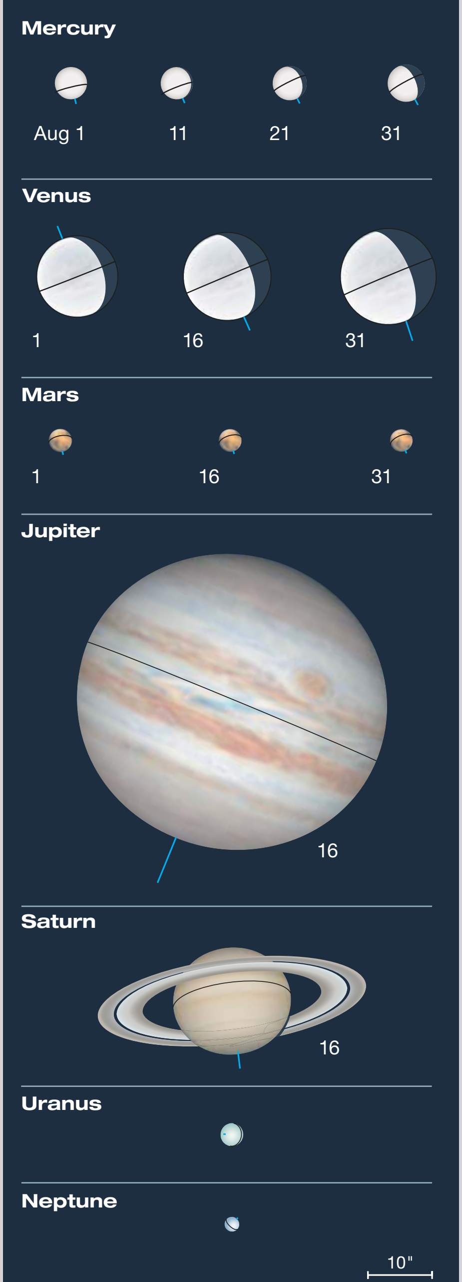
Just north of M56, find a rectangle of 5th- and 6th-magnitude stars, with the corners formed by 19 Lyrae, HD 180450, HD 181119, and HD 180314. In the eastern corner of the rectangle you'll see an equilateral triangle of fainter stars, about 12′ on a side, which is a nice asterism in its own right. Extend the line from 19 Lyrae to HD 180450 by another 25′ southeast and you'll land on M56.

Okay, so how do you get to the rectangle? Gamma Lyrae forms a squashed diamond with 17 Lyrae, HD 177808, and 19 Lyrae. Alternatively, from Albireo you can scan northwest past 2 Cygni and onward an equal distance to land on HD 181119 at the rectangle's eastern corner.

As for M56, at magnitude 8.3 it looks like a slightly fuzzy star at any binocular magnification. But we don't observe globs with binoculars for their indescribable beauty, but rather to savor their vast distances and incredible ages — 33,000 light-years and 13.7 billion years in the case of M56, whose light dates from the Ice Age and whose stars were born not long after the Big Bang. Now that's a view worth searching out.

■ **MATT WEDEL** is afraid he'll have his astronomer card yanked if people find out how often he gets lost up there. So far, he's always made it back.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** is lost in the Sun's glare all month • **Venus** shines brightly at dusk • **Mars** is too close to the Sun to be viewed all month • **Jupiter** and **Saturn** rise around sunset and are visible all night.



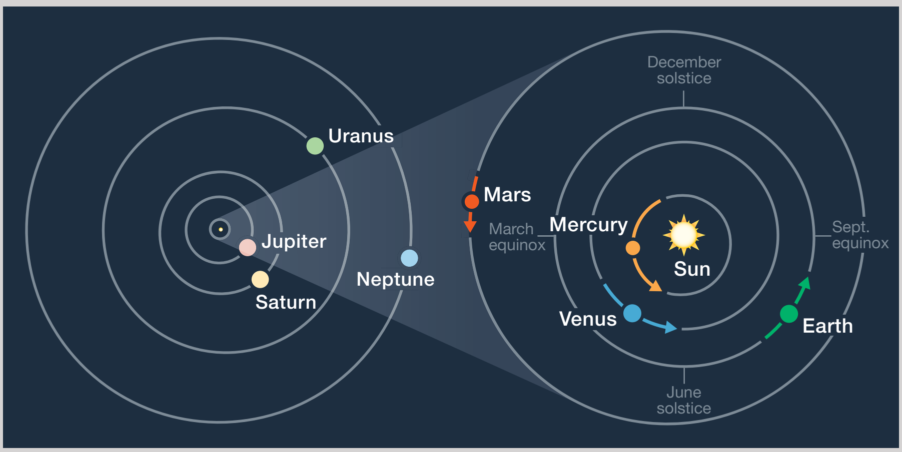
▲ **PLANET DISKS** have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

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

August Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$8^h\ 44.5^m$	+18° 05′	—	–26.8	31′ 31″	—	1.015
	31	$10^h\ 36.9^m$	+8° 45′	—	–26.8	31′ 41″	—	1.010
Mercury	1	$8^h\ 43.6^m$	+19° 52′	2° Mo	–2.1	5.0″	100%	1.339
	11	$10^h\ 02.9^m$	+13° 40′	10° Ev	–1.0	5.0″	94%	1.337
	21	$11^h\ 08.0^m$	+6° 20′	18° Ev	–0.4	5.3″	85%	1.266
	31	$12^h\ 02.0^m$	–0° 53′	23° Ev	–0.1	5.8″	75%	1.159
Venus	1	$10^h\ 54.3^m$	+8° 25′	33° Ev	–3.9	12.7″	82%	1.316
	11	$11^h\ 37.9^m$	+3° 26′	35° Ev	–3.9	13.3″	79%	1.252
	21	$12^h\ 20.5^m$	–1° 43′	38° Ev	–4.0	14.1″	76%	1.185
	31	$13^h\ 02.9^m$	–6° 49′	40° Ev	–4.0	15.0″	73%	1.115
Mars	1	$10^h\ 14.0^m$	+12° 07′	22° Ev	+1.8	3.7″	99%	2.557
	16	$10^h\ 49.6^m$	+8° 33′	17° Ev	+1.8	3.6″	99%	2.598
	31	$11^h\ 24.9^m$	+4° 47′	13° Ev	+1.8	3.6″	100%	2.625
Jupiter	1	$22^h\ 07.4^m$	–12° 47′	159° Mo	–2.8	48.5″	100%	4.068
	31	$21^h\ 52.7^m$	–14° 09′	168° Ev	–2.9	48.9″	100%	4.030
Saturn	1	$20^h\ 50.6^m$	–18° 30′	178° Mo	+0.2	18.6″	100%	8.936
	31	$20^h\ 42.1^m$	–19° 05′	150° Ev	+0.3	18.4″	100%	9.055
Uranus	16	$2^h\ 48.6^m$	+15° 47′	99° Mo	+5.7	3.6″	100%	19.565
Neptune	16	$23^h\ 33.4^m$	–4° 09′	151° Mo	+7.8	2.4″	100%	29.035

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.



The Queen Star of Summer

Brilliant Vega rules August evenings from the zenith.

By my count, Vega has at least three different titles. Alpha (α) Lyrae has been called the Queen Star of Summer, the Sapphire of Summer, and the Sirius of Summer. Each is apt in its own way.

Like a queen, Vega rules August evenings from the zenith — the very throne of the night sky. It passes nearly overhead for observers around the populous latitude of 40° north, so the Queen Star of Summer has more sky-watchers to reign over than any other stellar luminary.

Vega's name comes from the medieval Arabic title of its home constellation, Lyra, which means "the swooping eagle," not to be confused with neighboring Aquila, which means "the soaring eagle." But a slightly different translation has Lyra and Vega as "the *stooping* eagle." The part of the phrase we get "Vega" from is the "stooping" part, which fits well with the idea of Vega as queen. Its marvelous light radiating from straight overhead is like a queen stooping to look down upon us from her exalted throne.

Of course, Vega deserves to be called the Queen Star of Summer even if we don't invoke its zenithal position. At magnitude +0.03, it's by far the brightest star in any of the summer constellations, even if it's the second-brightest star plotted on our August star map. As described in the June issue, Arcturus is very slightly brighter, but on late-summer evenings it's falling ever lower in the west, where atmospheric absorption slightly dims its light.

Vega's stature is further enhanced by its dominant position in the well-known Summer Triangle asterism. Not that the other two Triangle stars are exactly faint! Deneb, in Cygnus, is a 1.25-magnitude spark, and Altair — in the aforementioned Aquila — is brighter still, at magnitude +0.76.

Queens and jewels go well together, so it's perhaps not surprising that Vega is also known as the Sapphire of Summer. But not everyone can readily detect star colors without optical aid. Like warm-hued Arcturus, however, Vega is bright enough that many of us can see a refreshing hint of frosty blue in its light. What may help is Vega's summer-evening altitude — there's less chance of turbulence in our atmosphere disturbing its color. That's not the case with bright stars like blue-white Sirius, which always appears fairly low in the sky from mid-northern latitudes.

The reference to winter's great star leads us directly to my third-favorite title for Vega, the Sirius of Summer. Vega rules the zenith precisely in those months when Sirius is hidden in the Sun's glare. Interestingly, for most readers of this magazine, Sirius has its *heliacal rising* — its return to visibility at dawn — in August.

Despite the two stars' similarities, some of the differences between Vega and Sirius are so diametrical that they bind the two together in our imaginations. Most notable is the fact that Sirius is located near the part of the Milky Way that Earth is moving away from, and Vega is near the part we're heading towards. To put it in automotive terms, we see Vega through the windshield in front of us, while Sirius is fixed in the rearview mirror. But, at a distance of 8.6 light-years, Sirius is much closer — Vega lies 25.0 light-years ahead of us (virtually the same distance as the bright autumn star, Fomalhaut).

There's another reason why Vega is such an object of wonder in August. Early in summer, nights at mid-northern latitudes are short, and evening twilight brightens the sky until late. By August, however, sunsets are noticeably earlier, and twilight doesn't linger quite as long. So you can watch Vega flower into full radiance in a fully darkened sky without having to stay up late.

■ **FRED SCHAAF** began writing his very first book, *Wonders of the Sky*, in the summer of 1980.

SUMMER LIGHT Brilliant Vega is a key part of two triangles. Along with Deneb and Altair, it's a member of the famed Summer Triangle. And as shown in this photo, it also marks the western point in a compact triangle that includes fellow Lyra stars Epsilon and Zeta. Well known as the Double-Double, Epsilon is a favorite target for telescope users.

GARY SERONIK

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

A Busy Month for the Moon

In addition to a few striking conjunctions, August offers an opportunity to sing the lunar blues.

MONDAY, AUGUST 2

The month opens with a pretty, naked-eye sight in the predawn. There, hanging above the eastern horizon, you'll find the waning crescent **Moon** near the Pleiades and Hyades clusters in Taurus. The Moon is roughly 4½° from the Pleiades and nearly 10° from Aldebaran. The lunar crescent also forms an appealing triangle with the bright stars Betelgeuse, in Orion, and Capella, in Auriga. The scene is most attractive at around 5 a.m. local daylight time — just before morning twilight starts to seriously interfere with the view. And if you miss out this time, the Moon passes through the area once again at the end of the month.

TUESDAY, AUGUST 10

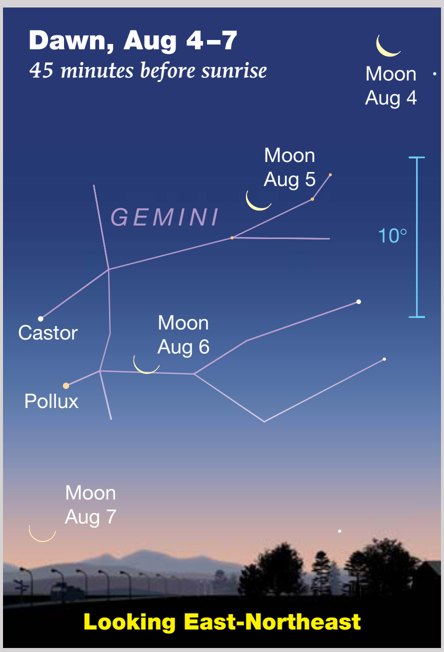
Having returned to the evening sky, the **Moon** now sits about 5½° right of the brilliant Evening Star, **Venus**. As Moon-Venus encounters go, this isn't an especially close one (they were less than 1° apart back in May), but any time the two brightest objects in the night sky get together, it's worth checking out. Both objects are low in the west, so the sooner you look, the better the view. And because the Moon is just 2½ days past new, it presents a thin crescent nicely illuminated by earthshine. Binoculars will help you appreciate this "twice-reflected sunlight," as *S&T* columnist Charles Wood describes the phenomenon.

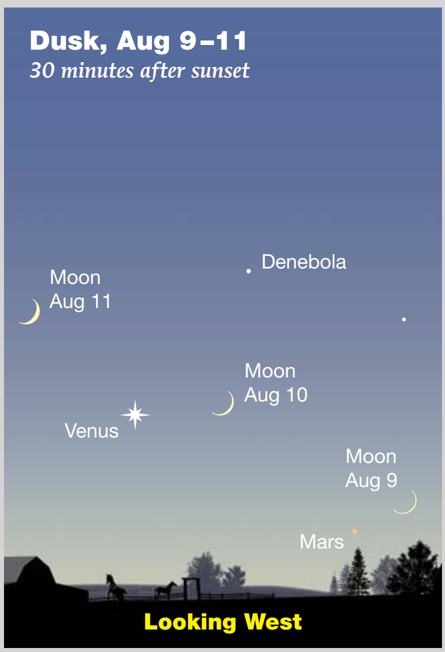
FRIDAY, AUGUST 13

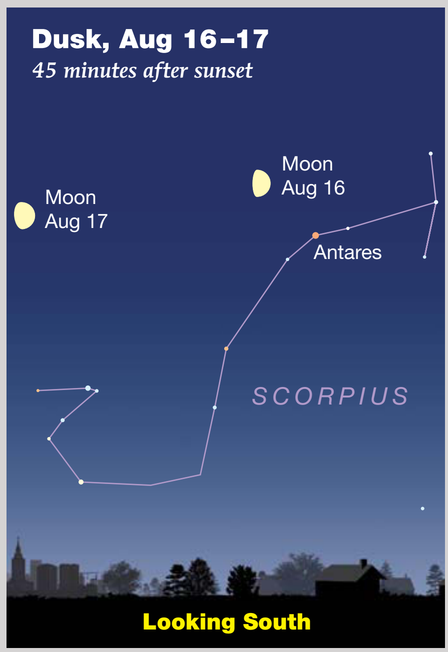
You wouldn't normally resort to binoculars or a small telescope to view **Venus**, but this evening you'll be rewarded for doing so. Fix your gaze on the planet and you might notice a tiny spark just below it. That's Beta Virginis. But the brightness mismatch is extreme. The star shines gamely at magnitude 3.6, but Venus dazzles 1,000 times brighter, at magnitude –3.9. Look for the star a scant 7′ southwest of the planet. Apart from the glare coming off Venus, the other challenge to seeing this conjunction is the low altitude of both targets. From mid-northern latitudes they're only a little better than 8° above the horizon 45 minutes after sunset.

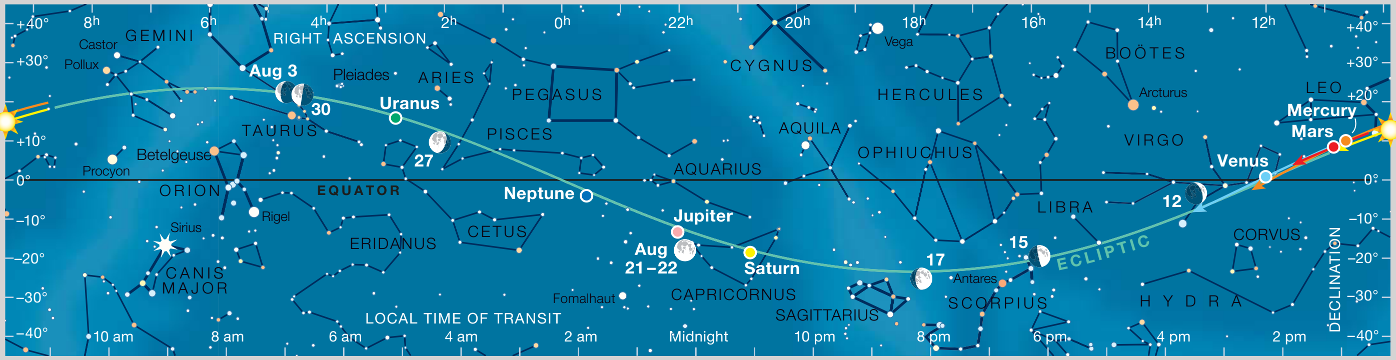
WEDNESDAY, AUGUST 18

Once again binoculars (or a small telescope) are your best friend as the waxing gibbous Moon glides just south of 2nd-magnitude Sigma (σ) Sagittarii, also known as Nunki. The star marks the northeast corner of the Sagittarius Teapot. How close the Moon gets to Nunki depends on how far south you







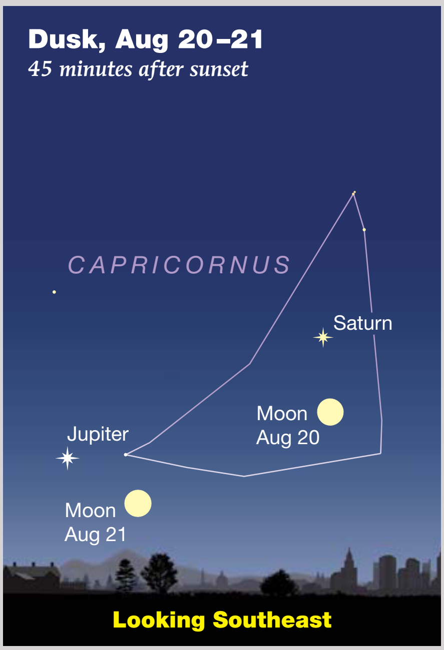


▲ The Sun and planets are positioned for mid-August; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

are. For lucky observers in the southernmost U.S., Mexico, and Central America, the Moon actually eclipses Nunki. The midpoint of the event (when the lunar disk is closest to the star, or the occultation is halfway through) occurs at roughly 11:47 p.m. EDT.

FRIDAY, AUGUST 20

Step outside this evening as twilight deepens and look towards the southeast for a delightful naked-eye sight. There, the **Moon** rises with **Saturn** positioned some 4½° above it, and with Jupiter a little better than 17° to their left, like a shy stranger hanging around and hoping for an invitation to the party. (Don't feel bad for Jupiter, though — its invitation arrives on the 22nd.) The ringed planet is fresh from its opposition night on the 2nd (see page 49 for more) and glows brightly at magnitude +0.3. And yet, by quite a margin, Saturn is the faintest of the threesome, so it'll be the last to show up as the sky darkens. How soon after sundown will you be able to spot it? Feel free to cheat with binoculars. One advantage to having the Moon nearby is you'll have a handy reference point, which should make finding Saturn in bright twilight that much easier.

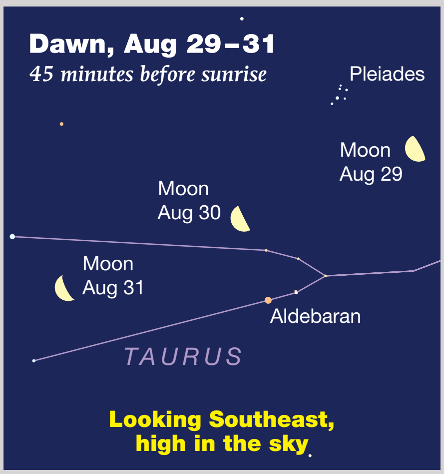


SUNDAY, AUGUST 22

Some astronomy enthusiasts cringe a bit when they see the phrase "**Blue Moon**" in print. Here at *S&T*, we perhaps cringe a little bit harder. That's because in 1946 we inadvertently played a significant role in establishing the modern definition of the Blue Moon as the second full Moon in a month that has two. And no amount of cringing is going to put that genie back into its bottle. However, it's worth noting that the original definition — as set out in the *Maine Farmers' Almanac* — had the full Moon as "blue" if it was the third one in a season that has four. Not to pick on the *Farmers' Almanac*, but that's convoluted enough that some confusion is almost inevitable. So, in honor of righting a historical error, take a moment tonight to enjoy a "classic" Blue Moon — the third full Moon in a summer that has four. You can read a *lot* more about the subject at **skyandtelescope.org/observing/what-is-a-blue-moon/**.

This full Moon actually occurs at 8:02 a.m. EDT on the morning of the 22nd. As it approaches this phase, the Moon will be setting in the west-southwest alongside **Jupiter**. Indeed, the gas giant will be just 4° right of the lunar disk. As noted on page 49, Jupiter reached opposition just two nights earlier and presently shines brilliantly at magnitude –2.9. So, if the allure of a Blue Moon isn't quite enough to get you out of bed early, perhaps this attractive pairing will do the trick.

◀▼ 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.



■ Consulting Editor **GARY SERONIK** has witnessed more Blue Moons than he cares to count.

A Near-Perfect Year for Perseids

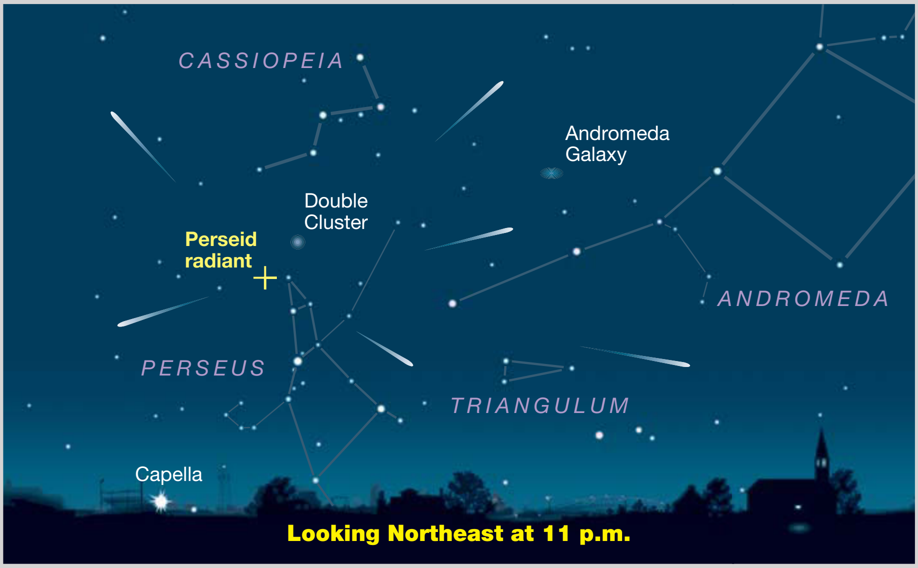
Sit back, relax, and enjoy this summer meteor spectacle.

▲ Rafael Schmall took nearly 1,000, 120-second exposures over three evenings to create this montage of the 2017 Perseid meteor shower. He used a Canon EOS 6D camera (set to ISO 6400) and a 16-mm lens at f/2.8.

The forecast couldn't be better. When the annual Perseid meteor shower peaks on the night of August 11–12, the Moon will be a thin crescent and safely tucked in bed shortly after the end of evening astronomical twilight. With no extraneous light to mar the view, this year's shower should be one of the best. Up to 100 meteors per hour will flare from the darkest skies, but 60-80 per hour is a more realistic number for most observers.

As shown in the chart below, Perseids stream from a radiant in Perseus, just near the W of Cassiopeia. In the same way parallel railroad tracks appear to converge in the distance, meteors follow parallel paths that seem come from a particular spot in the sky. Most meteoroid particles are no bigger than a grain of sand, with a few as large as M&M candies. Each Perseid is a fragment shed by Comet 109P/Swift-Tuttle during one of its many trips around the Sun.

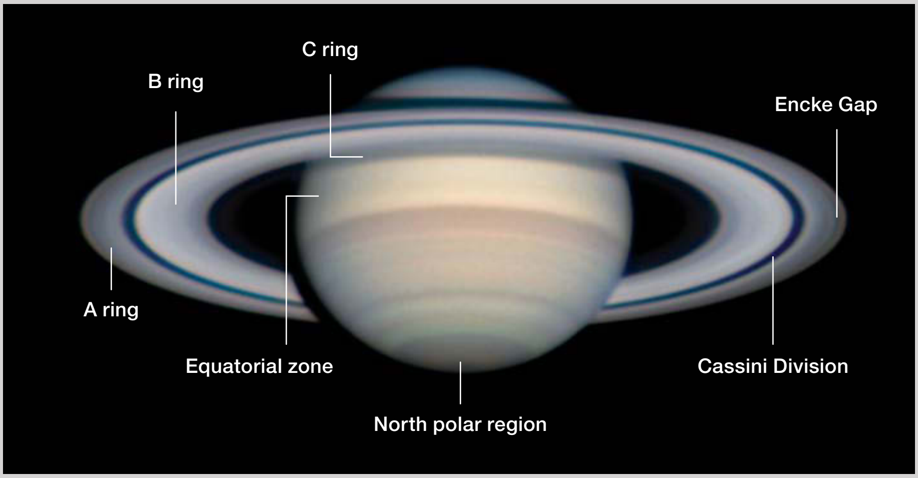
Every August, the Earth intersects the comet's path and plows through it at high speed. As each fragment slams into the atmosphere at some 60 kilometers (37 miles) per second, it glows white-hot from friction and burns to soot. At the same time, it excites (ionizes) the air molecules along its path. When those molecules relax back to their previous, unexcited state they emit light. Both the glowing, hot particle and trail of ionized air are responsible for the familiar and eye-catching meteor streak. Picture an incandescent pebble traveling 200 times faster than a jet airplane at the center of a self-created tunnel of luminous air. That's a meteor!



The best time to look for Perseids will be on the 12th from about 2 a.m. until dawn, when the radiant is highest in the sky. But you'll see a modest number as early as 10 p.m. on the 11th, even with the radiant low in the northeast. The later you stay up, the higher Perseus rises and the more meteors you'll see.

Pleasant August weather often makes it easy to stay up watching meteors all night. Bring the kids, and make sure you have comfortable lounge chairs so everyone can relax while gazing skyward. Dress warmly and cover up with a blanket to keep the chill at bay. Perseids streak all over the sky, so you can face any direction you like. Lie back and watch the constellations lazily drift by carried by Earth's rotation as you anticipate the next meteor flash.

Dog Days with the Gas Giants



▲ Australian amateur Anthony Wesley captured this image of Saturn on May 1, 2021. Most of the features labelled here are visible in modest backyard telescopes.

LAST YEAR WE WATCHED as Jupiter and Saturn drew together for December's historic close conjunction in Sagittarius. Since then, they've separated and now shine from neighboring constellations: Saturn in Capricornus and Jupiter in Aquarius. Yet both planets are still close enough to share the same month of opposition. Saturn reaches this milestone on August 2nd, Jupiter on the 19th (EDT; August 20th UT).

Nearly 20° separate the pair on August 1st, but that shrinks to 17.5° by month's end. Both planets are moving "backwards" in *retrograde* (east to west) as Earth laps them on its faster orbit.

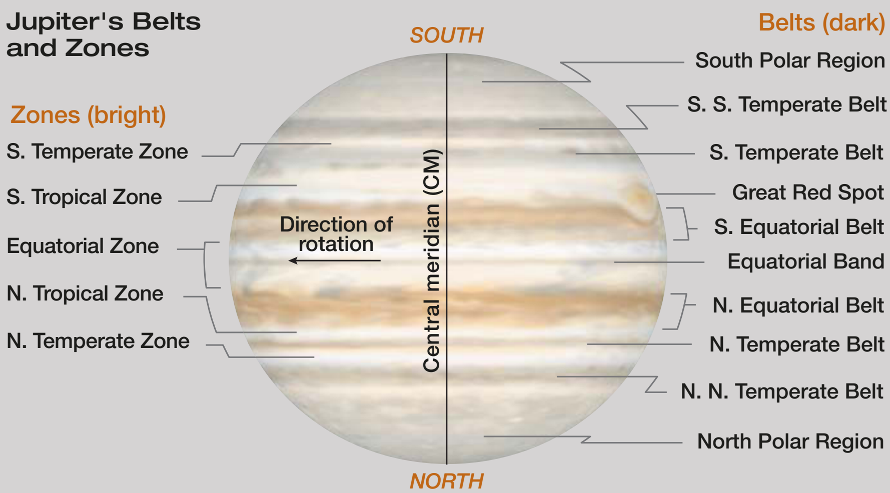
After bottoming out in Sagittarius last apparition, Jupiter and Saturn have drifted north and are better placed for observers at northern latitudes this time round. And every extra degree of altitude counts when it comes to discerning planetary detail.

For many, Saturn's rings are the most beautiful sight in the universe. Even the smallest telescope will reveal the rings with magnifications as low as 25×. I still remember how tiny and perfect the ringed planet appeared in my 60-mm (2.4-inch) refractor when I first saw it at the tender age of 11. My astronomy books pointed out that Saturn is made mostly of hydrogen and helium and would float if you could find an ocean big enough to hold it. For me, that ocean was the circle of sky that surrounded the planet in the eyepiece.

Saturn really comes into its own in a 4-inch or larger telescope and magnifications upwards of 75×. At opposition this year, the northern face of the rings is inclined earthward by 18° — steep enough for telescopic views of the three main rings and Cassini's Division, a 0.8″ gap separating the A and B rings. These two bright rings are easy to see, but the translucent C ring is more subtle. Look for a dusky, shadowlike band where it crosses the planet's disk. Owners of 12.5-inch and larger instruments can also seek the narrower, more elusive Encke Gap.

The rings are primarily composed of water-ice pieces that range in size from sand grains to mountains. The particles reflect light well, making the rings appear distinctly whiter and brighter than Saturn's butterscotch-cream globe. At opposition, we view the planet with the Sun directly at our back. Not only is Saturn's shadow hidden from view behind the globe of the planet, but the shadows cast by the ring particles in turn are hidden behind their tiny bulks. The result is a temporary surge in brilliance known as the *Seeliger effect*: When light strikes tiny, dustlike particles head-on, multiple reflections combine to create a single brighter reflection directed back to the observer's eye. And thus, for several days around opposition, Saturn's rings are even more radiant than usual.

Saturn has more known moons than any other planet. Of its 82 satellites, 8 are within reach of amateur telescopes. Five of them — Titan, Rhea, Dione, Tethys, and Iapetus — are visible in a 6-inch. At magnitude 8.5, Titan is the brightest and is easily visible in any scope. Iapetus is also remarkable because one hemisphere is coal-black and the other ice-bright. When it's at western elongation we see the bright hemisphere, and the moon shines at magnitude 10.2. At eastern elongation, the dark side is presented, and the satellite dims to magnitude 11.9. Enceladus can be viewed in an 8-inch scope, while both Mimas (the closest orbiting moon) and distant Hyperion require at least a 10-inch.



GREGG DINDERMAN / S&T

To locate the five brightest Saturnian moons, use the interactive Saturn's Moons app, found on the Tools page at **skyandtelescope.org.**

Compared to Saturn, Jupiter's disk overflows with detail. The dark North and South Equatorial Belts (NEB and SEB) that straddle the bright Equatorial Zone (EZ) are the easiest features to pick out. Increasing the magnification to around 100× will bring out additional bands. Consult the illustration on the preceding page to identify these.

In the past few decades, Jupiter's iconic Great Red Spot (GRS) has been shrinking and becoming more circular. The GRS currently bears a lush, red-orange color, which increases its visibility. Located just south of the SEB, the best time to see the GRS is when it crosses Jupiter's central meridian. Refer to the listings at right for transit times. You'll find that a #80A (blue) filter will improve visibility of the GRS as well as the rust-hued belts.

Jupiter's four bright Galilean satellites in their myriad configurations around the planet always make for an enjoyable sight. Each is big enough to show a tiny disk in a 6-inch scope at magnifications of 200× or greater. From biggest to smallest, the Galilean moons are: Ganymede (1.8″), Callisto (1.7″), Io (1.3″), and Europa (1.1″).

The table on the facing page lists various satellite events. Of special note are double-shadow transit events in which the shadows of two moons cross the Jovian disk at the same time. Observers in the western two-thirds of the Americas have an opportunity to observe a double-shadow transit on August 1st. The event begins at 10:08 UT (3:08 PDT) as Europa's shadow lands on the disk of Jupiter, joining Ganymede's. The double-shadow transit concludes just 11 minutes later when Ganymede's shadow departs the planet's disk.

In addition to their interactions with Jupiter, the moons can also eclipse and occult one another. Although the "mutual satellite event" season is winding down, in August there are two occurrences visible for observers in the Americas. Ganymede eclipses Europa on the 9th (from 3:37 to 4:45 UT), and once again on the 16th (from 10:03 to 10:35 UT). The combined light of the two satellites will dim by about 0.5 magnitude during the eclipses.

Minima of Algol

Aug.	UT
1	3:35
4	0:24
6	21:12
9	18:01
12	14:49
15	11:38
18	8:27
21	5:15
24	2:04
26	22:52
29	19:41

These geocentric predictions are from the recent heliocentric elements Min. = JD 2445641.554 + 2.867324*E*, where *E* is any integer. For a comparison-star chart and more info, see **skyandtelescope.org/algol**.

▲ Perseus approaches the zenith during predawn hours in August. Every 2.87 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.3 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

The Jupiter-observing season is in its prime as the giant planet reaches opposition on the night of August 19–20. As a result, you can observe Jupiter from dusk to dawn throughout the month and will have plenty of opportunities to look in on the comings and goings of its four brightest moons and check out its famous Great Red Spot. At mid-month Jupiter gleams at magnitude –2.9 near the border between Aquarius and Capricornus and presents a 49″ disk.

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

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

July 1: 0:13, 10:09, 20:05; **2**: 6:00, 15:56; **3**: 1:51, 11:47, 21:43; **4**: 7:38, 17:34; **5**: 3:29, 13:25, 23:21; **6**: 9:16, 19:12; **7**: 5:07, 15:03; **8**: 0:59, 10:54, 20:50; **9**: 6:45, 16:41; **10**: 2:37, 12:32, 22:28; **11**: 8:24, 18:19; **12**: 4:15, 14:10; **13**: 0:06, 10:02, 19:57; **14**: 5:53, 15:48; **15**: 1:44, 11:40, 21:35; **16**: 7:31, 17:26; **17**: 3:22, 13:18, 23:13; **18**: 9:09, 19:04; **19**: 4:59, 14:56; **20**: 0:51, 10:47, 20:42; **21**: 6:38, 16:34; **22**: 2:29, 12:25, 22:20; **23**: 8:16, 18:12; **24**: 4:07, 14:03, 23:58; **25**: 9:54, 19:49; **26**: 5:45, 15:41; **27**: 1:36, 11:32, 21:27; **28**: 7:23, 17:19; **29**: 3:14, 13:10, 23:05; **30**: 9:01, 18:57; **31**: 4:52, 14:48

August 1: 0:46, 10:42, 20:38; **2**: 6:33, 16:29; **3**: 2:24, 12:20, 22:16; **4**: 8:11, 18:07; **5**: 4:02, 13:58, 23:54; **6**: 9:49, 19:45; **7**: 5:40, 15:36; **8**: 1:31, 11:27, 21:23; **9**: 7:18, 17:14; **10**: 3:09, 13:05, 23:01; **11**: 8:56, 18:52; **12**: 4:47, 14:43; **13**: 0:38, 10:34, 20:30; **14**: 6:25, 16:21; **15**: 2:16, 12:12, 22:08; **16**: 8:03, 17:59; **17**: 3:54, 13:50, 23:46; **18**: 9:41, 19:37; **19**: 5:32, 15:28; **20**: 1:23, 11:19, 21:15; **21**: 7:10, 17:06; **22**: 3:01, 12:57, 22:53; **23**: 8:48, 18:44; **24**: 4:39, 14:35; **25**: 0:30, 10:26, 20:22; **26**: 6:17, 16:13; **27**: 2:08, 12:04, 21:59; **28**: 7:55, 17:51; **29**: 3:46, 13:42, 23:38; **30**: 9:33, 19:29; **31**: 5:24, 15:20

These times assume that the spot will be centered at System II longitude 4° on August 1st. If it has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 4° and 1⅔ minutes later for each degree more than 4°.

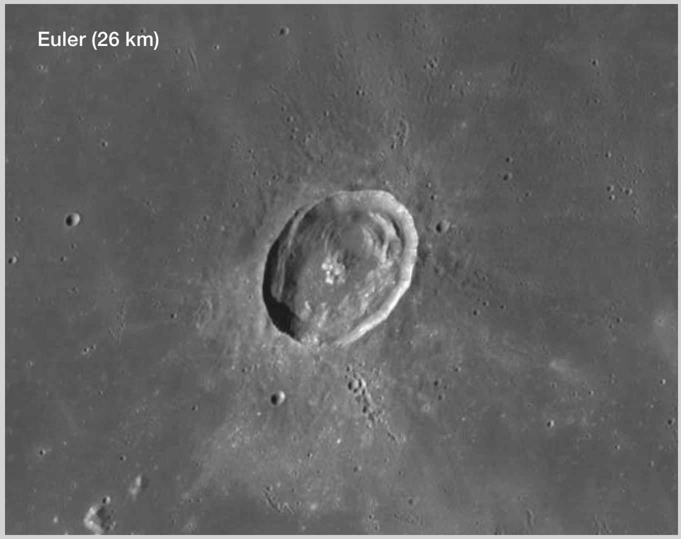
Phenomena of Jupiter's Moons, August 2021

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



▲These four examples illustrate the increased complexity of inner walls, floors, and central peaks that craters exhibit at ever-larger sizes.

CRATER IMAGES: NASA / ARIZONA STATE UNIVERSITY (4)

Hills in the Middle

The central peaks in larger lunar craters testify to the power of gravity in the moments after impact.

Impact craters are by far the most abundant landforms on the Moon. Thousands of them having diameters larger than about 5 kilometers are visible in most any backyard telescope. All can be classified into three fundamental types by inspecting their interior zones — the walls, floors, and central peak elevations (*S&T:* Feb. 2021, p. 52).

Most lunar craters are bowl-shaped *simple craters* with diameters up to about 15 km (9 mi). They have featureless walls, rounded or flat floors, and no central hills. **Piazzi Smyth**, for example, is a 13-km simple crater in southern Mare Imbrium.

Complex craters are larger than simple craters, and you need to observe their interiors closely to separate them into their two subgroups.

First are *complex-slump craters* typically 15 to 35 km wide. Their interior walls start with a steep scarp and then descend to the floor as chaotic slumps of material. Their floors are often largely filled with mounds of this slumped material, sometimes overwhelming any central hills.

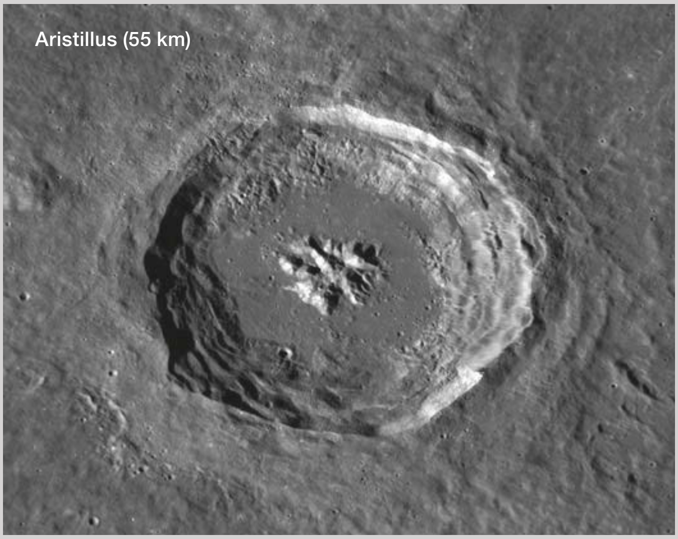
Then there are *complex-terraced craters* larger than about 35 km. These complex craters also have a shear scarp at their tops, with a cascade of terraces resembling concentric stair steps. Floors of these big craters are usually relatively flat and smooth, often peppered with small hills. The central peaks of complex-terraced craters are often massive mountains. Near the centers of the floors are clumps of hills or mountains — intriguing features that are the focus of this month's column.

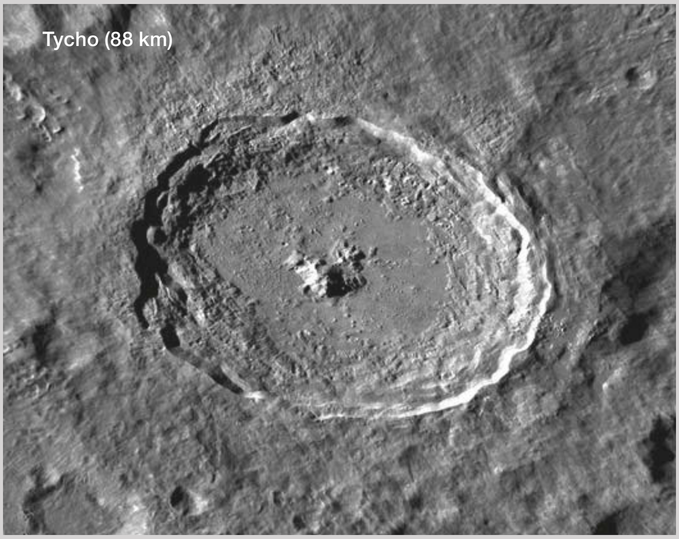
Let's examine the proportions of these features using the 55-km-wide complex crater **Aristillus** as a typical example. Aristillus's wall zone is about 45% of the crater's diameter and its floor roughly 55%; the central peaks encompass 45% of the floor. Larger-diameter craters have wider floors, making the walls and central peaks a smaller proportion of the whole diameter. Despite their small relative size, the central peaks are in many ways the most varied and interesting interior landforms within large craters.

To understand the formation of crater interiors, lunar geologists study only fresh impacts that preserve the morphology at the end of the crater-formation process. They recognize these craters by their sharp rim crests, few superposed craters piercing their ejecta fields and interiors, and bright rays that many (but not all) possess. Try viewing them under oblique lighting, which makes the subtle topography stand out.

Above is a sequence of complex craters, arranged by increasing diameter to aid in comparing their walls, floors, and central mountains. First is the 25-km-wide **Triesnecker** crater, familiar to many observers because it shares its name with a complex of nearby rilles to its east. Notice that the crater outline isn't round, especially on the west (left); there a bulge or scallop marks where a large part of the western wall slid down and scooted halfway across the crater floor as a jumble of ridges and mounds. Smaller collapses along its opposite wall created a rounded mound of debris along the eastern side of the floor, with the lowest part covered by smooth impact melt. Barely noticeable low hills in the center, rising just 300 meters above the melt pond, are nearly overwhelmed by piles of slumped wall material.

Although only slightly larger than Triesnecker, **Euler** in western Mare Imbrium has a 2-km-high wall scarp that marks the path of material that crashed down like a landslide and ended on the floor as ridges and crumpled mounds. A 7-km-wide collection of rounded hills rise 500 meters above Eul-





er's center. These are mostly surrounded by an annulus of smooth impact melt — floor debris isn't as pervasive as at Triesnecker but touches the central hills along their north-northwest side.

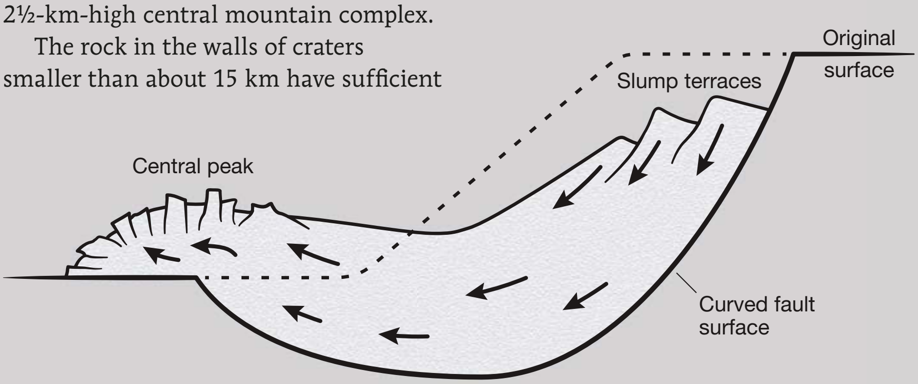
Now have a look at a much larger crater: 55-km-wide **Aristillus** in eastern Mare Imbrium. Its rim wall is a fairly orderly array of concentric terraces that faulted along curving fractures extending towards the crater's center. Its wide floor is fairly smooth, and a 13-km-wide cluster of mountainous peaks rises about 750 m above it.

Finally, let's turn our gaze to the famous **Tycho** crater, 88 km of majesty that visibly dominates the Moon's southern highlands. Tycho is like Aristillus on steroids. This 5-km-deep excavation is surrounded by terraced walls. Blocks of wall rock litter its wide floor of impact melt, which surrounds a towering, 2½-km-high central mountain complex.

The rock in the walls of craters smaller than about 15 km have sufficient strength to withstand wholesale collapse into the excavated hole. The walls of such simple craters are the unmodified transient cavity. The energy that impacts that form craters between 15 and 35 km wide delivers weakens the wall material exposed by the excavation of deeper transient cavities. The pull of gravity on these weakened side walls exceeds the tensile strength of those lunar crustal materials, causing the walls to crumble and collapse into the transient cavity, creating mounds of debris on the floor. Additionally, the energy of the impact transmits an intense shockwave that compresses the target rocks, which then decompress, uplifting rocks from the crater floor to emplace central peaks.

Even larger impacts that create complex-terraced craters transfer greater amounts of energy into the lunar target rocks. This causes coherent failure of arcs along the crater wall, which then slide down as slabs along a curved fault surface extending beneath the center of the crater. Each terrace we see is the top of a massive, curved slab of downfaulted rock. Craters are circular, so all the collapsing slabs converge beneath the crater center and, to fit into this smaller volume, must push the surface up, forming central peaks. Central peaks are readily visible samples of rocks lifted some 5 to 10 km above their original subsurface locations. Both the chaotic collapse and the downward-faulting movement of wall material enlarge the diameter of the original transient cavity.

Naturally, the basic physics of how central peaks form cannot encompass all the potential differences of impact energy and target rock complexity, so some fresh craters don't conform to our general understanding. **Eudoxus** and **Alpetragius** are glaring examples. Eudoxus is a 70-km-wide, terraced-wall crater, but it has no massive central structure, just a circular patch of small hills — like a fairy ring. Alpetragius is 40 km wide and admittedly somewhat smoothed by erosion, but its central peak fills the entire floor — observers liken it to an egg in its nest.



▲ In the moments after a large lunar impact, gravity forces material along the transient crater's wall (at right) to slump toward the center along fault planes. The result is often a set of terraces lining its inner wall and a pileup of material at its center.

S&T ILLUSTRATION, SOURCE: H. JAY MELOSH

■ Contributing Editor **CHUCK WOOD** published his first research on the central peaks of lunar craters in 1968, and they still intrigue him today.

Four Tips for Better Astropics

Your first night-sky shots may not be perfect, but they can teach you a lot.

If you're new to astrophotography and struggling to get pleasing results, I can help. Presented here are a few tried-and-true tips to help you take better astropics whether you're shooting the night sky with a DSLR and lens or photographing deep-sky marvels with a specialized astrocamera and telescope. These pointers are mutually supporting to help you obtain that "Oh, wow!" image. Familiarize yourself with all four tips and apply them together on your next imaging session.

1: SAAS! (Shoot, Assess, Adjust, Shoot)

I formulated the SAAS acronym for my own purposes because it succinctly describes the astrophotography process. No matter what equipment you use, a consistent process is key.

After carefully framing your subject, focusing, and inputting your camera settings, *Shoot* your image. That part is obvious, but it's only the beginning. Next, *Assess* the resulting picture, carefully evaluating its overall quality. I use my camera LCD (or computer monitor) at maximum brightness to properly assess what I've captured. Take your time with this step. Are the stars sharp and round? Is your target positioned within the frame where you want it? Is the amount of exposure sufficient?

Once you have completed your evaluation, *Adjust* whatever settings required to get closer to the photo you're after. Finally, *Shoot* your target again. Repeat the SAAS process again until you're satisfied with the results.

▲This photo of the Lagoon Nebula (M8) in Sagittarius is the end result of employing the tips described in the text. That means SAAS (explained below), recording lots of frames, and matching the choice of target to the sky conditions. This single, 4-minute exposure at ISO 5000 was captured using a Takahashi Mewlon M-210 reflector telescope and Nikon D810a DSLR camera — a model optimized for astronomical photography.

2: More Is Better – Shoot, Shoot, and Shoot Again

Reinforcing the SAAS methodology, this tip takes advantage of one of digital photography's greatest strengths — the ability to easily take

ALL IMAGES COURTESY OF THE AUTHOR UNLESS OTHERWISE NOTED lots and lots of shots. Bear in mind how much better things are today than they were for previous generations of astrophotographers, whose storage medium usually consisted of 36 exposures on a roll of film. Back then, you had to wait days for your results, making the SAAS process very long-term and expensive! Thankfully, times have changed.

Most beginning astrophotographers would be hard-pressed to fill up a single 32GB memory card in one night, let alone one with a capacity of 64GB or 128GB. But as you become more ambitious, that could change. A typical RAW image file from a current-model DSLR or Mirrorless camera can exceed 70MB, and thousands of video frames will eat up significant storage.

Thankfully, memory cards are relatively inexpensive. I always make sure I have several available for each outing. Don't make the single-point-failure mistake of having just one memory card available. Always have a spare at the ready. Ensure it's been formatted and tested so if you do fill up your primary card or suffer a technical glitch, you're still in the imaging game.

Choose a large memory card if you expect a long astrophotography session or plan to shoot video. For routine imaging, I typically use a 32GB memory card, but if I'm capturing a lunar eclipse or an all-night meteor shower, I'll use a 64GB or 128GB card to be sure I don't run out of storage.

You'll rarely get the photo you're after on the first try, but that's okay when you SAAS and ensure you have plenty of storage available.

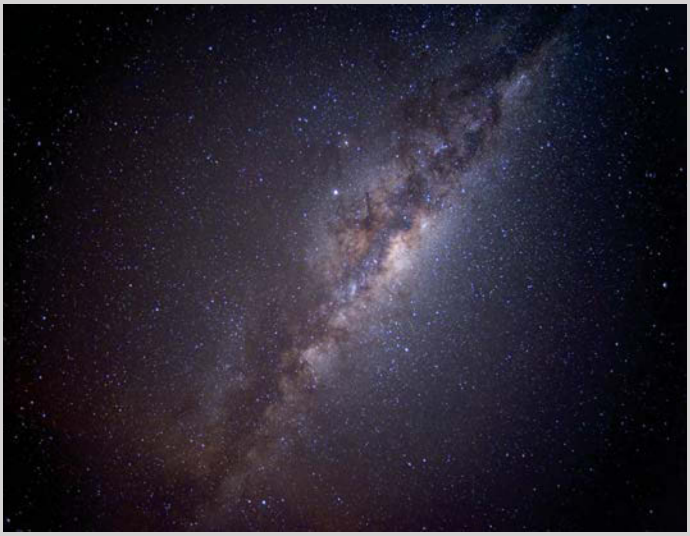
▶ The author preparing for a night of astrophotography with his Takahashi telescope and heavy-duty equatorial mount. Although light pollution compromises the skies above his central Virginia home, he still manages to produce some very pleasing images despite the local sky conditions.

3: Take What the Sky Gives

In the June installment of "First Exposure," Tony Puerzer discussed how to work with just the equipment you have on hand. The corollary to Tony's point is my Tip #3: Take what the *sky* gives you. Chances are you won't have steady seeing conditions, perfect transparency, or freedom from light pollution or moonlight. You'll likely have to contend with some combination of these factors each and every outing. In time, you'll acquire enough experience to be able to read sky conditions well enough to make the best of each clear night.

If you don't have your own observatory and are a "set up and take down" astrophotographer like me, watch the weather forecast for a string of several good nights in a row. This makes it possible to leave your equipment set up to maximize imaging time. But make sure you have a good weatherproof cover for your gear to protect it from the Sun during daylight hours, or from a surprise passing rain shower.

To help make my go/no-go decision easier, I consult **cleardarksky.com** or **astrospheric.com**. Both sites allow you to enter a specific location and get a detailed night-sky forecast that includes



▲ *Left:* This portrait of the famous Dumbbell Nebula (M27) in Vulpecula was recorded from the author's backyard using a Nikon D810a DSLR camera and Takahashi telescope working at f/9.2 with a focal reducer. It is a single exposure of 4-minutes duration at ISO 5000. *Right:* The author captured this view of the heart of the Milky Way during *Sky & Telescope*'s 2019 Chile Total Solar Eclipse Tour from the incomparable skies of the Atacama Desert. He used a tripod-mounted Nikon D810a camera and a 14mm f/2.8 lens for this 30-second exposure at ISO 3200.

AUTHOR AT TELESCOPE: LAURIE REDFERN

◀ The Flame Nebula (NGC 2024) is located just east of 2nd-magnitude Zeta Orionis, the bright star in this photo. The author captured the pair with the same equipment used for the M27 image on page 55. The spikes around Zeta are a diffraction effect caused by the telescope's secondary mirror support vanes. In this case they add to the overall appeal of the image.

seeing, cloud cover, transparency, and a host of other factors. The information presented is truly indispensable.

Sky conditions play a key role in what kind of imaging you'll be able to do on a given night. If the seeing is unsteady but the transparency is good, you can still take camera-and-lens shots, provided the Moon isn't too bright. Nights like these are great for photographing constellations, star trails, and the Milky Way (if visible). Often these nights also work well for imaging large deep-sky objects with a wide-field telescope. However, reverse the conditions (steady seeing and so-so transparency) and you have a fine night for high-resolution imaging of the Moon, planets, or even bright planetary nebulae.

When the seeing is poor, the shimmering image in your telescope makes it more difficult to get good focus. How much shimmering depends on the seeing conditions and the image scale you're working with. If your camera or computer software allows you to zoom in, that'll help you get accurate focus while you work the telescope's focuser back and forth.

To get reasonably sharp images when the seeing is unsteady, try using a high ISO setting, which allows faster shutter speed to hopefully mitigate atmospheric blurring effects. Similarly, if you shoot video sequences, you have the ability to acquire lots of frames and use computer software to sort the fuzzy ones from the sharp ones and assemble them into a surprisingly good end result.

And if it's cloudy on a night when you want to image, all is not lost. Use that time to process the backlog of astrophotos that you haven't gotten to yet. We all lead busy lives, so make the most of that time you set aside for astrophotography — even if you're forced to stay indoors.

4: Learn from Each Astropic

Reviewing your images will help you develop your "astrophotographer's eye" — and that's key to refining your sense of which images are keepers and which can be safely deleted. Take time to analyze each shot to understand what went right and what went wrong. This is how you learn the ropes of astrophotography and gradually improve.

▲ This first attempt at shooting with camera and telescope together is a 15-minute exposure of Comet C/1987 P1 (Bradfield) made with gas-hypered TP 2145 black-and-white film. Although the photo isn't technically remarkable, it *is* packed with nostalgia and provides a starting point for the author to gauge his progress in the decades since.

In addition to the various technical aspects of astrophotograpy I've focussed on in this article, I'd urge you to consider your images in the "big picture" sense too. When you've finish working on an astrophoto, take a few moments to appreciate what it is you've captured. Read up on the objects in your photos and learn how they came to exist and how they fit into the overall structure of the universe. The more you know, the more interesting and meaningful your images will become.

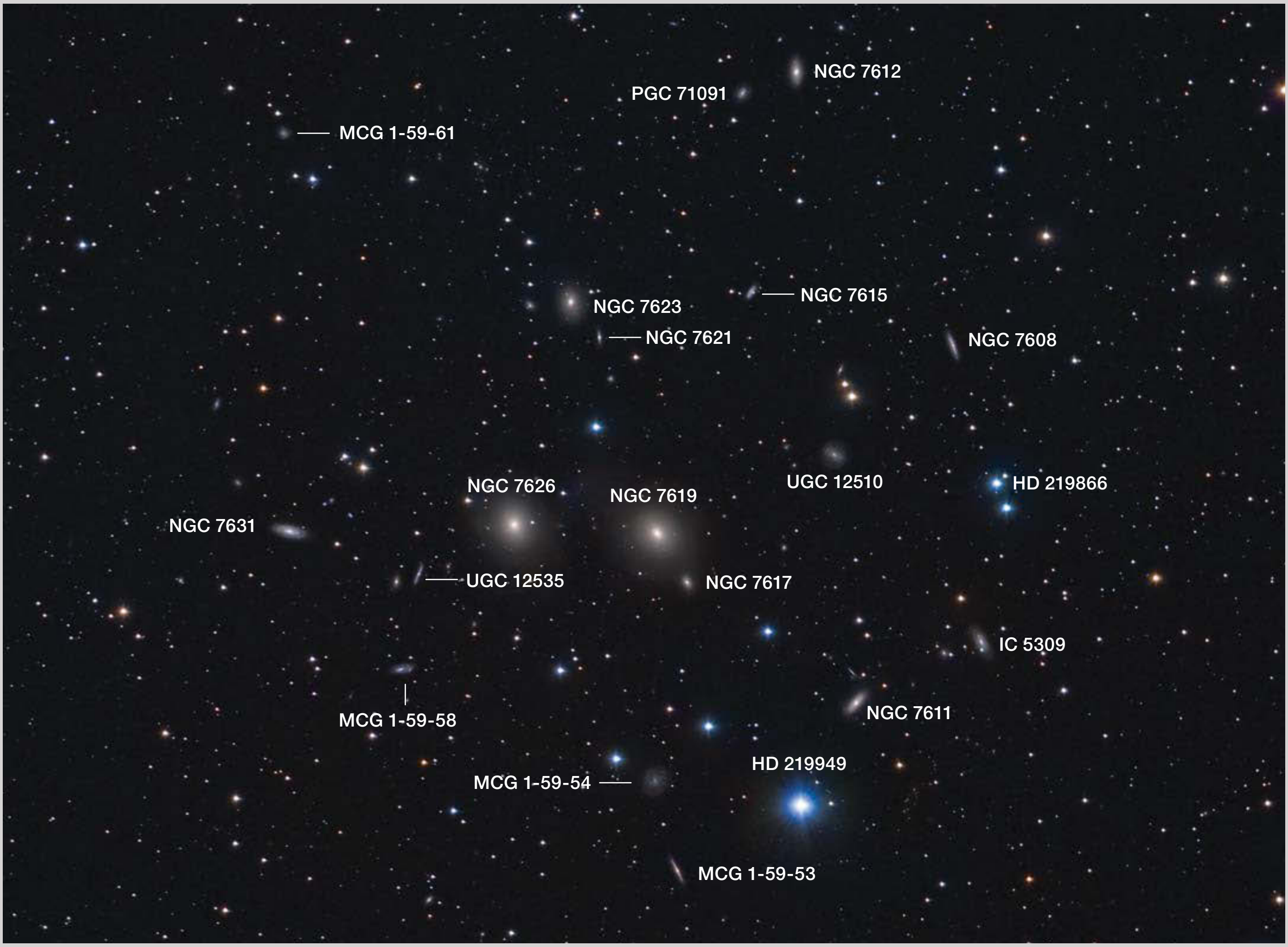
Even if your images aren't perfect, they're still records of unique moments in space and time. Consider the photons of light that had to travel unimaginable distances to reach your camera's sensor. Whether your photos capture objects in the solar system, targets within the Milky Way, or distant galaxies, every picture has a story to tell.

After over a half century I still have my first ever photo of the Moon that I developed and printed myself. I also have the pictures I took of the Moon through my 6-inch f/8 Newtonian telescope when Apollo 8 and 11 were in lunar orbit. They preserve a special moment in history that I was able to capture for myself. They also remind me of how far we astrophotographers have come in our pursuit of photons. So, I'd encourage you to keep your first astropics. Trust me — years from now, you'll be glad you did.

■ GREG REDFERN is a regular contributor to this magazine and the author of two books, *Astrophotography Is Easy! Basics for Beginners* and *Cruise Ship Astronomy and Astrophotography*. Both titles are published by Springer.

Observing the Pegasus I Galaxy Cluster

Up for a challenge? Try scoping this collection of distant island universes.



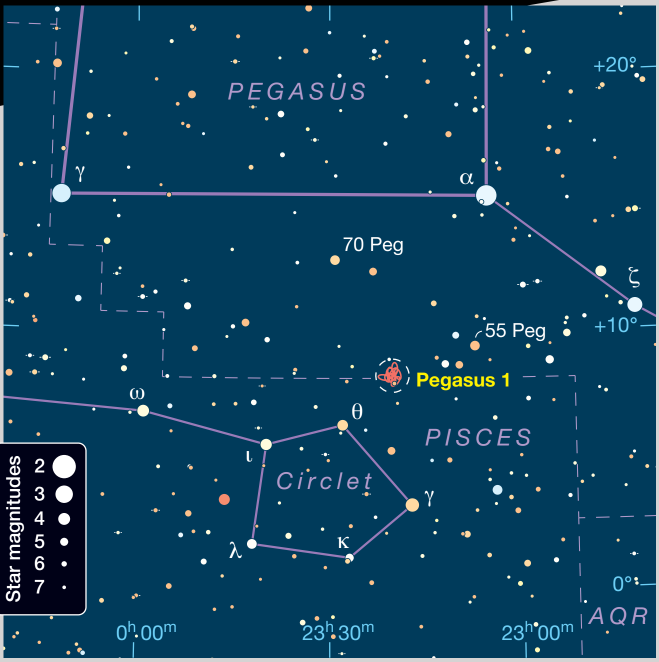
JIM THOMMES

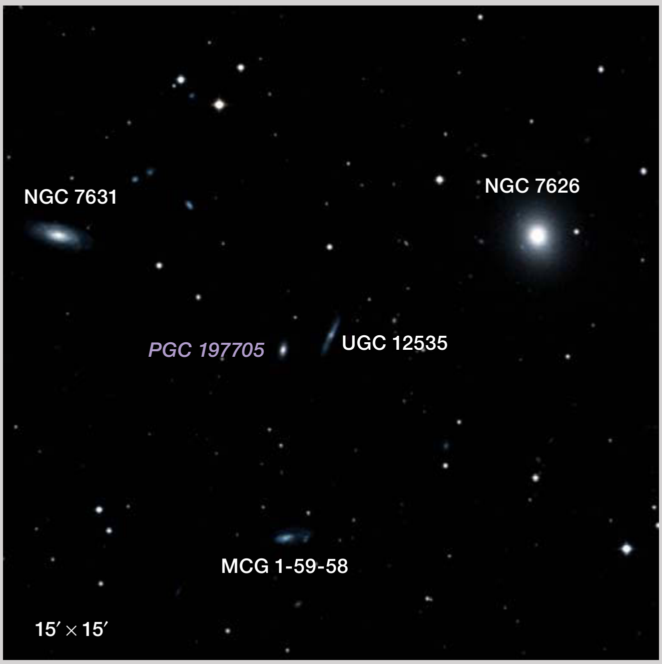
▲ **DEEP INSIDE THE CLUSTER** The targets discussed here may be challenging, but if you detect them you'll be peering into a cluster of galaxies that might even hold clues to the origin of dark matter.

On September 26, 1785, William Herschel discovered a trio of nebulae along the Pegasus-Pisces border, which he recorded as II 439, II 440, and III 435. John Louis Emil Dreyer listed these three objects in his *New General Catalogue of Nebulae and Clusters of Stars* (published in 1888) as NGC 7619, NGC 7626, and NGC 7623.

The three galaxies anchor a medium-compact group known as the Pegasus I cluster that lies about 170 million light-years away. The collection occupies the southwestern end of the Perseus-Pisces Supercluster. Pegasus I has been extensively studied since the 1920s, and in that time our understanding of its membership has evolved somewhat. A 1982 paper included 75 member galaxies, but lately that number has shrunk to perhaps as few as 13. More recent research has also adjusted the distance to the center of Pegasus I, with radial-velocity measurements separating the NGC 7619 group from a more distant background component.

Nonetheless, a query in planetarium software yields 102 galaxies within 1° of NGC 7619, which, at magnitude 11.1, is the brightest galaxy in the group. Twenty-three galaxies are brighter than 16th-magnitude and 11 are brighter than 15th-magnitude, potentially putting them within reach of a 12-inch telescope. My own investigation of the area began on an October night in 1999 when I logged 13 galaxies with an 18-inch Dobsonian (the same scope I used for the observations detailed here, unless otherwise stated) and seven more





▲ **ELUSIVE TARGET** Can you detect the faint companion to the distant galaxy UGC 12535?

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

in a friend's 25-inch. It has since become a favorite galaxy-hunting ground.

Starting Point

At the center of the group are the two dominant members of the cluster, **NGC 7619** and **NGC 7626**. They're a pair of large, similar-looking ellipticals with bright cores, visible in an 8-inch telescope. Milton Humason, observing at Mount Wilson Observatory, first measured the radial velocity of NGC 7619. Edwin Hubble's iconic 1929 paper that established a relationship between recessional velocity and distance noted that this was the first reliable result consistent with the linear relationship that's now known as the Hubble-Lemaître Law.

In X-rays, NGC 7619 is quite bright and sports an intriguing, long tail that streams off to the southeast. Astronomers study this enigmatic feature in order to understand the physical properties of the hot interstellar medium and the dynamics and evolution of galaxy clusters. Researchers find NGC 7626 equally fascinating due to its kinematically peculiar core. At its heart, separate coexisting cores rotate with different velocities and axes of rotation, revealing details of the galaxy's merger history. NGC 7626 was one of the first-known examples of such a peculiar core.

Moving about 11′ north of the pair, we find **NGC 7623** forming the apex of an isosceles triangle with NGC 7626 and NGC 7619. Larger apertures reveal a north-south elongation in the small and round bright core. Herschel didn't note nearby **NGC 7621**, 2.2′ to the southwest; German astronomer Albert Marth discovered it 79 years later. Since NGC 7621 is rather faint and very elongated, I used averted vision to pick it up.

NGC 7619 also has a companion: **NGC 7617**. It's located 2.8′ to the southwest and is small and faint with a slightly brighter core. The *NGC* entry for 7617 credits both Heinrich d'Arrest and Marth — who both observed it in 1864 (two months apart) — with the discovery. However, Bindon Stoney, while serving as assistant to William Parsons, the Third Earl of Rosse, at Birr Castle may have first detected the galaxy in 1851. Unsure of his observation, he noted that the nebulous object may have been stars instead, and so Dreyer didn't credit him with the discovery. But, either Bindon Stoney or his older brother George Johnstone Stoney discovered **NGC 7631** in August 1851 at Birr Castle, while d'Arrest independently noted it 11 years later. Sitting about 11′ east of NGC 7626, this 13.1-magnitude galaxy is elongated roughly in the east-west direction, brightening gradually toward the center.

Nudging North

Look 15.6′ northwest of NGC 7623 to find **NGC 7612**. This relatively small, moderately faint lenticular galaxy has a brighter core and a challenging companion. With averted vision, I see **PGC 71091** as a very small, very faint spot of nebulosity 2.8′ east-southeast of NGC 7612.

About 8′ west of the NGC 7623/7621 pair, we come to **NGC 7615**, a small spiral galaxy with a smooth brightness distribution. John Herschel discovered it in 1830; however, d'Arrest, as well as German astronomer Wilhelm Tempel and Swedish astronomer Herman Schultz, failed to recover this galaxy during their investigations of the group in the 1860s. At 197 million light-years away, this is the most distant object in the collection. About 10′ farther west-southwest you'll find slightly fainter **NGC 7608**. With averted vision, it appears very elongated and a little brighter toward the center. Nearby **UGC 12510** manifests as a small, nebulous spot 7.8′ southeast of NGC 7608.

Face the Challenge

Moving southwest from the 7619/7617 pair, we encounter two spiral galaxies. D'Arrest discovered **NGC 7611** in September 1862 while observing with the 11-inch refractor at Copenhagen Observatory. Located 12.7′ southwest of NGC 7619, it appears as a moderately large, smoothly illuminated oval with a bright stellar core. French astronomer Stéphane Javelle discovered its similar-size neighbor, **IC 5309**, on October 23, 1903. Look for the 13.7-magnitude spiral 6.8′ northwest of NGC 7611. IC 5309, involved with a 14th-magnitude star at its southern tip, is faint and requires averted vision to detect. You can also use a pair of stars of magnitude 9.2 (HD 219866) and 9.6 to locate the galaxy 7.2′ to their south.

The brightest star in the vicinity of the Pegasus I cluster is 6.9-magnitude HD 219949, sitting 5.6′ southeast of NGC 7611. It's a convenient guidepost for locating the next two objects.

MCG 1-59-54 lies 7.2′ east-northeast of HD 219949 and 2.2′ southwest of a 10.2-magnitude star. (It's also about 12′ due south of NGC 7619.) I required averted vision to see this very faint dwarf spiral. Its neighbor 4.5′ to the south-southwest is **MCG 1-59-53**, a very elongated, low surface brightness streak.

For an even greater challenge, look 5.2′ southeast of NGC 7626 to see if you can detect the elongated spiral **UGC 12535**. At 185 million light-years, this is the second farthest galaxy on our tour. On my most recent visit to the Pegasus I group, I finally spotted this nearly edge-on spiral with my 30-inch Dob. The DSS image on page 58 shows a close companion — even though I didn't reliably spot it, I have confidence in my detection of UGC 12535.

About 4.7′ south of UGC 12535 is **MCG 1-59-58**, which may be a barred spiral or a double system — images show what might be two nuclei in its core. Using averted vision with my 18-inch Dob, I see MCG 1-59-58 as a faint smudge elongated roughly east-west.

Wrapping Up

For our final stop, let's jump back to the northern edge of the cluster and look in on **MCG 1-59-61**, which you'll find 16.2′ northeast of NGC 7623. This nearly face-on barred spiral is probably the faintest galaxy I have detected so far in the Pegasus I group and the one I would describe as the most challenging. I haven't found a distance estimate or a visual magnitude for this galaxy, and I was a little surprised to be able to detect it. It appears as a small, round splotch of nebulosity.

Professional astronomers study galaxy groups and clusters for a number of reasons. Galaxy clusters are slow to evolve and therefore leave indelible evidence of how they formed. Unlike single galaxies, clusters are closed systems that tend to retain their gas and thus provide a ready laboratory for the study of nucleosynthesis. They're also of paramount importance to our understanding of dark matter. Amateur astronomers are also drawn to these clusters. For me, it's to enjoy the thrill of the hunt in tracking down these faint wisps of light that push the limits of detection, to revel in the contemplation of our vast universe, and to vicariously retrace the steps of the great visual observers of a bygone era.

Faraway Galaxies

Object	Type	Surface Brightness	Mag(v)	Size/Sep	Dist (M l-y)	RA	Dec.
NGC 7619	Elliptical	12.9	11.1	2.5′ × 2.3′	163	$23^h\ 20.2^m$	+08° 12′
NGC 7626	Elliptical	13	11.1	2.6′ × 2.3′	146	$23^h\ 20.7^m$	+08° 13′
NGC 7623	Spiral	12.8	12.9	1.2′ × 0.9′	162	$23^h\ 20.5^m$	+08° 24′
NGC 7621	—	12.4	14.7	0.7′ × 0.2′	167	$23^h\ 20.4^m$	+08° 22′
NGC 7617	Spiral	13.2	13.8	0.9′ × 0.7′	183	$23^h\ 20.2^m$	+08° 10′
NGC 7631	Spiral	13.2	13.1	1.8′ × 0.7′	163	$23^h\ 21.4^m$	+08° 13′
NGC 7612	Lenticular	12.9	12.8	1.6′ × 0.8′	137	$23^h\ 19.7^m$	+08° 35′
PGC 71091	Barred Spiral	14.3	14.8	0.7′ × 0.5′	139	$23^h\ 19.9^m$	+08° 34′
NGC 7615	Spiral	13.3	14.3	0.9′ × 0.5′	197	$23^h\ 19.9^m$	+08° 24′
NGC 7608	Spiral	13.5	14.2	1.5′ × 0.4′	151	$23^h\ 19.3^m$	+08° 21′
UGC 12510	Elliptical	14.6	15.1	1.1′ × 0.6′	153	$23^h\ 19.7^m$	+08° 16′
NGC 7611	Barred Spiral	12.3	12.5	1.5′ × 0.6′	139	$23^h\ 19.6^m$	+08° 04′
IC 5309	Spiral	13.4	13.7	1.4′ × 0.6′	184	$23^h\ 19.2^m$	+08° 07′
MCG 1-59-54	Spiral	15.4	14.8	1.5′ × 1.4′	117	$23^h\ 20.3^m$	+08° 00′
MCG 1-59-53	Spiral	13.8	14.5	1.4′ × 0.3′	116	$23^h\ 20.2^m$	+07° 56′
UGC 12535	Spiral	14.1	13.3	1.0′ × 0.2′	185	$23^h\ 21.0^m$	+08° 11′
MCG 1-59-58	Barred Spiral	13.8	14.6	1.1′ × 0.5′	169	$23^h\ 20.3^m$	+08° 00′
MCG 1-59-61	—	—	—	0.5′ × 0.4′	—	$23^h\ 21.4^m$	+08° 32′

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

■ Contributing Editor **TED FORTE** enjoys observing the deep sky from his backyard observatory in southeastern Arizona.

Buying Binoculars for Astronomy

Much of the sage advice of the past has become obsolete following recent changes in the equipment marketplace.

The advantages of binoculars over telescopes are many — especially for night-sky novices. Not only are binoculars affordable, but they're also easy to use thanks to the wide fields of view they offer and their right-side-up image orientation. Everyone starting out in astronomy should have a good pair of binoculars.

If you're a veteran observer, you're already aware of these advantages, but you might be using the same well-worn pair you've owned for decades. Every aspect of binocular performance — field of view, eye relief, optical coatings, and build quality — has improved in recent years. It just might be time to consider an upgrade!

Here's my up-to-date guide to buying the best binoculars for astronomy.

Aperture and Power

Even otherwise commendable review websites often assume that the best stargazing binoculars must have at least 70-mm

BINOCULAR GAZING Few astronomical activities surpass the simple pleasure of scanning the Milky Way with binoculars. The wide views of rich star fields contrasting with lanes of dark nebulae are unmatched in any telescope.

(2.8 inches) lenses and high magnification. Not so! While big, high-powered binoculars do have their place, they lack many of the advantages I just listed. My advice is to avoid the temptation of magnifications greater than 12×. Simply put, more power doesn't always equal a better view.

Out of all the combinations of power and aperture on offer, binoculars with lenses 42 mm to 50 mm in diameter and magnifications from 7× to 10× yield the best combination of light-gathering and resolution without sacrificing the wide fields of view and hand-held convenience that make binoculars such a joy to use. These are the models I reach for most often for a night of stargazing.

◀ **APERTURE TRIO** The bigger the front lenses, the brighter the images, but the heavier the binoculars. If you're looking for all-purpose binos, a lightweight 42 mm is a fine choice. While 56-mm binoculars are great for astronomy, they can be heavier and harder to hold steady.

While 42-mm binoculars are ideal for all-purpose use, when shopping for binoculars primarily for astronomy, consider a 50-mm model. The extra aperture will gather about 40% more light, allowing you to see objects nearly ½ magnitude fainter.

Most 50-mm binoculars tip the scales at 800 to 1,000 grams (28 to 35 ounces), which makes them about 100 to 300 grams heavier than 42-mm binoculars. However, unlike daytime users such as birders, we astronomers don't carry our binoculars around for hours at a time, so a bit more weight is a tolerable trade-off for brighter images. Even so, any model weighing much more than 1,000 grams can be difficult to hold up to the sky for more than a quick glance. In general, binoculars with 50-mm lenses provide a good balance of aperture versus weight. And that's why I'll focus my attention on 50-mm binoculars in this survey.

So what about magnification? Among binocular astronomy enthusiasts, the hot debate used to be between choosing 7×50s or 10×50s. The 10× camp argued that the higher magnification resolved detail better, while the 7× camp countered that the extra magnification made 10× binoculars harder to hold steady.

Today the debate is effectively over. Buy the 10×50s. The reason is simple — there just aren't many 7×50s being made anymore. With the exception of heavy and costly binoculars for marine use (from companies such as Fujinon and Steiner), the few 7×50s left are budget models ($100 and less) with narrow fields of view and performance that's inferior to most 10×50s.

If you have shaky hands and prefer lower magnification, consider 8×42 roof-prism binoculars of the best quality you can afford. (I'll say more about the two main prism types

▼ **BINOCULAR ENSEMBLE** For stargazing, a pair of 10×50s is arguably the best choice. The designation indicates a magnification of 10× and front lenses that are 50 mm in diameter. It's a popular size with many different models to pick from.

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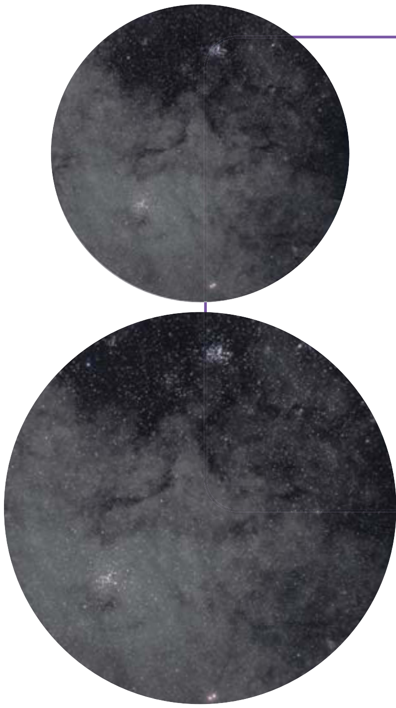


▶ **FIELDS OF VIEW COMPARED** How much sky a particular pair of binoculars shows depends on the apparent field of view of its eyepieces and on the magnification. The formula is: Actual FOV = Apparent FOV ÷ Magnification. So, 7×50 binoculars (top circle) with a 50° apparent field will show 7.1° of sky. By comparison, a pair of 10×50s (bottom) with a 65° apparent field presents a wider circle but shows slightly less actual sky (6.5°) due to its higher magnification.

Calculating Field of View

Fields of view are sometimes expressed in feet or meters at 1,000 yards or meters.

Convert feet @ 1,000 yards into actual FOV in degrees by dividing by 52.5. For example, binoculars that advertise 367 ft. @ 1,000 yds would yield a true field of view of 7°.

Convert meters @ 1,000 meters into actual FOV in degrees by dividing by 17.5.

later.) I've tested several models and can recommend Celestron's Nature DX ED ($170), the Vortex Crossfire HD ($190), Zeiss Terra ED ($450), and the Hawke Frontier ED X ($550).

Exit Pupils and Eye Relief

For a long time, observers were advised that for the brightest images, the light cone exiting the each eyepiece — called the *exit pupil* — should have the same diameter as the dark-adapted pupils of your eyes, which is around 7 mm for younger people.

To calculate the exit pupil, simply divide the aperture of the main lenses by the magnification. For example, 7×50 binos have 7.1-mm (50 ÷ 7) exit pupils, thus the long-standing preference by mariners and stargazers for 7×50s.

The trouble with this advice is that, after age 30, the pupils of our eyes typically lose a millimeter every 20 years or so. For us older observers, our pupils effectively stop down the binocular's aperture. So, while 7×50s might, in theory, provide brighter images, in practice 10×50s with 5-mm exit pupils will offer images just as bright for older eyes. Once again, 10×50s prove the better choice.

Observers who must wear eyeglasses to correct for astigmatism, or who simply prefer to keep their glasses on while viewing, will benefit from binoculars with long *eye relief*. This is the distance from the top of the eyepiece to where you position your eyes. For eyeglass wearers, you typically want at least 15 mm or more eye relief.

Not long ago we had to pay a premium for so-called "high-eyepoint" models. Fortunately, that's not the case today. Of the more than a dozen binoculars I tested for this survey, almost all had excellent eye relief. Even if you don't wear glasses, long eye relief makes binoculars more comfortable to look through.

Prism Considerations

With the exception of a few pricey marine binoculars, models with Porro prisms are now restricted to entry-level instruments selling for under $200. Roof-prism binoculars start at $200 and go up from there. Because of their compact size, this design is now the most popular among demanding birders and hunters. For this reason, roof-prism binoculars generally get the better optics. In the best models I tested, stars snapped to perfect pinpoints, without the spikiness often present in low-cost Porros.

However, roof-prisms have a couple of potential strikes against them compared with Porro prisms. The majority of roof-prism binoculars use the Schmidt-Pechan design of prisms, which have one reflective surface that introduces some minor light loss. However, better models

◀ **FOLLOW THE LIGHT** Binocular prisms fold the light path and produce right-side-up, correct-reading images. Porro-prism models (left), named for 19th-century optician Ignazio Porro, have the familiar N-shaped light-path. Roof-prism binoculars (right) are distinguished by their straight tubes.

▶ **TRIPOD MOUNTING** Most binoculars have a standard ¼-20 socket hidden behind an easy-to-lose cap, for an optional adapter to attach the instrument to a tripod for steadier views. Roof-prism binoculars (at right) often need a narrow adapter to fit between closely set barrels.

have dielectric coatings on the reflective surfaces to minimize this dimming. Roof-prisms are also subject to a reduction in image contrast arising from the light beams shifting out of phase as they pass through the prism assembly. For this reason, all but the lowest-cost roof prism binoculars now have phase-correcting coatings.

In side-by-side tests, I've seen no noticeable difference in brightness and limiting magnitude between a 50-mm Porro-prism model and a well-coated 50-mm roof. However, if it's maximum image brightness and quality you're after, seek out binoculars with Abbe-Koenig roof prisms. They're larger, heavier, and more costly to make than Schmidt-Pechan prisms but provide the greatest light transmission. The design is reserved only for the most premium binoculars, selling for $1,000 and up.

Field of View and Coatings

Just as with telescope eyepieces, the diameter of the circle of light seen through binoculars is called the *apparent field of view* and is measured in degrees (°). The wider the apparent field, the more impressive and panoramic the view. Most 10×50s now have eyepieces with apparent fields of 60° to 65°. In picking models to test, I selected only those with advertised apparent fields of at least 60°. By comparison, binoculars with 45° to 50° fields (typical of 7×50s) provide a less appealing, tunnel-like viewing experience.

Almost all binoculars feature anti-reflection multi-coatings on most (if not all) air-to-glass lens surfaces. Only the lowest-cost models have lesser coatings, usually distinguished by bright reflections off the front lenses. However, the best binoculars have more costly coatings with even more layers to minimize light loss and to reduce glare and ghost images from bright objects, such as the Moon and Venus.

Higher-priced binoculars also feature additional coatings on external lens surfaces to repel water, oil, and dust, and to protect against scratches. As with refracting telescopes, better binoculars are also equipped with objective lenses made using extra-low dispersion (ED) optical glass to reduce color fringing around bright targets.

Mechanical Features

Low-cost, Porro-prism binoculars have prisms that are merely glued in place and can be prone to misalignment if handled

▶ **7×50 PORRO-PRISM BINOCULARS** These economy models are good for beginners on a budget. Despite their low prices, all have 18 mm of eye relief. (All prices quoted in this article are approximate retail.) Left to right:

Celestron Cometron ($40) This model suffers from a vignetted field due to undersized prisms. Stars are sharp in only the central 50% of the relatively narrow (48°) apparent field. Great for kids and casual users.

Orion Scenix ($100) With eyecups rolled down, eye relief is just enough for use with eyeglasses. The apparent field is 50°, yielding an actual field of 7.1°, typical for 7×50s.

Nikon Aculon A211 ($110) These Nikons have twist-up eyecups and the best edge-of-field performance of this trio. But the apparent field is just 45°. Weight is a hefty 920 grams (32 oz).

carelessly. A more rugged arrangement is to hold the prisms in metal cages, which is typical of most roof-prism models.

The bodies of both binocular types are made from either polycarbonate, aluminum, or (in the best) magnesium for light weight and rigidity. But models in every price range are now covered in non-slip textured armor, often incorporating finger and thumb rests. Many binoculars are also weather-sealed and filled with dry nitrogen or argon, to keep out moisture and dust.

All roof-prism binoculars have precision internal focusing. By comparison, Porro-prism models typically use an external mechanism to focus by moving the eyepieces back and forth. This can impart a "rocking" motion, causing one eyepiece to go out of focus compared with the other. In better binoculars of any type, the grease on the focuser won't freeze up on winter nights.

While all binoculars now have soft rubber eyecups for comfortable viewing, in lower-cost instruments these just roll up and down — an adjustment that eyeglass wearers can find fiddly — and they often degrade and crack over time. Eyecups that twist up and down are easier to set to the best height for comfortable viewing.

Image-Stabilized Binoculars

Back in the mid-1990s, Canon introduced electronic image-stabilization technology — a common feature in modern digital camera lenses — to binoculars. Their "IS" series quickly became popular with amateur astronomers. Press a button and the shifting prisms magically dampen out vibrations, allowing sharper views without giving up the convenience of hand-held viewing.

Some observers favor Canon's 10×42 L WP ($1,500) as the best for astronomy, but at 1,030 grams they're hefty for their size. The benefit of image stabilization really shows itself with the 15×50 and 18×50 models ($1,300 to $1,500), which offer magnifications impractical for hand-held use with conventional binoculars. The optics of these high-power units are razor sharp, and the apparent fields span an impressive 66° to 68°. However, at 1,180 grams, both 50-mm models are moderately heavy to hold. While image-stabilized binoculars do work well, I still find myself grabbing lightweight 10×50s as my binoculars of choice.

Country of Origin

Sport optics companies based in the United States, such as Athlon (in Kansas), Leupold (Oregon), and Vortex (Wisconsin), outsource manufacturing overseas, usually to China and some to the Philippines or Thailand. Binoculars from Tract Optics (Pennsylvania) and premium models from Leupold and Vortex are made in Japan. Only Wyoming-based Maven assembles its high-end models in the U.S., in California, using Japanese components.

The major European optics companies, Leica, Steiner, Swarovski, and Zeiss, take pride in manufacturing most of their binoculars in-house (including glass production) in Portugal, Austria, or Germany. Companies based in Japan, such as Canon, Kowa, and Nikon, make only their top-of-

▼ **10×50 PORRO-PRISM BINOCULARS** These models provide fine performance for under $200 and will please both first-time buyers and experienced observers looking for a budget upgrade. All have apparent fields of 60° to 65°. Left to right:

Pentax SP ($80) These have a wide, 65° apparent field. The shallow eyecups don't roll down easily, and the 12-mm eye relief is just adequate for views without glasses. Another economical choice for kids.

Bushnell Legacy WP ($110) The eyecups twist up and down. Stars are sharp in the central 50% of the 63° apparent field. WP stands for waterproof; weight is 970 grams.

Bresser/Alpen Magnaview ($120) Sold in the U.S. through Explore Scientific, the Magnaview has twist-up eyecups and the widest apparent field at 65°, with stars sharp over the central 50%.

Celestron Ultima ($140) At 790 grams, these are the lightest of the 10×50 Porros here. Stars are sharp over the central 70% of the 60° apparent field. Eyecups are fold-down.

Orion UltraView ($140) These Orions have a similar apparent field as the Bushnell Legacy, but with stars sharp over the central 60% of the field.

Nikon Action Extreme ($180) The apparent field is similar to the UltraViews, but stars are sharp over 70%. While these are the best of the group optically, at 1,015 grams, they're also the heaviest.

▲ **10×50 ROOF-PRISM BINOCULARS** These roof-prism models start at $200. All have excellent eye relief, but as the price goes up, the field of view widens and becomes sharper towards the edge. Left to right:

Nikon Prostaff 5 ($200) The polycarbonate body makes it the lightest 10×50 roof model tested, at 830 grams. Lacking ED glass objective lenses, some color fringing is apparent. Eye relief is long, at 20 mm.

Celestron Nature DX ED ($210) These have a similar 56° field as the Nikon Prostaff but with less false color and with stars sharp in the central 70%. Overall, a great value.

Vortex Diamondback ($310) Stars are sharp across 70% of the 60° apparent field. While not ED, false color is minimal. For ED glass look to Vortex's Viper HD line, at $550.

Bresser/Alpen Apex ($480) Lacking ED glass, the Apex shows some false color. However, images are very sharp. Stars remain pinpoint across 70% of the 65° apparent field.

Athlon Midas G2 UHD ($490) The apparent field is 66° and sharp across 80% — the best of the group. Construction is magnesium, the objectives are ED, and the prisms have dielectric coatings.

the-line binoculars in-house. While it is still possible to buy domestically produced instruments or opt for European craftsmanship, the price for doing so is high. That said, binoculars made in Asia are superb, with cost being a very good indicator of overall quality.

While all binoculars come with a factory warranty, the best will have 10- to 30-year warranties. American companies Leupold, Maven, Tract, and Vortex are unique in offering unconditional lifetime warranties. You break them, they'll replace them.

Price Versus Performance

Good-quality Porro-prism binoculars can be purchased for about $100 to $200. A jump up to a $400 to $500 roof-prism model gets you noticeably better performance with optics and mechanics far superior to those well-worn binoculars you bought 20 or 30 years ago.

Of course, you can pay several times more, but the improvements become increasingly more subtle. At the top of the range are Swarovski's 42mm NL Pure binoculars and Nikon's 7×50 and 10×50 WX, all with immersive 76° eyepieces and Abbe-Koenig prisms. For $4,000 to $6,000! However, for $150 to $500 you can purchase a superb pair of binoculars that will serve you well for many years to come.

■ Contributing Editor **ALAN DYER** is coauthor of the eagerly anticipated fourth edition of *The Backyard Astronomer's Guide* (**backyardastronomy.com**).

▶ **LIE BACK IN COMFORT** Gazing up high with binoculars can be a pain in the neck. A "zero-gravity" lounge chair makes the activity more comfortable, especially with big, hand-held binoculars like these Celestron 15×70 SkyMasters.

The NGC at Your Fingertips

A COMPREHENSIVE FIELD GUIDE TO THE NGC

Written and published by Bhavesh Jivan-Kala Parekh
pdxastronomy.com
Vols. 1 & 2 (Autumn/Winter): $125
Vols. 3 & 4 (Spring/Summer): $125
All four volumes: $225

THE *NEW GENERAL CATALOGUE OF NEBULAE AND CLUSTERS OF STARS* (NGC) includes nearly every deep-sky object an amateur astronomer will observe over the course of a lifetime. Not all, but the vast majority of interesting objects in the sky have NGC numbers. Some are bright, some are dim, and some are practically invisible. Wouldn't it be nice to have a photographic field guide so you could tell ahead of time what you're seeking, what the star field around it looks like, and how easy or hard it might be to find?

Portland, Oregon amateur Bhavesh Jivan-Kala Parekh has compiled just such a guide. His *Comprehensive Field Guide to the NGC* provides photos of 7,047 confirmed NGC objects in a beautiful four-volume set.

Each spiral-bound volume is printed on waterproof paper. (When asked *how* waterproof, Parekh replied, "This is *water proof* paper, baby!!!! You can dunk it in a bucket of water, take it out, and wipe it dry with a cloth.") The sheet size is 11 x 17 inches, so each of the 12 Digitized Sky Survey (DSS) images per page is a generous 2.6-inch square.

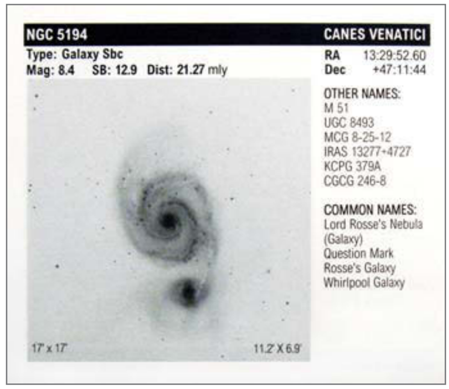
▲ *A Comprehensive Field Guide to the NGC* comes in four beautiful spiral-bound volumes.

The images have black stars on a white background, which minimizes the need for light to see them well at night, and they're rotated 180 degrees to match the view in a Newtonian telescope. They're labeled with magnitude, object type, object size, field size, right ascension and declination, other catalog designations, common names, and even surface brightness on many objects.

In addition to the photos, each volume contains an index to the entire set, cross-referenced to the Messier, Caldwell, Herschel 400, and Arp catalogs. Each also features a constellation map with a page index, a sky-zone planning tool, and a list of duplicate entries. Volumes 1 and 2 cover autumn and winter, volumes 3 and 4 spring and summer. It's generally only necessary to take two volumes at a time to the field to observe.

Part of the fun, though, is to flip through the pages during the day and decide which objects you want to view at night. The DSS images of each NGC object are a pleasure to look at, and it's exciting to wonder how much of them you might see in your telescope.

For his first night out with the *Guide*, Howard decided to observe the planetary nebula NGC 2242 in Auriga and saw in the *Interstellarum Deep-Sky Atlas* that NGCs 2281 and 2303 were nearby. Opening up volume 1 of the *Guide* to page 30, he found these objects lined up side-by-side at the bottom of the page. Nice! This doesn't happen every time, but it did show the organizational power of the *Guide* while exploring a region of the sky.



▲ Each entry includes a photo and a great deal of information about the object.

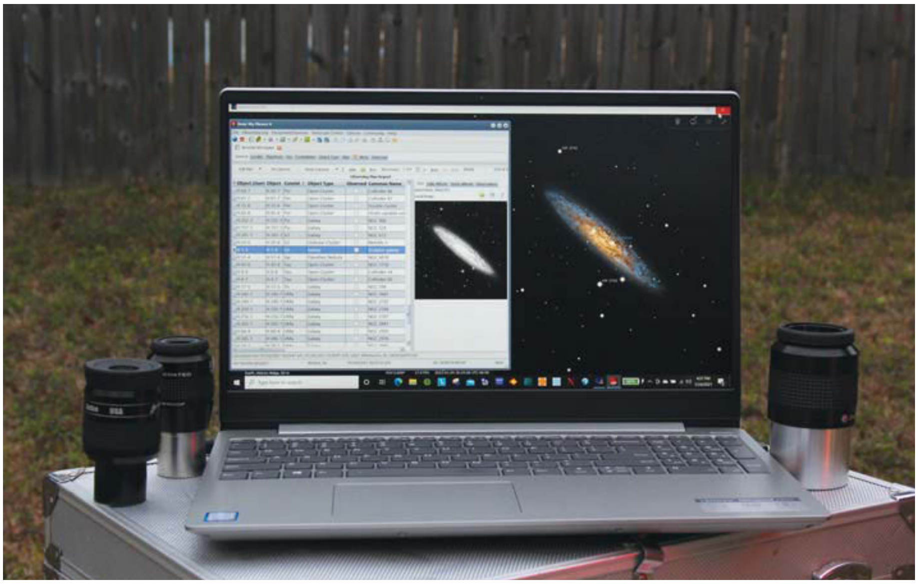
That was on a clear, mid-January night earlier this year, which in western Oregon means heavy dew. As a test, Howard left the page open to the sky for about four hours, and it was drenched when he brought it back inside. He casually wiped it off with a towel and let it air-dry overnight. The paper was ever so slightly wrinkled, but the images and print were as good as new.

Of course, you could pull up DSS images of every NGC object on a smartphone if you wished, but that's not always possible or even desirable out in the field. Plus, the images would never be as well organized or as readily accessible as in Bhavesh Parekh's *Comprehensive Field Guide to the NGC*. This is a well-made, intelligently laid-out, and professionally produced four-volume set that nicely fills a niche for those of us who prefer not to rely on electronics while observing.

■ As residents of soggy western Oregon, Contributing Editors **JERRY OLTION** and **HOWARD BANICH** understand the importance of waterproof paper.

Knightware's *Deep Sky Planner 8*

There's a lot to like about this observation-planning software for Microsoft Windows.



Deep Sky Planner 8

U.S. Price: $75

Knightware.biz

What We Like

Clean, simple interface

Large, well-maintained databases

Quick and responsive search engine

What We Don't Like

No slew button in the telescope toolbar

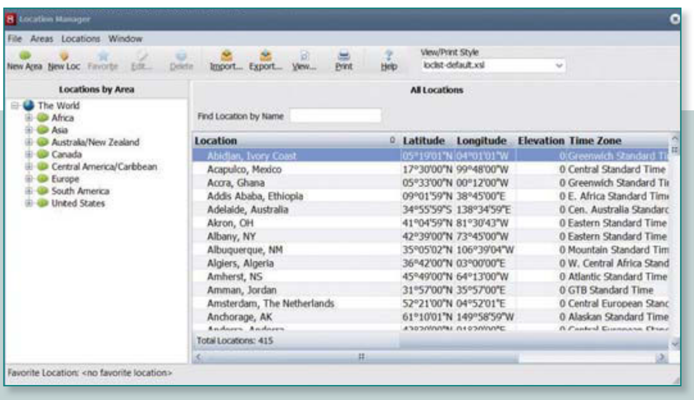
Marking an object as "observed" requires making a log entry

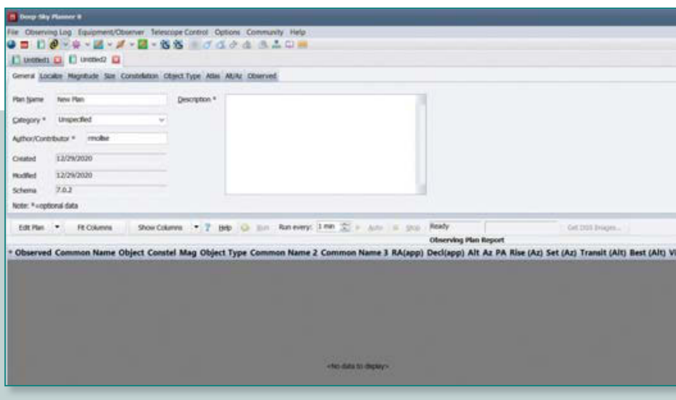
ONE OF THE MANY THINGS I learned as a novice astronomer was that if I didn't have a list of objects to view when I went into the backyard with my telescope, I wouldn't see much. I'd look at M13 or M42 or a few other bright wonders and end up calling it a night. Fifty years later that hasn't changed. I still need a list if I hope to see much. And that's where planning software comes in.

When most beginning observers think about astronomy software, they often envision a program that displays a rendition of the night sky on the computer. These planetarium programs can be attractive, but many of us find observation planning software even more useful.

A planning program is essentially a huge database (many now offering millions of objects) along with tools for searching that database and displaying results in a spreadsheet format as an observing list. There have been numerous planners on the market since the genre became popular, but one of the most established is Knightware's *Deep Sky Planner* (*DSP*), a Windows-only program now in version 8. I gave the software a thorough checkout indoors as well as in the field during late winter into early spring.

I've been using this software, authored by Phyllis Lang, since it came to market in 1994, so I was interested to learn about the newest features in the current release. What could be added to a program that's been around for over a





▲ *Left: Deep Sky Planner 8*'s Location Manager makes it easy to choose your observing location. *Right:* When you create a new plan, it's immediately ready to be named and filled with objects.

ALL PHOTOS PROVIDED BY THE AUTHOR

quarter of a century? A visit to Knightware's website reveals an impressive list of additions and improvements to this program, including an expanded and improved database of 1.6 million objects, support for 4K monitors, an improved tool to download orbital elements of asteroids and comets, and support for the freeware planetarium program *Stellarium*.

The most interesting addition for me was the inclusion of *Stellarium* in the list of planetarium programs *Deep Sky Planner 8* works with. *DSP* has never had built-in star charts of its own, but rather it links to various planetarium programs to create them. Click on an object in *DSP*'s observing plan and a star chart displays just as if the program had a charting engine of its own.

While *Deep Sky Planner 8* is available on a CD, in these days of broadband internet, few will be interested in paying more for physical media, opting instead for a digital download.

Installation and Configuration

After running the installation app, you launch *DSP 8* by clicking the attractive icon placed on your computer's desktop, but if you're using the program for the first time, I advise against that. Instead, check the Windows Start menu entry for *Deep Sky Planner 8*. Expanding that will reveal a user's guide in pdf format. It's a good idea to read it or at least have it available for reference before proceeding.

Once the program is opened, what appears at first is somewhat overwhelming: a blank expanse of screen real estate with a Windows menu bar at the top along with a row of icons. Never fear — it's easy to fill the screen with objects and images. First, however, it's necessary to do some configuring.

Since this is an astronomy program, the most important configuration task is entering your latitude, longitude, and time zone. Without that information, *DSP 8* won't be able to determine what's visible at a given time and date. Fortunately, the software presents an extensive list of cities and towns to choose from in the Location Manager section of the Options menu.

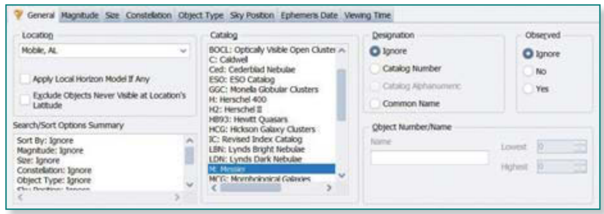
There's more to be done, of course, like building a list of telescopes, eyepieces, and other equipment so those things can be easily entered when recording your observations in *DSP 8*'s logbook. However, after time and location are set, *Deep Sky Planner 8* is ready for basic use. Note that if you are a *Deep Sky Planner 7* user, you can conveniently back up that program's settings, equipment inventory, images, and other items and use Restore in *DSP 8*'s File menu to load them into the new program.

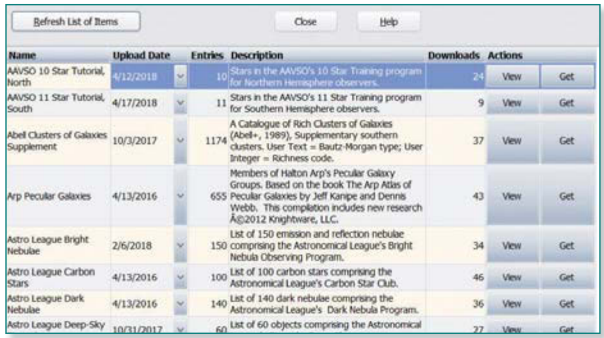
Building Plans

Even after configuration, the screen remains blank — you still have to put an observing plan together. There are two ways to do that: by downloading a ready-made plan from Knightware, or by building one of your own.

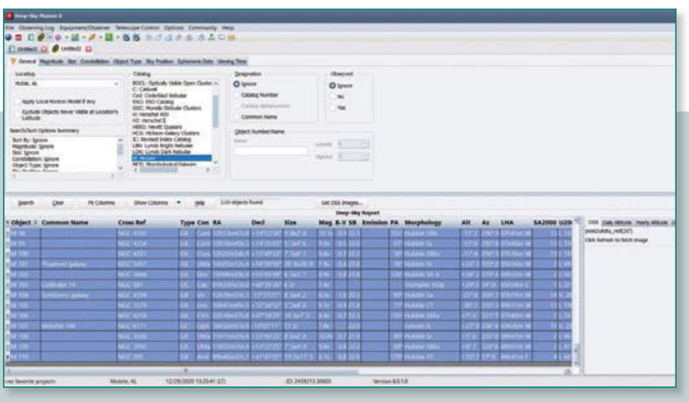
An extensive library of nearly 600 plans is available and is accessed through the Community menu. Downloading even large plans was so quick that I first thought something was wrong. The program took five seconds to fetch the entire Herschel 400 list!

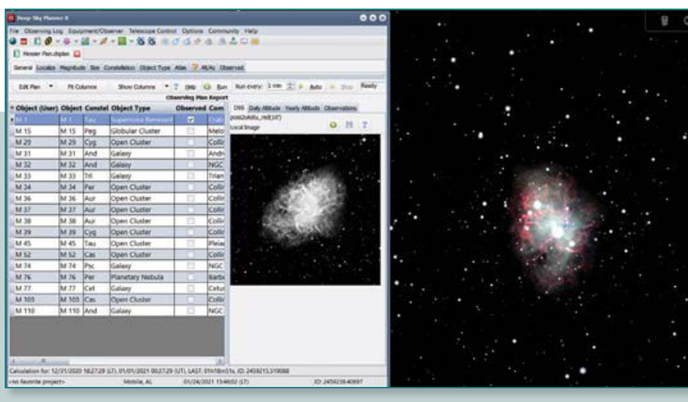
Once you know how, building your own plan is simplicity itself, though I had a little trouble with that at first. To create a plan, choose New Observing Plan in the File menu and a blank plan



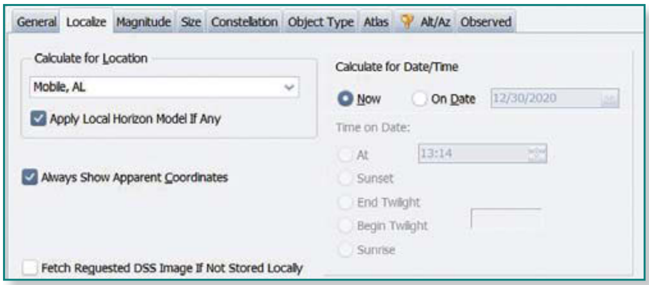


▲ *Top:* It's easy to set search parameters for retrieving objects from the internal databases with the Search Document tool. *Bottom:* Nearly 600 ready-made observing plans are available for download from Knightware's website.





▲ *Left:* Users can copy observing targets from the Search Document to a new observing plan using the Ctrl+C keys to copy and Ctrl+V to paste. *Right:* The most popular planetarium programs can be linked to *Deep Sky Planner 8* to provide star charts for your observing plans.



▲ The Localize tab in the observing-plan windows allows objects shown in the plan to be tailored for a particular time and for the positions of the objects.

appears on the desktop. It can be given a name and a detailed description if desired (useful when sharing plans with other users).

You populate the new plan with objects by opening a Search Document, a fancy name for the software's search engine. Clicking on one of the Search Document icons in the toolbar — such as the galaxy icon for deep-sky objects — allows you to sort that database. A dropdown next to the deep-sky Search Document icon accesses specific deep-sky catalogs.

With the Search Document onscreen (it's in a tab next to the one containing the new plan), the database can be searched by its catalog designation (number), magnitude, and numerous other parameters. As a test, I decided to build a plan consisting of the Messier objects. The program retrieved all 110 Messiers in about two seconds.

As soon as objects appear in the Search Document, you can select the ones of interest with a left click to pick individual objects, shift+click to choose groups of sequential objects, or Ctrl+click to highlight each in a non-contiguous group. It was easy to select all the Messiers, but now what?

That's where I ran into trouble. In the previous version of the program, objects were added to a plan by placing it and the Search Document on the screen at the same time and dragging and dropping objects into the plan. However, there was no obvious way to do that with *DSP 8*. The "Window" command was missing from the menu bar, so there was no way to tile two documents onscreen. I also didn't see any copy-and-paste commands that would allow objects to be transferred that way. I was stumped.

Then I recalled the best way to get help with *Deep Sky Planner* is the excellent instructional videos on the program's website. Viewing the one on plan creation clued me in. Due to changes in Windows 10, multiple documents in multiple windows are no longer supported. The way to move objects from the Search Document is by copying with the usual keyboard shortcut, Ctrl+C, and pasting them into the plan with Ctrl+V. That worked well, and I soon had the Messier objects in my new plan.

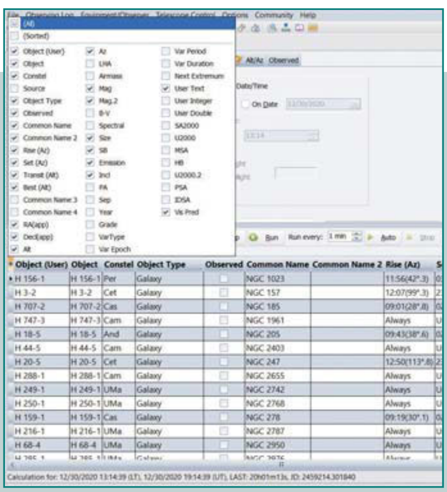
With the plan composed, it was time to enter a date and time of interest by visiting the Localize tab on the Plan window. Localize allows the program to calculate the rise, set, and transit times for objects shown in the plan. Using it in concert with the Altitude tab enables objects in a certain altitude range and visible at a specific time to be displayed. I set Localize for "now," altitude for 30 degrees minimum and 90 degrees maximum, and clicked the Run button in the Plan window. The list went from 110 objects to 18.

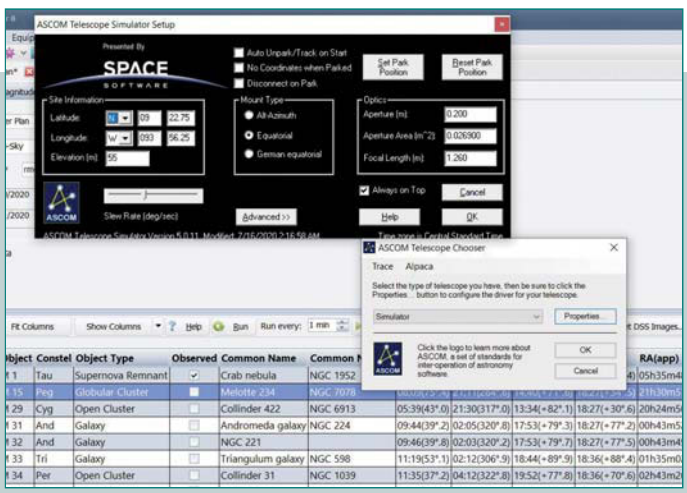
What if you don't see enough information or the desired information on plan objects? Columns can be hidden or displayed with the Show Columns button on the plan screen. There's an extensive list of data columns that can be enabled. The order of the columns is altered by dragging and dropping column titles.

Star Charts

Setting up a planetarium program to work with *DSP 8* is done with the Star Charts selection in the Options menu. After choosing a planetarium program from a list that includes most of the popular ones, an Edit button allows some customization. That includes the size of the chart field shown and whether *DSP 8* should automatically minimize itself when a chart is displayed. Once *Stellarium* was set up, choosing Star Chart on an object's right-click context menu quickly moved the chart to my target object.

In addition to star charts, another function I find useful is having images





▶ Numerous data columns are available for display in an observing plan.

▶▶ *Deep Sky Planner* uses ASCOM drivers for telescope control. Users can download the drivers for their specific telescope from the ASCOM website at **ascom-standards.org**.

of objects available. *DSP 8* furnishes deep-sky pictures by downloading them from the Digitized Sky Survey (the online repository of the Palomar Observatory Sky Survey). Users may choose to download images for all objects in a plan or only for selected targets. The photos are saved and are available for use the next time the plan is loaded.

Outside with *DSP 8*

How you use the software under the stars depends on whether you intend to take a laptop outside or work with a printed observing list. I often leave the PC inside when I want a relaxing time with a non-computerized telescope.

For my first observing session with *DSP 8,* I opened my Messier plan and localized it, telling the program to show objects that would be in the sky at the end of twilight. All that was left to do was print the plan. It was easy to produce a nicely formatted observing list, and the program's improved ability to do so is one of the strengths of *DSP 8*. While there are many formatting options, all I did was click Print in the File menu, choose landscape printing, and my printer produced a good-looking and legible list. I had fun visiting my old Messier friends.

▼ Once configured, it's easy to produce attractive and legible printed observing lists with *Deep Sky Planner 8*.

Observing Plan

Plan Name: Messier Plan
Create Date: 12/30/2020
Modify Date: 12/30/2020
Location: Mobile, AL
Date/Time: 12/31/2020 18:27:29 (LT)
Apply Horizon: No

Page 1

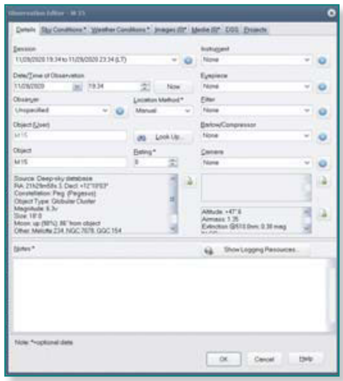
Author: rmollise
Category: Deep-Sky
Description: (null)
Apparent Coords: Yes
Time Zone: Central Standard Time

Object (User)	Object	Constel	Object Type	Observed	Common Name	Common Name 2	Rise (Az)	Set (Az)	Transit (Alt)
M 15	M 15	Peg	Globular Cluster	☐	Melotte 234	NGC 7078	08:09(75°.4)	21:11(284°.6)	14:40(+71°.6)
M 29	M 29	Cyg	Open Cluster	☐	Collinder 422	NGC 6913	05:39(43°.0)	21:30(317°.0)	13:34(+82°.1)
M 31	M 31	And	Galaxy	☐	Andromeda galaxy	NGC 224	09:44(39°.2)	02:05(320°.8)	17:53(+79°.3)
M 32	M 32	And	Galaxy	☐	NGC 221		09:46(39°.8)	02:03(320°.2)	17:53(+79°.7)
M 39	M 39	Cyg	Open Cluster	☐	Collinder 438	NGC 7092	05:49(28°.7)	23:35(331°.3)	14:42(+72°.2)
M 52	M 52	Cas	Open Cluster	☐	Collinder 455	NGC 7654	Always	Up	16:35(+59°.0)
M 76	M 76	Per	Planetary Nebula	☐	Barbell nebula	NGC 650	09:32(23°.3)	04:16(336°.7)	18:52(+69°.0)
M 103	M 103	Cas	Open Cluster	☐	Collinder 14	NGC 581	Always	Up	18:43(+59°.9)
M 110	M 110	And	Galaxy	☐	NGC 205		09:39(38°.6)	02:05(321°.4)	17:50(+78°.9)
M 1	M 1	Tau	Supernova Remnant	☐	Crab nebula	NGC 1952	15:46(63°.8)	05:45(296°.2)	22:44(+81°.3)
M 33	M 33	Tri	Galaxy	☐	Triangulum galaxy	NGC 598	11:19(53°.1)	02:12(306°.9)	18:44(+89°.9)
M 34	M 34	Per	Open Cluster	☐	Collinder 31	NGC 1039	11:35(37°.2)	04:12(322°.8)	19:52(+77°.8)
M 36	M 36	Aur	Open Cluster	☐	Collinder 71	NGC 1960	15:08(48°.8)	06:27(311°.2)	22:46(+86°.5)
M 37	M 37	Aur	Open Cluster	☐	Collinder 75	NGC 2099	15:30(50°.8)	06:37(309°.2)	23:02(+88°.1)
M 38	M 38	Aur	Open Cluster	☐	Collinder 67	NGC 1912	14:54(46°.6)	06:26(313°.4)	22:38(+84°.8)
M 45	M 45	Tau	Open Cluster	☐	Pleiades	BOCL 188	13:53(61°.2)	04:04(298°.8)	20:56(+83°.5)
M 74	M 74	Psc	Galaxy	☐	NGC 628		12:06(71°.1)	01:31(288°.9)	18:46(+75°.2)
M 77	M 77	Cet	Galaxy	☐	Cetus A	NGC 1068	13:50(89°.6)	01:58(270°.4)	19:52(+59°.4)

The following night was a high-tech one. I planned to pursue my current, big observing project, viewing the Herschel 400 list of deep-sky objects. From my backyard, many of these appear dim, and I wanted star charts to help me identify them, even though I'd be using an accurate Go To telescope mount. I also wanted to send my telescope to targets using *Deep Sky Planner 8* rather than the telescope's hand control. So I took the laptop into the backyard.

DSP 8 includes a night-vision mode that does a good job of tinting the screen red (including white spaces in the Windows toolbar) to preserve night vision. As with other programs I've used, however, it was still too bright. I had to place a red Plexiglas filter over the screen.

Sending the telescope to objects with *DSP 8* was faultless. While the program doesn't include telescope drivers of its own, it instead uses ASCOM drivers available as a free download from ASCOM's website (**ascom-standards.org**). Once I had the driver for my scope set up, I'd right-click an object in the plan, choose Slew from the context menu, and the telescope would immediately move to the target. It would be nice, though, to have a Slew button in the program's telescope control panel and not just in a context menu.



◀ *Deep Sky Planner 8* includes an observing logbook for recording detailed observations of objects.

I've logged my observations throughout my stargazing career. Forty years ago, I did that with a loose-leaf notebook. Today I use a computer. Thankfully, an observing log is an integral feature of *DSP 8*. To add a log entry, simply check the Observed box for an object in the plan. That brings up the log in the right-most column. Clicking Add Observation opens a window where you can enter detailed information on observations. However, in order to simply mark an object as observed, it's necessary to create a log entry even if you have nothing further to add.

And so it went, through the night. I'd highlight an object, look at its image and maybe a *Stellarium* star chart, have *DSP 8* send the telescope to it, log it, and head for the next one. One thing I realized about halfway through the evening is how legible *DSP 8* is. Its layout is clean and simple, and the fonts are large enough for my aging eyes.

Summing Up

More than 25 years since it was first published, *Deep Sky Planner 8* is a mature and full-featured program that has added new capabilities without sacrificing its clean design and simple operation. The program includes everything I need and much I have yet to explore. While I have a hard drive full of astronomy software, I could easily get along with just *DSP 8*. It is a joy to use indoors or on an observing field.

■ Fifty years on and Contributing Editor **ROD MOLLISE** still gets excited to hunt for deep-sky objects on a clear, moonless night.

▲ PLANETARY CAMERAS

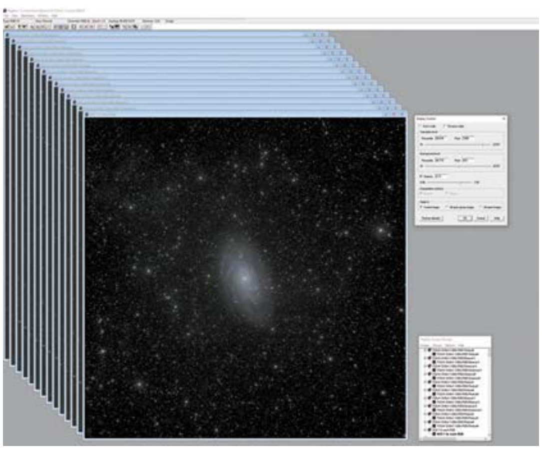
Player One Astronomy announces a series of planetary imaging cameras. Its Mars-M ($329) and Mars-C ($269) cameras are built around high-sensitivity Sony IMX290 monochrome and IMX462 color CMOS sensors, respectively. Both sensors utilize 2.9-micron pixels in a 1,944 × 1,096 array. Each USB 3.0 camera can record 136 full-resolution frames per second, and even more when using on-chip ROI cropping. Additionally, both models include 256MB DDR cache memory to ensure no frames are lost when operating with slower computers. The Mars cameras also feature easy-access sensor-tilt adjustments to perfectly square the sensor to the optical system. The cameras can also issue guiding commands to your telescope mount via an ST-4-style guiding port. Each purchase includes a 2-meter USB 3.0 cable and 1¼-inch nosepiece.

Player One Astronomy
168 Yuxin Road, Bldg. 1, Rm. 522, Suzhou, China 215027
player-one-astronomy.com

▲ CARBON-FIBER APOCHROMAT

Stellarvue adds a new model to its extensive line of Raptor apochromatic refractors. The SVX 130T-R ($5,695) is a 130-mm (5.1-inch) triplet apochromat that combines a super-low-dispersion center element and a lanthanum rear element to produce color-free views. Its fully baffled, carbon-fiber tube limits focus shift due to temperature changes. The instrument weighs 10 kilograms (19.8 lbs) and measures 75 centimeters (29.5 inches) long with its dew shield retracted. The SVX 130T-R comes with a robust 3½-inch-format Feather Touch focuser, but users have the option of upgrading to a 3½-inch, computerized, rotating Moonlight focuser at additonal cost. Both focusers are designed to accommodate the largest imaging detectors on the market today. Each unit includes two CNC-machined mounting rings, a threaded metal dust cap, and a padded C130L case.

Stellarvue
11802 Kemper Rd., Auburn, CA 95603
530-823-7796; stellarvue.com



◀ BETTER REGISTRATION

Auriga Imaging releases a major update to its flagship image-alignment software. *RegiStar* 1.0.10 ($179, but free for existing customers) now includes RAW camera file support, several pre-processing operations, and a display control that allows you to adjust the gamma of an image to better show linear data onscreen. In addition, *RegiStar* can now calibrate groups of images before registering and saving them using batch scripts. This feature works with image files captured with astronomical cameras as well as DSLR and other one-shot-color cameras. Users can also rotate, flip, and crop images before registration.

Auriga Imaging
6430 Main St., Vancouver, BC V5W 2V4 Canada
aurigaimaging.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.*

A Better Ronchi Tester

An even light source and ease of use make all the difference.

MANY MIRROR MAKERS use the Ronchi test to evaluate their mirrors during the parabolization phase. With the Ronchi test, over- or under-parabolization, zonal deviations, and turned edges are easy to detect and easy to quantify. The test is simple: Shine a light at the mirror through a grid of evenly spaced lines and look at the reflected image of those lines through that same grid. The result will be a series of bars that bend in ways that are specific to the shape of your mirror. A spherical mirror will display straight bars, and a parabolized mirror will show curved bars.

The devil is in the details, and one of those details is the test apparatus itself. I've seen many mirror makers struggling to get a decent image out of their Ronchi tester, and the problem is almost always the light source. Somehow, a relatively large number of people have become convinced that they should use an LED or a pinhole or slit. The problem with that approach is that it doesn't fully illuminate the mirror until you're very close to the center of curvature, and the Ronchi test is useful at a far greater range of

▲ The LED head from a mini flashlight and two diffusers provide a nice, even light source.

distances than that. At least it is when you have a good light source.

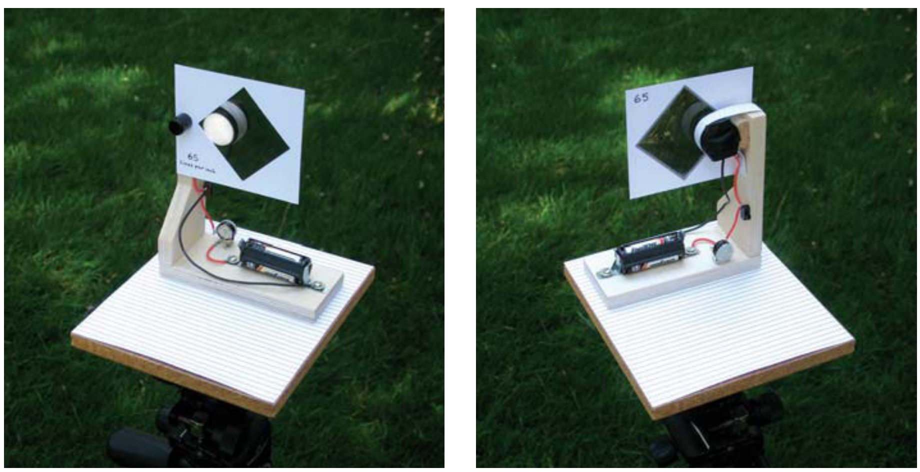
The ideal light source for a Ronchi test is a wide, evenly illuminated white flat-field about an inch across. I've seen people put light bulbs inside ping-pong balls, and that works pretty well except that the light falls off toward the edges. A better solution is to repurpose the head of one of those ubiquitous, cheap 9-LED flashlights.

You can't just stick the flashlight up against the grid. If you do that, you're back to staring at individual LEDs; you'll just have nine to choose from. You need to put a diffuser between the LEDs and the Ronchi grid.

I've experimented with various materials, and I've discovered that the best diffuser, one that evens out the light without dimming it very much, is a two-stage unit that holds two layers of white plastic bag about half an inch apart. The first layer goes right over the flashlight head, and the second layer goes next to the Ronchi screen. I use a thin bag for the one closest to the light and a thicker, whiter one for the outer stage. That combination seems to give me the most even light.

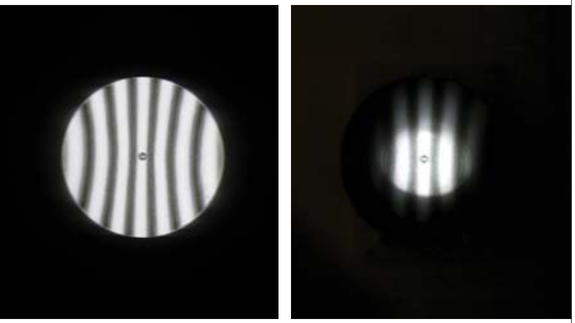
You could just stick the diffuser on a flashlight and hold that up against the screen, but you'll soon find that the flashlight body gets in the way of your head. You want to get your eye as close to the light source as possible to minimize the angle between the outgoing and incoming light beams.

I take the LED pack out of the flashlight. Some models can be removed down to the circuit board, like the one pictured here; others are most easily used by simply cutting off the barrel of the flashlight just behind the light element. Either way, what you get is short



▲ *Left:* The light source is uniform across a wide swath of the Ronchi grid. The grid is interchangeable for lower- or higher-resolution testing. *Right:* The potentiometer and on/off switch are simply glued to the frame.

ALL IMAGES COURTESY OF THE AUTHOR



▲ *Left:* The pattern produced by this tester is evenly lit throughout. *Right:* A single LED doesn't provide an even light source, making the Ronchi pattern harder to read.

enough to stay out of your way.

I use a length of plastic tubing for my diffuser, but if you can't find a suitable tube you can simply make a cardboard ring. Lay your first sheet of plastic bag over the flashlight head, shove the ring over it, and drape the second sheet of plastic over the front of the ring. You can hold the second layer neatly in place with a second ring over the first. Ideally, as noted above, there should be about ½ inch between the two layers of plastic.

The rest is just gingerbread. Make a framework to hold the light, the grating, the battery pack, a switch, and a potentiometer to adjust the light's intensity.

For those doing a matching Ronchi test, where you compare your view to a computer-generated image, make yourself a platform with evenly spaced lines that match your pattern spacing. I put a ¼ × 20 tee nut on the bottom so I can attach the platform to a photo tripod, making setup a snap.

If you've been struggling with the Ronchi test, or even if you've become accustomed to using a bare LED or a slit, give this wide, even light source a try. You'll find that it makes the test much easier and more enjoyable to perform.

An excellent resource for Ronchi testing can be found at Mel Bartels's website at **bbastrodesigns.com/ronchi.html**.

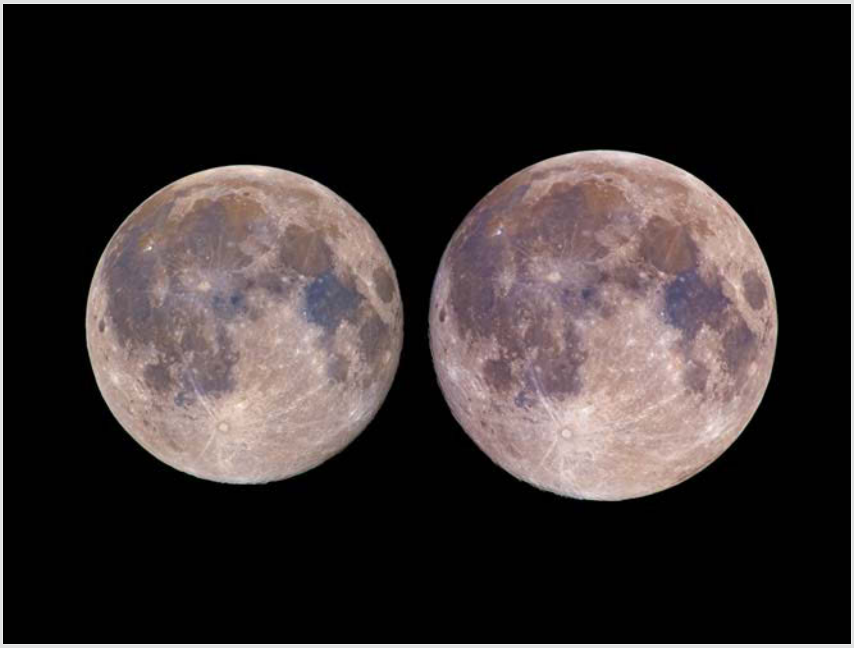
■ Contributing Editor **JERRY OLTION** has used a pocket comb and a flashlight in a pinch, but he puts a piece of paper in front of the flashlight.

CELESTIAL FOUNTAIN

Philippe Moussette

The bluish ion tail and broad white dust tail of Comet NEOWISE (C/2020 F3) flare across the sky over Lévis, Québec, pairing nicely with the tree to the right.

DETAILS: *Canon 1DX Mark III DSLR camera with 100mm f/2.8 lens. Total exposure: 3 minutes at ISO 1600, taken on the evening of July 20, 2020.*



◁ APOGEE AND PERIGEE

Soumyadeep Mukherjee

The full Moon of December 30, 2020 (left) appears almost 10% smaller than at its closest approach in 2021 on April 27 (right).

DETAILS: *Nikon D5600 DSLR camera with Sigma 150-to-600 zoom lens at 600 mm. Each photo is a stack of 238 frames.*

▽ HEAVENLY SWATCHES

Dan Crowson

Dark clouds swirl amidst the yellowish dust of IC 4606, which is lit up by the red giant star Antares (below center). At right is red emission nebula Sharpless 2-9, while blue reflection nebulosity surrounds multiple star Rho Ophiuchi at the top.

DETAILS: *FLI ML16200 CCD camera with Nikon 200-mm f/2 lens. Total exposure: 3 hours through RGB filters.*

GALACTIC SOMBRERO
Bray Falls
M104 does indeed call to mind the wide-brimmed Mexican hat that lends it its common name. This edge-on spiral galaxy in Virgo has almost 2,000 globular clusters strewn across its disk.
DETAILS: *16-inch RCOS Ritchey-Chrétien telescope with SBIG STXL-6303 CCD camera. Total exposure: 66 hours through LRGB filters.*

Gallery showcases the finest astronomical images that our readers submit to us. Send your best shots to gallery@skyandtelescope.org. See **skyandtelescope.org/aboutsky/guidelines**. Visit **skyandtelescope.org/gallery** for more of our readers' astrophotos.

In the summer of 2020, mankind takes the next step in space exploration with the launch of the "Perseverance" Mars Rover. On a journey that will take it more than 140 million miles through our solar system and across the cold and barren landscapes of the Red Planet, its mission will reveal vast secrets and uncharted territories, unlocking the answers to key questions many have pondered since the age of Galileo Galilei.

Now, you can celebrate this robotic explorer and its historic journey to uncover the mysteries of the Red Planet with the *"Perseverance" Mars Rover Sculpted Masterpiece*, available ONLY from Hawthorne Village.

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Revisiting Dreams

The pandemic gave the author a chance to realize long-held aspirations.

ALMOST 60 YEARS AGO NOW, my dreams of playing competitive basketball were shattered. Torn ligaments from a careless dive for a loose ball effectively ended my career. Rather than shooting varsity hoops, I faced a winter of knee surgery followed by weeks of physical therapy.

To pass those long Illinois winter months that year, I decided to read Jean Texereau's book *How to Make a Telescope* and build my own. Grinding, polishing, and testing a 6-inch mirror helped me make it to March. Building an optical tube assembly and mount helped me make it to May.

Observing Saturn as my "first light" object completed my telescope-building project — and unexpectedly changed my life. I had seen bigger and better images of Saturn in magazines, but, as all *S&T* readers know, there's something magical about viewing the planet directly. I was no longer a teenage basketball player; I was a teenage amateur astronomer. My focus shifted from varsity letters to NGC objects.

Filled with a youthful self-confidence — and very little astronomical knowledge — I decided to follow up my Saturn sighting with two objects I'd read about: the Horsehead Nebula and Pluto.

Wow, reality was quick to teach me a lesson! Seeing those two objects was not just challenging for anyone; for me, it seemed unattainable. I did spend many wonderful nights with my telescope observing objects such as the Orion Nebula and Jupiter, but that Holy Grail of detecting the Horsehead Nebula and Pluto was always on my mind.

Over the next six decades my professional career went down multiple paths, ending just recently in my last position as an assistant professor of research, statistics, and astronomy. While teaching astronomy, I had an excuse to learn more about astrophotography, and I discovered that an amateur could take some quite decent photos using the newest computer and detector technology. Even if directly seeing the Horsehead Nebula or Pluto wasn't possible for me, I thought, perhaps I could photograph them.

In early 2020, as the coronavirus pandemic overwhelmed New York State, I realized that sheltering at home provided an opportunity for me to develop my photographic skills by purchasing some new equipment. Despite — and because of — the pandemic, things were coming together perfectly: time, technology, and lifelong dreams. Maybe my astronomy ambitions as a teenager were finally within reach.

In March 2020, I realized my first dream, capturing a photo of the Horsehead Nebula. Fast optical systems, computerized mounts, autoguiders, bandpass filters, CMOS detectors, and post-processing are truly gifts from heaven. To my delight, over two successive nights in June 2020 I realized my second dream, photographing the slight movement of Pluto among the stars. Add planetarium software as another benefit that helped me both locate Pluto and confirm its movement.

Thinking back on those March and June nights last year, the emotions I experienced of once-thwarted teenage wishes coming true were palpable. How fortunate I've been to be able to continue pursuing my dreams. Perhaps somewhere in the world there's a young person right now who is deciding to build a telescope because they can't play a sport during the pandemic. I hope so.

■ **TOM DEEVER** lives in Fairport, New York, where he continues to learn about astrophotography.

YAO XIAO, ILLUSTRATOR

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Losing a precious clear night of observing is incredibly frustrating, especially when it's due to something as benign as an operating system update. Faulty updates can render imaging systems inoperable and require hours of often exasperating troubleshooting to recover.

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TheSky Fusion's Linux-based operating system provides exceptional stability with more up-time, night after night.

Without knowing it, you may already use Linux-based embedded systems (think cars, smart televisions, and microwave ovens). As with these devices, you don't have to learn Linux in order to operate TheSky Fusion.

TheSky Fusion lets you wirelessly operate your *entire* imaging system from just about any Wi-Fi enabled computer equipped with a Web browser. That includes most tablets, smartphones, laptops, and desktops.

Since TheSky Fusion performs most of the heavy lifting, even older machines should be up to the task of advanced astronomical imaging.

Speedy performance comes from multi-threaded software architecture that takes full advantage of TheSky Fusion's powerful 64-bit, six-core CPU — this is especially noticeable with its lightning-fast renderings of the sky.

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