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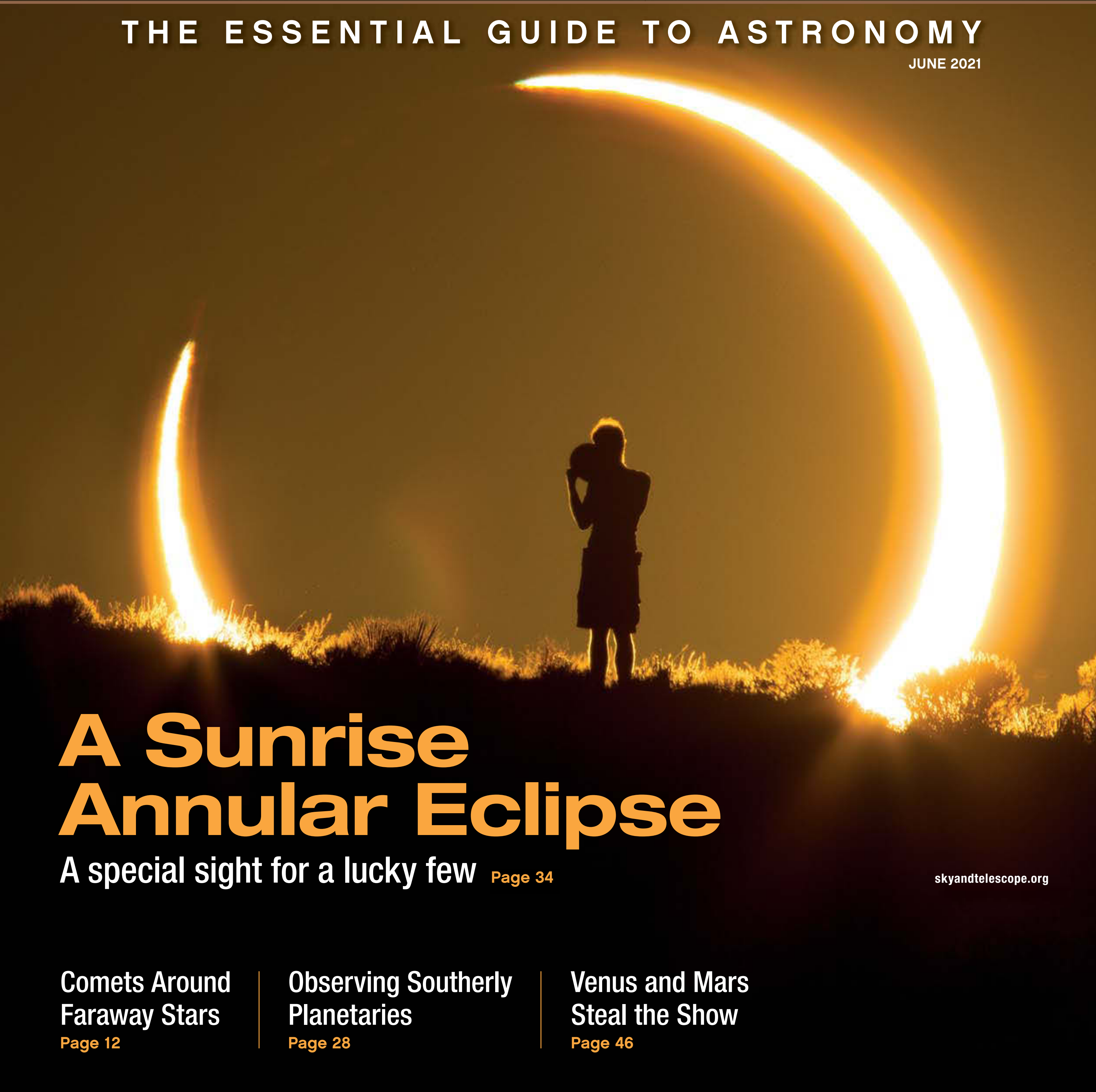
SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

JUNE 2021



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THE ESSENTIAL GUIDE TO ASTRONOMY

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Fortuitous shot of the May 2012 annular eclipse as the Sun set

PHOTO: COLLEEN PINSKI

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An Exquisite Precision

A SOLAR ECLIPSE PRESENTS a fine opportunity to acknowledge one of astronomy's signature traits: the ability of its practitioners to predict celestial events with extraordinary exactitude. Throughout every issue of *Sky & Telescope* — most noticeably in the observing section starting on page 41 — you'll encounter precise times, positions, brightnesses, and other measurements that attest to this characteristic. But to grasp just how painstaking such calculations can be, one need look no further than at eclipse forecasting.

A quick glance at the tables found in Joe Rao's cover story (page 34), for instance, will show how meticulous the timings are for this month's annular eclipse. But get a fix on this: Such to-the-instant timings already exist for every eclipse that has occurred or will occur between 2000 BC and AD 3000. Created by Fred Espenak and Jean Meeus, the Five Millennium Canon of Solar Eclipses (**https://is.gd/5mcanon**) tells us that, during that 5,000-year stretch, our planet will experience exactly 11,898 eclipses of the Sun. That includes 3,173 total, 3,956 annular, 569 hybrid, and 4,200 partial eclipses.

▲ The ring (Latin: *annulus*) that defines an annular eclipse, this one from 1994

DENNIS DI CICCO

Consider annulars alone. Want to know the longest-lasting annular eclipse of this century? That happened on January 15, 2010, and it lasted 11 minutes, 8 seconds. (That's the duration of the "ring" effect caused by the Moon mostly but not completely covering the Sun.) Don't worry if you missed it: This century's second-longest annular will take place on January 26, 2028 (10 minutes, 27 seconds). Such precision holds even further out. The lengthiest annular of the fifth millennium AD? That will transpire on January 20, 4885 (11 minutes, 8 seconds).

Espenak and Meeus are careful to note that these extremely rigorous predictions aren't *perfectly* precise. The largest uncertainty in their calculations, they say, comes from lunar tidal friction causing fluctuations in Earth's rotation, which results in a drift in apparent clock time. But for your and my purposes, they might as well be perfect.

How can astronomers be so definite? In broad strokes, the process they use to determine exactly when an eclipse will begin and end for any spot on the planet essentially boils down to this: Take the sizes of Earth, Moon, and Sun, factor in how the three bodies move in relation to one another, and run the numbers.

Of course, there's much more to it than that, and eclipse aficionados like Joe Rao love to parse the particulars. But you don't need to be so fastidious to appreciate an eclipse. When the Moon comes between you and the Sun, just grab your eclipse glasses and enjoy the spectacle.

Peter

Editor in Chief

Editorial Correspondence
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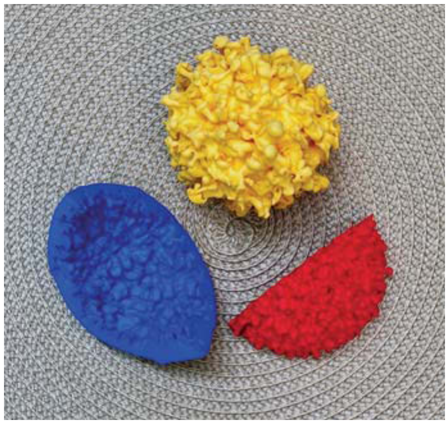
Teaching Astronomy to the Visually Impaired

Kate Crohan's review of *Touch the Stars* (*S&T:* Feb. 2021, p. 68) reminded me of my mother, Ruth Craig, who was involved in teaching blind students and training teachers of the blind. She wrote the first tutorial textbook for the Nemeth Code, which used to represent mathematics in Braille. I was also reminded of one of the most engaging presentations on astronomy I have ever seen. It was several years ago at the Rocky Mountain Star Stare. The presenter, Ben Wentworth, was a former Air Force officer who had taken a job teaching the visually impaired. He repeatedly said he wasn't a trained teacher, but clearly he was a born one.

I will mention just a few of the clever means he had used to present astronomical concepts. One of the best was standing a volunteer against a Sun-warmed wall and having the other kids squirt water at them. When the volunteer stepped away, the dry, warmer part of the wall behind them became a "water shadow." Shadows are a tricky concept for blind students. Combining that idea with a stake driven into the ground and a buzzer powered by a solar cell helped the students learn about the changing angle of the Sun's rays. His *pièces de résistance* were dome tents that his students used to create tactile representations of the constellations using different sized and shaped hardware nuts glued to the inside of the tents to represent the different brightnesses of the stars and tape for the constellation lines. Brilliant!



▲ NASA has released a series of digital models with files that enable 3D printers to create models of the X-ray universe (see **chandra.harvard.edu/deadstar**) like this one of the remnant of Supernova 1006. They're excellent tools for teaching tactile and visually impaired learners about astronomy.

My mother would have been delighted by this teacher's creativity and enthusiasm, to say nothing of how pleased she would have been by Noreen Grice's book. It's wonderful that there are resources like this cleverly designed book.

John Craig • Orem, Utah

The Women Behind RCB Stars

Greg Bryant's "The Ups and Downs of RCB Stars" (*S&T:* Mar. 2021, p. 30) missed out on an opportunity to tell a multi-decade diversity story. The fact that most stars have nearly the same surface composition was the discovery of Cecilia Helena Payne (later Payne-Gaposchkin) in 1925. Valerie P. Myerscough created the first model atmosphere of R Coronae Borealis and demonstrated that helium and carbon were the dominant elements **[https://is.gd/Myerscough1968]**. Anne B. Underhill violently opposed the model and claimed (until her death) that the star had a normal composition but anomalous ionization and excitation.

▶ Cecilia Helena Payne-Gaposchkin was a British-American astronomer who in 1925 discovered that stars are composed primarily of hydrogen and helium.

A [1972] study of pulsating helium stars confirmed that one could fit the period and amplitude of the Cepheid-like pulsations of RY Sagittarii with its effective temperature, around 6000K, a luminosity of almost 20,000 times that of the Sun, and a mass of about 2 Suns, if and only if, the atmosphere contained mostly helium plus some extra carbon. The pulsation light curve was the work of the late Michael Feast, but we have to let the men have some of the fun. Oh, and the 1972 author is also a woman, though I'm a good deal older than I was then **[https://is.gd/Trimble_1972]**.

Virginia Trimble
Irvine, California

Helium White Dwarfs

I enjoyed reading "The Ups and Downs of RCB Stars." The author writes that the progenitors of the helium white dwarfs are very low-mass stars. I was wondering what the mass and expected lifetime of helium white dwarf progenitor stars are, and if the existence of a helium white dwarf is compatible with the age of the universe. I remember reading that the lowest-mass stars burn their fuel so slowly that they haven't had time to reach the white dwarf state yet.

Paul Waddington
Rome, Italy

Greg Bryant replies: *It's generally believed that helium white dwarfs don't form in a solitary environment. Rather, they reach this evolutionary phase in a binary system in which the companion star strips the white dwarf of matter, bringing it down to below around 0.5 solar masses, at which point it can't fuse helium. The helium white dwarfs that have been found thus far are in the 0.2–0.5 solar-mass range. As with other white dwarfs, helium white dwarfs are thought to then slowly cool and fade until they eventually become black dwarfs — the timeframe for this is estimated to be longer than the current age of the universe.*

The Origin of Theia

Nola Taylor Redd's "How Did We Get the Asteroid Belt?" was a joy to read (*S&T:* Mar. 2021, p. 22). Yet I couldn't help but think about the origin of the large planetoid that astronomers believe crashed into Earth early in the solar system's history, bounced off, and formed our atypically large Moon. Could the lunar progenitor have come from the early planetoid chaos described in the article?

3D PRINT: NASA / CXC / SAO / K. AND C. ARCAND; PAYNE-GAPOSCHKIN: SMITHSONIAN INSTITUTION ARCHIVES / SCIENCE SERVICE RECORDS

Articles like these are why I have been reading *S&T* for more than 50 years!

Jim Hartley
Fair Oaks, California

Camille M. Carlisle replies: *That is an interesting question you've posed! I asked planetary scientist Sean Raymond, who has worked on the asteroid-belt formation scenarios. He says, "The Moon is thought to have formed from a late giant impact from a big (Mars-sized-ish) object that is often called Theia. Most researchers think that Theia grew near Earth and was made of basically the same stuff* **(https://is.gd/EarthMoonGenetics)**. *But there is a crazy new idea that Theia might have originated farther out, in the primordial asteroid belt, and even delivered Earth's water when it collided* **(https://is.gd/BroughtWatertoEarth)**. *New results are shooting down that idea, but it's worth thinking about."*

*Also, the impactor likely didn't bounce off Earth but was obliterated, mixed with Earth's debris, and created a big, center-filled doughnut that then coalesced into Earth and its Moon (*S&T: *Aug. 2018, p. 26).*

Missing Arecibo

Having spent a couple of wonderful years at the Arecibo Observatory as a graduate student in the 1970s, I share David Grinspoon's dismay at its demise in "Adiós, Arecibo" (*S&T:* Mar. 2021, p. 12). But Arecibo's dish is not a paraboloid — it's spherical. The antenna's surface still reflects like a sphere when the focal point is moved to observe a different part of the sky.

This is the design magic that allows the dish to be fixed in the ground and still observe objects up to 20° from the zenith. It was an ingenious design concept and will be sorely missed.

Nathan Krumm
Pearblossom, California

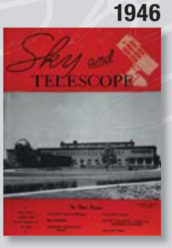
FOR THE RECORD

- Joel Marks's observation of a geostationary satellite (*S&T:* Jan. 2021, p. 6) was made with an unguided telescope, and his impression was that the geosat appeared to move through the background stars even though the satellite was itself motionless in the eyepiece field.
- Saint Raphael is from the Book of Tobit. Therefore, all of Julius Schiller's constellations in the Southern Hemisphere (*S&T:* Jan. 2021, p. 64) are from the Old Testament.
- Discounting political alterations, time zones are centered on even 15° meridian lines. They don't begin and end on those lines as stated in "Finding North by Day" (*S&T:* Feb. 2021, p. 72).
- An electron went missing from Branch 2 of the "Rare Reactions" diagram (*S&T:* Apr. 2021, p. 17). The electron combines with a proton in Beryllium-7 to produce Lithium-7 and a neutrino.

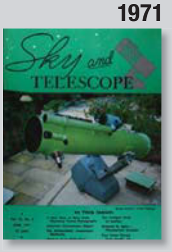
SUBMISSIONS: Write to *Sky & Telescope*, One Alewife Center, Suite 300B, Cambridge, MA 02140, USA or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1946



1971



1996

June 1946

Vermont Gathering "The war is over and many of us are finding time to pursue our old hobby of telescope making. Consequently, there has been considerable demand for the Springfield telescope makers to hold again their annual Telescope Makers Convention at Stellafane. The date is set for the weekend of August 3rd, during the first quarter of the moon.

"The banquet and program will be that evening. We are glad to report that Russell Porter will be here from Caltech to give the latest information on the 200-inch at Palomar. . . . There should be a new generation of telescopes both wonderful and weird that are worthy of exhibit on Breezy Hill."

John W. Lovely's announcement followed a four-year wartime lapse in Stellafane conventions, their first interruption since 1926. Hopefully, the current lapse, due to COVID-19, will end on August 5–8, 2021.

June 1971

Cygnus X-1 "Perhaps the most spectacular discovery from Uhuru data is the very rapid variation of the X-ray emission from Cygnus X-1, a source in our Milky Way which has been known since 1966. . . . Unlike other strong sources, Cygnus X-1 shows a jagged rise and fall [in counts] collected over 0.384-second intervals. . . .

"This [has] led to the suspicion that the actual period might be shorter than the sampling interval of the detector . . . On this viewpoint, a reexamination of the records indicated a period of 0.073 second. [Investigators] note that the very short but persistent pulse period can be reasonably interpreted only by the rapid rotation of a collapsed star. This, they suggest, might be a 'black hole' instead of a neutron star."

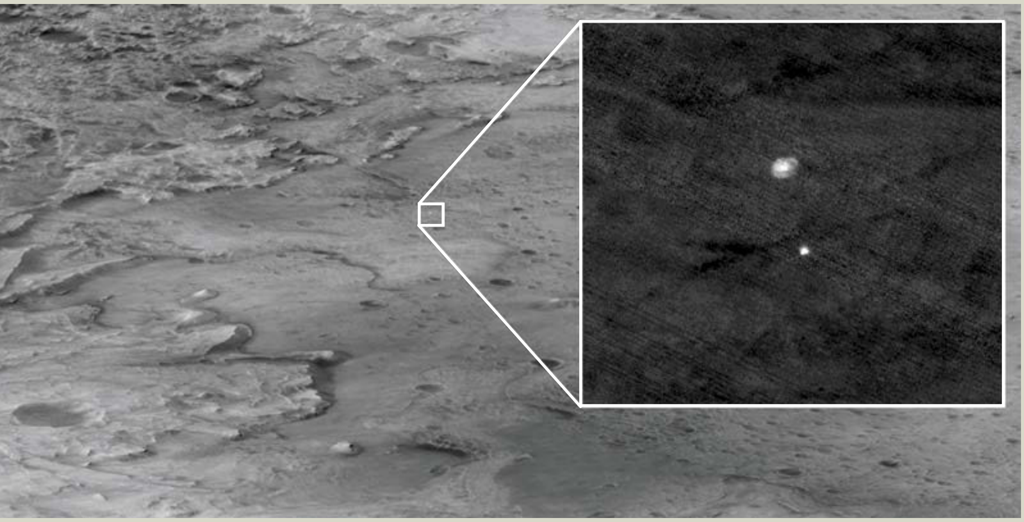
As the first dedicated X-ray satellite, Uhuru was, in fact, looking at a stellar-mass black hole orbiting a 9th-magnitude star about 7,200 light-years away. According to a 2021 study, Cygnus X-1 spins 800 times a second and has the mass of 21 Suns.

June 1996

Spring Comet "'Something from a fantasy world.' 'Absolutely beautiful!' 'The most unbelievable sight I've ever seen in the sky.' These are among the acclamations that arrived in our offices as Comet Hyakutake, C/1996 B2, sailed past Earth in late March. . . .

"When Japanese amateur Yuji Hyakutake stumbled upon an 11th-magnitude smudge with his 25×150 binoculars in the predawn hours of January 30th, little did he realize that it would soon become a huge naked-eye spectacle whose great tail spanned halfway across the heavens."

Edwin Aguirre went on to say that some observers were calling the comet "electric-arc blue" or "aquamarine." And on March 22nd in Norway, Bjørn Granslo estimated that its head was nearly as bright as Arcturus.



◀ The Mars Reconnaissance Orbiter imaged Perseverance as it descended toward the landing site, its parachute unfurled behind it (*inset*). The ancient river delta is on the left.

SOLAR SYSTEM

Three Missions Arrive at Mars; Perseverance Touches Down

THREE EMISSARIES arrived at Mars within two weeks of one another after traversing more than 470 million km (300 million miles) of interplanetary space (*S&T:* July 2020, p. 22).

The United Arab Emirates' Hope probe, formally known as the Emirates Mars Mission, kicked things off when it entered orbit around Mars on February 9th. The country's fledgling space agency was the fifth to successfully send a spacecraft to Mars, behind the United States, Soviet Union, European Space Agency, and India.

The probe's 55-hour orbit takes it from 22,000 to 44,000 km above the Martian surface. Hope is farther from the planet than other orbiters to obtain a global view of its climate. Its two-year nominal science mission starts in May, with a possible extension to 2025.

The day after Hope's arrival, China's Tianwen 1 spacecraft also reached Mars. The orbiter could release its lander/rover in May, targeting a landing site in Utopia Planitia — the same general region that hosted NASA's Viking 2 mission. The solar-powered rover's nominal mission is around three months long, and the orbiter should last at least two years. Between the two of them, the mission carries 13 scientific payloads to map water ice and study the planet's tenuous atmosphere and magnetic environment.

▲ The United Arab Emirates' Hope orbiter shot this image shortly after arrival.

On February 18th, the third and last of this batch of Mars-bound explorers — NASA's Perseverance mission — came in hot, going straight from interplanetary travel to atmospheric entry. In the time it takes to brew a pot of coffee, an aerodynamic shield, parachute, and rockets reduced the arriving spacecraft's velocity from 5.4 kilometers per second (12,100 mph) at the top of the Martian atmosphere to a gentle touchdown on the frigid landscape.

To aid its descent, Perseverance came with a few upgrades: a range trigger that timed the parachute's opening and terrain-relative navigation that matched the ground below to stored imagery. With that help, the rover touched down within the 7.7-km-long ellipse inside Jezero Crater. This pinpoint precision ensured that Perseverance landed near the rugged fan of debris deposited on the crater's floor when a river long ago breached the western rim and formed a lake. The eons-old sediments left behind may have preserved organic molecules that could help determine whether Mars was once inhabited.

Perseverance carries 23 cameras, including seven specifically for scientific purposes. It also brought a caching system, which will package samples for a later mission to pick up and bring home. The rover carries seven instruments to explore the ancient lake basin — including SHERLOC, a spectrometer specifically designed to detect organic molecules and potential biosignatures.

As a bonus, tucked under Perseverance's belly is the Ingenuity Mars Helicopter — an autonomous rotorcraft. If successful, it would be the first to fly on any planet beyond Earth.

■ J. KELLY BEATTY & DAVID DICKINSON

▼ A piece of Perseverance's first high-resolution panorama is shown below; explore the full view at **https://is.gd/percypanorama**.

PERSEVERANCE PARACHUTING: NASA / JPL-CALTECH / UNIVERSITY OF ARIZONA; MARS: MOHAMMED BIN RASHID SPACE CENTER / UAE SPACE AGENCY; PERSEVERANCE IMAGE: NASA / JPL-CALTECH / ASU / MSSS

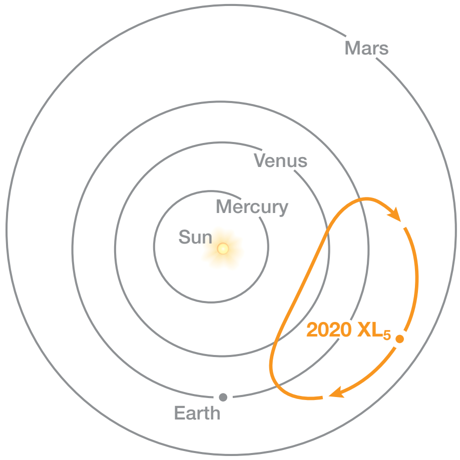
ASTEROIDS

Second Earth Trojan Observed

A RECENTLY DISCOVERED asteroid appears to be an Earth Trojan, orbiting a gravitationally stable area with only one other known occupant.

Amateur astronomer Tony Dunn reported the potential find January 26th on the Minor Planet Mailing List. Given the preliminary designation 2020 XL_5, the asteroid is a few hundred meters across and appears to be orbiting the L_4 Lagrange point.

Trojan asteroids occupy the gravitationally stable Lagrange points about 60° ahead or behind the planets in their orbits around the Sun. In theory, Trojan orbits should be stable around every planet except Saturn, in which



▲ This orbit diagram shows 2020 XL_5's trajectory (orange) relative to Earth. View the animation at **https://is.gd/2ndearthtrojan**.

case Jupiter's gravity pulls them away. But Earth Trojans have proven difficult to find because they're small and appear close to the Sun on the sky.

Earth Trojan orbits can meander — relative to Earth, 2020 XL_5 ranges from inside Venus's orbit and outward almost to Mars. The wide-ranging orbit shows that 2020 XL_5 is "almost certainly a garden-variety bit of rock," whose orbit was disturbed during a close pass by Venus, says Bill Gray, creator of the Project Pluto astronomical software.

The newest Trojan isn't alone: NASA's Wide-field Infrared Survey Explorer spacecraft spotted the first Earth Trojan, 2010 TK_7, in October 2010. But while that one may orbit stably for about a quarter million years, calculations suggest 2020 XL_5 will remain a Trojan only a couple thousand years. Amateur astronomer Sam Deen says additional observations to confirm the asteroid's orbit will be possible late this year.

■ **JEFF HECHT**

BLACK HOLES

Star-shredding Black Hole Makes High-energy Neutrino

A SUPERMASSIVE BLACK HOLE some 690 million light-years away tore apart a star — and may have created neutrinos in the process.

The IceCube Neutrino Observatory in Antarctica detected a single high-energy neutrino on October 1, 2019. The tiny, ghostlike particle came from a region in Delphinus and packed a punch of about 200 teraelectron volts (15 times more energetic than what the Large Hadron Collider can produce).

Robert Stein (DESY, Germany) and colleagues observed the area within hours using the Zwicky Transient Facility. They found the fading glow of a tidal disruption event (TDE), produced months earlier when a black hole 30 million times the Sun's mass had shredded a star that ventured too close.

To create a neutrino, a high-energy proton must slam into another proton or a photon. This could occur in TDEs, possibly in the relativistic jets of plasma that shoot out from near the black hole.

The TDE the team found had flared up months before, on April 9, 2019, but while its X-rays had faded rapidly, its radio emission actually increased. The radio waves resulted from high-energy electrons spiraling around magnetic field lines. Whatever accelerated the electrons would have sped up protons too, but it's still unclear if that happened within a jet.

Stein's team reports no evidence for relativistic jets, writing February 22nd in *Nature Astronomy*. They posit instead that the protons accelerate in a broad, slower-moving outflow. The energized protons then collide with plentiful ultraviolet photons produced by hot gas torn from the star that's farther out.

In the same issue of *Nature Astronomy*, Walter Winter (DESY) and Cecilia Lunardini (Arizona State University) suggest that the TDE did produce jets, but we can't see them because they're obscured by outflowing material. But Lunardini acknowledges that "with only one neutrino observed from a TDE, you cannot really draw firm conclusions, and the data remain open to interpretation."

Both teams' models suggest that TDEs can be efficient particle accelerators, sustaining the process for months after a stellar snack. However, the researchers also note there's a 0.5% chance that the neutrino and TDE are unrelated. Additional examples of TDE-neutrino associations are forthcoming and will help confirm the link and differentiate between models.

■ **GOVERT SCHILLING**

▶ This artist's impression shows a tidal disruption event, which could produce high-energy neutrinos.

ORBIT DIAGRAM: GREGG DINDERMAN / *S&T*; SOURCE: TONY DUNN; STAR-SHREDDING BLACK HOLE: DESY / SCIENCE COMMUNICATION LAB

SOLAR SYSTEM

New Map of Water Ice on Mars

SCIENTISTS HAVE MAPPED water ice in the northern hemisphere of Mars.

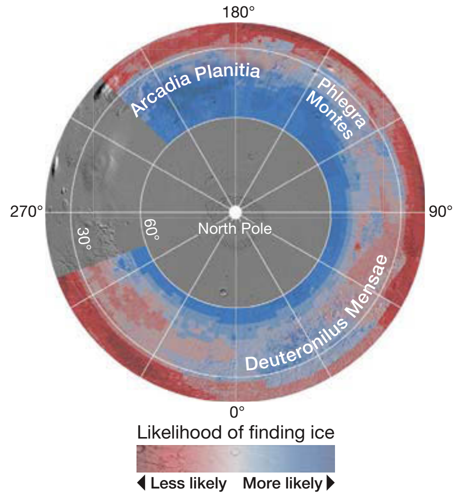
Most crewed mission proposals rely on the availability of ice to generate return fuel, so mapping large, accessible reservoirs is key to planning. The poles, where most of the known water is, are too inhospitable, so NASA funded the Subsurface Water Ice Mapping (SWIM) project to search for buried ice resources across the planet's mid-latitudes.

On February 8th in *Nature Astronomy*, the SWIM team indicates where future missions might find usable ice deposits with higher likelihood and better resolution than before.

The SWIM team combined seven data sets from six instruments aboard four orbiters: two thermal spectrometers (TES and THEMIS), a neutron spectrometer (MONS), two types of radar returns (surface and subsurface) from SHARAD, and two visible imagery sets from the CTX and HiRISE cameras. The thermal spectrometers detect mineral concentrations based on visible and infrared reflections off the planet's surface, while MONS measures the release of neutrons from the soil, which indicate the presence of underground water. These techniques examine the surface and just beneath it, whereas radar probes deeper than about 15 meters (50 feet).

At in-between depths, the team has to infer what's happening. Combining the imagery with terrestrial geology, the team connected surface features to deeper ice structures.

Planetary scientist Frances Butcher (University of Sheffield, UK) praised the "fantastic resource" for future crewed missions. "But this is not going to be the final map before we go to Mars," she adds. At the moment, the average resolution of the SWIM map is 3 kilometers (1.8 miles) — not quite fine enough to guide a mission.



▲ The map points to Arcadia Planitia and the glaciers across Deuteronilus Mensae as promising ice-bearing locations for future missions.

To that end, NASA is developing the International Mars Ice Mapper in collaboration with space agencies in Canada, Japan, and Italy. The mission's aim is to map the depth, extent, and abundance of water ice in more detail.

■ ARWEN RIMMER

MILKY WAY

Explaining the Alignment of Our Galaxy's Entourage

DOZENS OF DWARF GALAXIES orbit our own, and unlike around many other Milky Way-like galaxies, many of these satellites are aligned along a thin plane, like slices of pepperoni stuck on a thrown disc of pizza dough.

While this alignment is unexpected, a detailed look at the formation of galaxies and their dwarf entourages, to appear in the *Monthly Notices of the Royal Astronomical Society*, suggests that such satellite planes are not as rare as previously thought.

Graduate student Jenna Samuel (University of California, Davis) and colleagues used the Feedback in Realistic Environments (FIRE) computer simulation to see how rare such an alignment would be. They measured the distribution of satellites around a set of Milky Way-like galaxies and found that 1–2% of these systems had satellites that fell along planes as thin as our own. In other words, the phenomenon is unusual but not outside the realm of possibility.

Most of those simulated structures were short-lived, though — they typically lasted less than 500 million years. On the other hand, some think the Milky Way's sheet of satellites could last up to a billion years.

Then again, our galaxy's satellite group is noteworthy, dominated as it is by the Large Magellanic Cloud (LMC), a dwarf galaxy with about a tenth of the Milky Way's mass (see page 20). So, Samuel looked at the simulations again, this time only selecting systems with a giant dwarf in their midst. She found that thin satellite planes were more common in these systems, occurring 7 to 16% of the time. They also lasted much longer, with lifetimes up to 3 billion years.

◀ The FIRE simulations make galaxies similar to the Milky Way, like the one pictured here.

The LMC might be bringing in some of its own satellites, but Samuel also thinks that the LMC's presence had an impact on the orbits of dwarf galaxies already around or coming in toward the Milky Way.

"The LMC plays a major role in the origin of the Milky Way's plane of satellites," agrees Gurtina Besla (University of Arizona), who was not involved in the study. But she adds that astronomers still need to iron out the detailed physics of the LMC's effect on the Milky Way system.

■ MONICA YOUNG

View a 3D map of the Milky Way system at https://is.gd/planeofsatellites.

MAP OF WATER ICE ON MARS: MORGAN ET AL. / *NATURE ASTRONOMY* 2021 FEB. 8; SIMULATED GALAXY: LATTE PROJECT

GALAXIES

Amateur Astronomers Reveal Galactic Echoes

IN A PROMISING proof of concept, a professional astronomer has teamed up with five amateurs to capture the echoes of long-ago mergers ringing nearby galaxies. The team is now looking to expand their number of galaxies — and observers.

Duilia de Mello (Catholic University of America) is leading the Deep Images of Mergers (DIM) project to capture the faint shells of stars on the outskirts of a class of galaxies thought to have had a merger in their past. The shells are likely the remains of a less massive galaxy disrupted during the collision.

To test this idea, de Mello, who is from Brazil herself, engaged five Brazilian amateurs — Marcelo Wagner Silva Domingues, Cristóvão Jacques Lage de Faria, João Antônio Mattei, Eduardo de Jesus Oliveira, and Sérgio José Gonçalves da Silva — to observe such galaxies, including Centaurus A and Arp 230.

▲ The DIM team's image of Centaurus A (*left*) reveals shells of stars after processing (*right*).

Centaurus A was the proof of concept: The Victor M. Blanco 4-meter telescope at the Cerro Tololo Inter-American Observatory in Chile had made deep observations of the dusty edge-on galaxy 13 million light-years away. With more than 40 hours of combined integration time, the team was able to reveal the stellar shells the professional telescope had seen previously.

The team then turned to Arp 230, a galaxy about five times farther away. Serendipitously, this galaxy turned out to have Hubble observations, but the team selected it for the large amounts of neutral hydrogen gas along its edges, probably knocked loose during a long-ago merger. With 10 hours of integration, the team revealed four shells that Hubble had also detected — and possibly something more.

"We have hints of another outer shell not seen in the Hubble image, but it needs to be confirmed with deeper images," de Mello says.

De Mello presented the preliminary results at the January meeting of the American Astronomical Society. If you're interested in contributing observations to the team, learn more and sign up at **https://is.gd/DIMproam**.

■ MONICA YOUNG

IN BRIEF

Star Cluster Has Black-hole-filled Center

The globular cluster NGC 6397 packs more than 100,000 stars into a ball a few dozen light-years across. Its crowded center is a prime location for an intermediate-mass black hole (IMBH) with at least 100 times the Sun's mass. Eduardo Vitral and Gary Mamon (both at the Institute of Astrophysics of Paris) sought to detect an IMBH hiding in the cluster's core by analyzing the stars' motions. But there wasn't just one black hole in the middle — there were several. The "dark mass" extends to a few percent of the size of the cluster, Vitral explains. While some of that might be white dwarfs and neutron stars, the astronomers calculate that most is stellar-mass black holes. The results appear in February's *Astronomy & Astrophysics*.

■ MONICA YOUNG

First Black Hole Upsized

Discovered in 1964, Cygnus X-1 is the first-known black hole orbiting a supergiant companion. Now, new observations reported in the February 18th *Science* suggest it's even more massive than originally thought: 21 solar masses rather than 15. While previous radio parallax measurements had shown Cygnus X-1 to be 6,000 light-years away, James Miller-Jones (International Centre for Radio Astronomy Research-Curtin University, Australia) and colleagues used the Very Long Baseline Array to fine-tune parallax measurements conducted over a seven-year baseline, putting Cygnus X-1 at more than 7,000 light-years away. So the black hole must be more massive to power the same amount of radiation. The larger mass suggests that the star — which astronomers already thought directly collapsed into a black hole, sans supernova — lost even less bulk than thought via stellar winds toward the end of its life.

■ JULIE FREYDLIN

Farfarout Orbit Confirmed

Astronomers have confirmed the most distant object in the solar system: a 400-km rock nicknamed "Farfarout." The team — Chad Trujillo (Northern Arizona University), Scott Sheppard (Carnegie Institution for Science), and David Tholen (University of Hawai'i) — found the object in January 2018, following their discovery of the previous record-holder, dubbed "Farout." With additional observations they have confirmed Farfarout's orbit and thus its distance; it's now provisionally designated as 2018 AG_{37}. And it really is far, far out at 132 astronomical units (a.u.) from the Sun, nearly four times farther away than Pluto. The orbit is elongated, though, so while Farfarout travels out to 175 a.u., it also comes in as close as 27 a.u., inside Neptune's orbit. Its trajectory suggests a past gravitational tussle with Neptune; the two may interact again in the future.

■ MONICA YOUNG

DUILIA DE MELLO / DIM TEAM

Astronomers have detected signs of icy interlopers around faraway stars.

Last summer, people around the world admired the view of Comet NEOWISE (C/2020 F3). In fall, many looked up for Leonid meteors, the dust from Comet 55P/Tempel-Tuttle. Do stargazers in other stellar systems enjoy similar views? Do the tails of comets adorn their alien skies with trails?

As far as we can tell, the answer is yes.

True, we don't know whether alien stargazers actually exist. But we do know that alien comets exist. These *exocomets* are much like the comets in our solar system: small celestial bodies that orbit stars and release gas and dust, mostly through sublimation when they get close to the stars and heat up. Astronomers currently know of exocomets roaming around four stars, and they've seen hints in the light of more than two dozen additional stars and white dwarfs.

We think that exocomets form the same way comets do — in the outer expanses of protoplanetary disks, where it is cold enough for volatile materials to freeze and cluster into kilometer-size bodies. From there, the gravitational effects of massive planets may tug them towards their star. Some will end up traveling in loops around the star, but others will set off into interstellar space. Two such expelled nomads recently made our acquaintance: 1I/'Oumuamua nearly snuck by us in 2017, and 2I/Borisov appeared in 2019.

ALIEN Come

▲ **COMET STORM** This artist's concept shows sublimating icy bodies in the Beta Pictoris system. Beta Pic is the most striking of several star systems with signs of exocomet companions.

ESO / L. CALÇADA

Astronomers detect celestial rovers around other stars mainly using two methods: photometry, which reveals the decrease in the light of the host star as exocomets pass between it and Earth, and spectroscopy, which picks up the selective absorption of the light in the star's spectrum by the exocomets' elements and molecules.

Transit photometry is also one of the main tools for finding exoplanets — used, for example, by the Kepler space telescope. However, unlike with exoplanets, the drop in light because of an exocomet is distinctively asymmetric: It resembles an upside-down shark fin. First comes a sharp decrease, when the head of the comet obscures the light, explains Paul Strøm (University of Warwick, UK). Then as the tenuous dust tail passes across the star's disk, the starlight gradually increases again, as more and more light shines through.

As for spectroscopy, the gas in the coma and tail absorbs specific wavelengths of light, leaving its fingerprint in the star's spectrum. The features of the missing lines change within a timescale of hours, implying that whatever is absorbing the light is moving fast. The absorption also repeats regularly, meaning that what causes it orbits the star, sometimes with periods as short as a few days or even hours.

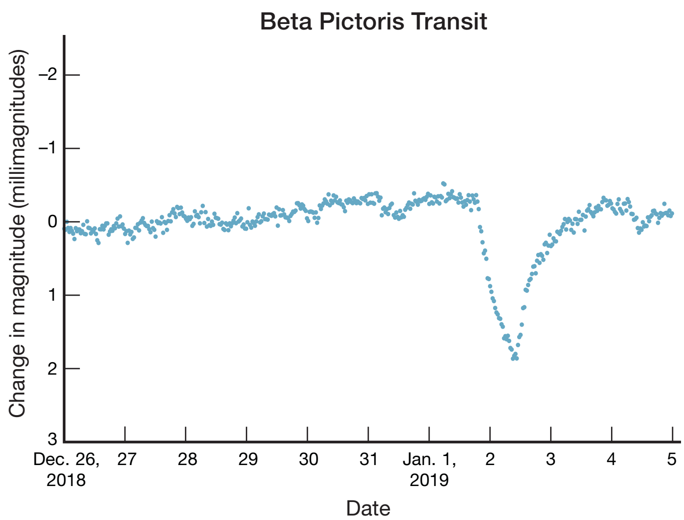
Using these two detection methods, astronomers have found exocomets flying around four stars lying within sev-

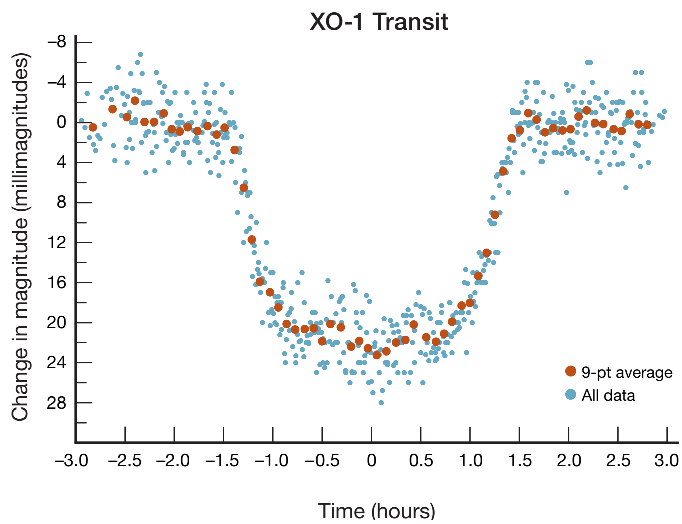
eral hundred light-years of the Sun. The real “star” among these is Beta Pictoris, in the southern constellation of Pictor, the Painter. Its system is both the first in which astronomers saw signs of exocomet activity (back in the late 1980s) and the one with the largest number of observations by far: In the last decade, researchers have recorded hundreds of passages annually.

Strøm explains that this star is special for many reasons. “First of all, it is bright. Very bright. If you are in the Southern Hemisphere you can see it with the naked eye, even in polluted skies. This ensures the best signals, as we collect more light.” In addition, Beta Pic has a sizable debris disk, and we see it nearly edge-on, meaning that bodies orbiting the star pass across our line of sight, and we're more likely to spot them. The star even has two giant planets, which likely cause a lot of exocometary orbits to change, slinging some exocomets in towards the star.

Conclusive Exocomet Systems

Name	Spectral Type	Primary Detection Technique	Distance (ly)
49 Cetus	*A*1V	Spectroscopy	186
β Pictoris	*A*6V	Spectroscopy	64
HD 172555	*A*7V	Spectroscopy	92
KIC 3542116	*F*2V	Photometry	749





▲ **UNUSUAL TRANSIT** This sawtooth-shaped dip *(left)* is one of three exocomet transits spotted in the light curve from Beta Pictoris. (The light curve is a cleaned-up version of the data, with the star's pulsations removed.) The shape is unlike exoplanet transits, which are often round- or flat-bottomed dips, as shown here in this light curve from amateur Bruce Gary of the Jupiter-mass XO-1b transiting its star *(right)*.

The majority of exocomet observations in Beta Pictoris are spectroscopic. But the bright star makes for a good backdrop for smaller telescopes, and in 2019, astronomers also found three exocomets via the dimming of its light. Graduate student Sebastian Zieba (now Max Planck Institute for Astronomy, Germany) came across the "shark fins" in the data of NASA's Transiting Exoplanet Survey Satellite (TESS) while studying the star's pulsations. He found dips in the star's brightness that he couldn't explain with its regular pulsations — which happen on a timescale of about half an hour — or with any other common cause. Instead, the signals were remarkably similar to models of exocomets published 20 years earlier.

The other three conclusive cases are 49 Cetus, HD 172555 in Pavo, and KIC 3542116 in Lyra. Along with Beta Pic, all are either *A*- or *F*-type stars, significantly hotter and brighter than the Sun. And all four, as well as almost all of the stars that show serious hints of exocomet companions (29, including one binary), are also remarkably young. Beta Pic, for example, is only about 23 million years old, so there is still a lot of debris left over from its planet-forming disk. Similar debris might explain the exocomets in other systems.

Astronomers have detected elements such as calcium, aluminum, carbon, and iron in exocomet systems.

But some exocomets seem to circle celestial objects that are definitely not young: white dwarfs, the moderate-size cores of extinguished stars. Their much smaller surface areas mean a passing exocomet can block a higher fraction of starlight, creating larger dips in their light curves. Astronomers have seen such sawtooth features in the light from two white dwarfs, WD 1145+017 and ZTF J0139+5245. They've also seen telltale elements that are not supposed to exist in white dwarfs' atmospheres, such as on WD 1425+540, which is polluted with material similar to that which surrounds Halley's Comet. Such debris might come from exocomets or rocky bodies, either falling onto or grazing a white dwarf.

Distant Spectacles

Astronomers can't image exocomets directly, but they think the observed ones are much larger than solar system comets, given how much light they absorb. The cores may be tens to hundreds of kilometers wide, similar to large asteroids in the solar system — although some detections may be swarms of exocomets traveling together, not single bodies.

Their tails would be correspondingly massive, and in the Beta Pictoris system, "surely they would be magnificent," says Flavien Kiefer (Paris Observatory). "The light flux from the star is ten times stronger than the Sun. Thus, evaporation is at least ten times more efficient at the surface of the Beta Pictoris exocomet nuclei, and the radiation pressure would push atoms and dust [out to] much larger distances."

Astronomers have detected elements such as calcium, aluminum, carbon, and iron in exocomet systems, although they cannot yet say for sure how the chemical ratios compare to those of solar system comets. A marked difference, says Kiefer, is that in exocomets, astronomers have yet to find traces of water, whereas water is one of the main constituents of solar system comet ices.

"But water is more difficult to observe," he cautions, "because it is more fragile and rapidly disintegrates into hydrogen and oxygen atoms." Understanding exocomets' compositions will help astronomers investigate which compounds are forming in planetary systems and how they're

EXOCOMET TRANSIT: S. ZIEBA; EXOPLANET TRANSIT: BRUCE GARY

mixing together, processes that also mattered in making Earth what it is (*S&T:* Dec. 2020, p. 34).

On the Horizon

The number of exocomet systems will continue to increase, although many finds will arrive serendipitously, thanks to other research. Exocomet hunting doesn't need a dedicated facility, explains Stefanie Milam (NASA Goddard Space Flight Center). Observations so far have come from ground-based telescopes, like the Atacama Large Millimeter/submillimeter Array and the Herschel Space Telescope for studies of debris disks, but also notably from the orbiting TESS and its predecessor, Kepler. Kiefer envisions that the millions of light curves expected from TESS could even enable the public to join the discovery process through crowdsourced science, since the human eye is better than current AI at detecting the unique exocomet features.

In spectroscopy, many of the current composition measurements are at far-ultraviolet wavelengths, but the only instrument currently scanning that part of the spectrum is the Hubble Space Telescope. Its successor, the James Webb Space Telescope, will focus on infrared wavelengths, and "comets around other stars are not ideal for it in general, due to the unknown timing of these events," says Milam.

To increase the number of confirmed systems, astronomers need an ultraviolet-sensitive mission like the proposed LUVOIR space telescope, says Sharon Montgomery (Clarion University). If funding were no object, she would add a second proposed mission: the Origins Space Telescope, which would look instead in the mid- and far-infrared — much farther than JWST will — and could spot cold water in planetary systems. Both mission concepts are competing for support in astronomers' soon-to-be-released roadmap for the next decade of project development.

The millions of light curves expected from TESS could even enable the public to join the discovery process through crowdsourced science.

Meanwhile, when visitors come again to the solar system, we might make more out of it through a bold plan. In the late 2020s, the European Space Agency plans to launch the Comet Interceptor mission, which will wait beyond the Moon's orbit until astronomers spot a newly discovered body approaching the Sun and then fly to meet it. Deputy principal investigator Colin Snodgrass (University of Edinburgh, UK) says that the objective is to "visit a really pristine comet from the dawn of the solar system," unaltered by encounters with the Sun. With a lot of luck, the newfound object could be an interstellar visitor; if this happens, he adds, it would be a fascinating opportunity to see something from another star up close.

With our preliminary knowledge about exocomets crystallizing and more data expected, the era of these impressive celestial objects is dawning. The short list of star systems suspected to contain exocomets will expand, fueling astronomers' interest. "We are getting to watch these star systems as they grow their planets and seed those planets with volatiles necessary for life," Montgomery says. "So this will remain great fun for many of us."

A particle physicist by training, **ELENI PETRAKOU** now works as a data scientist and writer. Find more about her work at **chapette.net**.

Read the detailed report from the 2019 exocomet workshop at Leiden University: arxiv.org/abs/2007.09155.

BORISOV

The interstellar visitor 2I/Borisov — shown here in a Hubble image from December 9, 2019 — contained at least 150% more carbon monoxide ice than water ice. That's a stark contrast to solar system comets, for which the ratio is typically around 4%. Astronomers speculate that the object might have formed around a much cooler star or in the outer regions of its star's planet-forming disk, where temperatures were cold enough for CO ice to form abundantly.

NASA / ESA / D. JEWITT (UCLA)

 by Anthony Mallama & Monica Young

BEYOND STARLINK:

The Satellite Saga Cont

SpaceX has engaged astronomers and made improvements, but with other companies set to launch their own satellite fleets, goodwill is not enough.

DKTUE / WIKIMEDIA COMMONS / CC0 1.0

The first launch of 60 Starlink satellites aboard a SpaceX Falcon 9 rocket alarmed many, from amateur and professional astronomers to dark-sky advocates and space debris experts (*S&T:* Mar. 2020, p. 14). And for good reason: That batch was only the first volley. SpaceX has now lofted more than 1,100 satellites into low-Earth orbit with the aim of providing high-speed broadband internet to hard-to-reach places around the world. Initial plans call for a "constellation" of 1,584 Starlinks, but ultimately the company intends to fill out a network of as many as 42,000 spacecraft.

SpaceX is the leader of a growing pack when it comes to large satellite constellations. UK's OneWeb, which has launched 74 satellites so far, has approval for 6,372 satellites in all. Amazon's Project Kuiper has likewise filed and received approval for 6,236 satellites. Other companies and countries are getting in the game, too. China, for example, recently

inues

GOING GLOBAL
A train of Starlink satellites still raising their orbits flies over the town hall in Tübingen, Germany.

filed with the International Telecommunication Union to fly 12,992 satellites.

Even as SpaceX has led the charge into this new industry, the company has also led the way in engaging with astronomers and voluntarily reducing its impact on astronomy. At the virtual 237th meeting of the American Astronomical Society (AAS) in January, SpaceX representative Patricia Cooper presented improvements to the original Starlink design, using a radio-transparent shade to prevent much of the incident sunlight from reflecting to observers on the ground.

The first so-called VisorSat launched on June 4, 2020, and it follows an earlier attempt at mitigation that painted parts of a Starlink satellite black. (This "DarkSat" resulted in thermal issues and was discontinued.) Since August 7, 2020, all Starlink satellites have been VisorSats. SpaceX also altered the relative orientation of the satellite bodies and their solar arrays with respect to the Sun, in order to further diminish their reflectivity. The software changes enacting these adjustments were uploaded to all operational satellites.

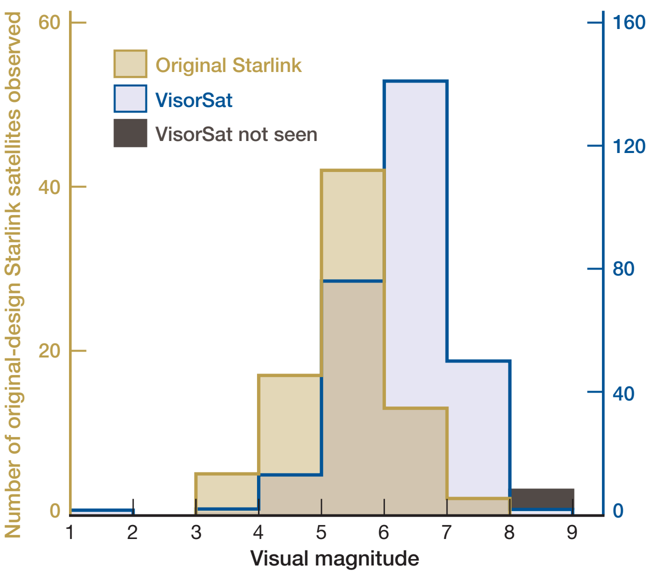
Despite these recent developments, though, the growing number of satellites still deeply troubles astronomers. First, while the mitigations resulted in significant improvement, even the VisorSat design isn't completely unobtrusive to stargazers. And even if SpaceX continues to iterate on that design, there's no legal reason for other companies to follow suit.

VisorSat Is Dimmer . . . But Is It Enough?

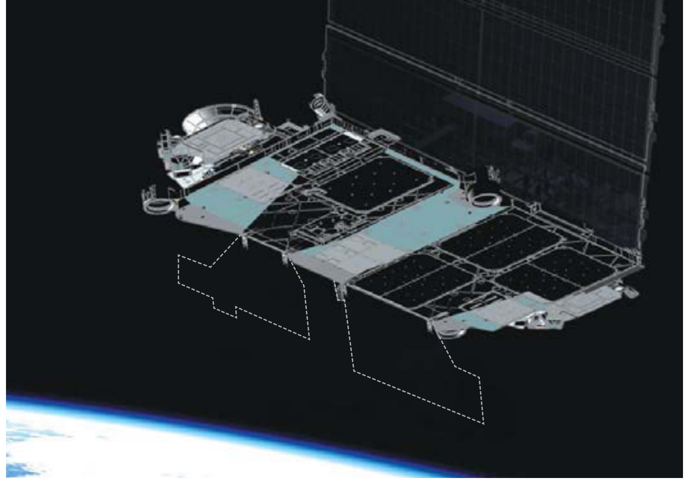
One of us (Anthony Mallama) has studied more than 1,000 observations of original-design and VisorSat satellites in order to compare their brightness at operational altitude (550 kilometers, or 340 miles). The data include visual estimates by Anthony and Jay Respler, both members of the SeeSat-L group of observers, who compared passing satellites to nearby reference stars of known magnitudes. Photometric measurements from a robotic observatory in Russia called Mini-MegaTORTORA (MMT) provide a close match to the eyeball estimates.

To compare the two designs, Anthony first corrected the magnitudes for where the satellite is in the sky. Starlink satellites are nearest, and thus brightest, when passing directly overhead, while those observed toward the horizon are farther away and correspondingly fainter. Anthony adjusted all observed magnitudes to the apparent brightness that would be measured at zenith.

The average magnitude of the original Starlinks is 4.63, making them visible under even moderately light-polluted skies. Conversely, the average VisorSat magnitude is a third of that brightness, at magnitude 5.92 — significantly fainter but still visible from dark, rural skies.



▲ **DIMMING THE LIGHTS** The distribution of visual magnitudes for VisorSats is shown in blue. These satellites are generally fainter than original-design Starlinks, indicated by the beige bars, though the brightness varies due to the spacecrafts' complex reflectivity. A few satellites were too faint to be seen (dark gray) and were assigned magnitude 8.5.



▲ **STARLINK SUNSHADE** This artist's concept of the VisorSat design shows the deployable visor that shades the antennas from sunlight. The visor is transparent to radio frequencies.

There's some variation, though. The brightness of a Starlink satellite can range from roughly 5th magnitude to 7th, likely due to the complicated reflecting properties of these satellites' many surfaces. Thus, an observer under dark skies will see some VisorSats while others will pass by unnoticed.

Based solely on the MMT data, astronomer Patrick Seitzer (University of Michigan, Ann Arbor) estimates that SpaceX's mitigations have dimmed the VisorSats a bit more, to about a quarter of the original design's brightness. But even this result is still brighter than the 7th-magnitude limit recommended by the AAS. That limit is designed in part to put all satellites out of range of unaided eyes.

"The 7th-magnitude brightness target is enormously helpful," Cooper said at January's AAS meeting. "Now we have something to drive toward." At the same time, though, she suggested there might be a limit to what the company can do. "We're going to come to a point of — not the end of creative brainstorming, but some lead prospects that we want to put more effort and emphasis on," she added.

Even if satellite operators meet that limit, though, it won't solve the problem for professional astronomers. The Vera C. Rubin Observatory's chief scientist, J. Anthony Tyson (University of California, Davis), pointed out in the same AAS session that a 7th-magnitude Starlink streaking across the observatory's wide-field camera would still be 40 million times brighter than a typical galaxy in the image.

In a single exposure, astronomers can't apply simple rejection algorithms, such as those that suffice to clean stacked astrophotos. And at that level of sensitivity, a bright-enough satellite creates electronic "ghosts" throughout the image, he explained. While astronomers can remove the ghosts if the satellite streak is fainter than magnitude 7, they can't excise the trail itself. "There's an impact there that's difficult to mitigate," Tyson said.

Beyond Starlink

The 7th-magnitude recommendation came as part of the Satellite Constellations 1 workshop, which took place virtually from June 29 to July 2, 2020. Besides SpaceX, other participants included OneWeb and Amazon's Project Kuiper

VISORSAT: SPACEX; MAGNITUDE COMPARISON: ANTHONY MALLAMA

as well as professional and amateur astronomers and dark-sky advocates. They worked together to assemble guidelines for both satellite and telescope operators to mitigate the threat that numerous, bright satellites pose to astronomy, wide-field astrophotography, and stargazers.

In addition to the blanket 7th-magnitude limit, the group also proposed an altitude-dependent brightness limit (starting with 7th magnitude for satellites at 550 km) and recommended that satellites fly no higher than 600 km.

OneWeb's satellites are above that limit, at 1,200 km. They're correspondingly fainter than Starlinks at first glance, with a median magnitude of 7.9. But due to their greater distance, OneWeb satellites travel at slower speeds and therefore appear more in focus to telescopes. According to Tyson, the surface brightness of a 7.9-magnitude, 1,200-km OneWeb satellite streaking across an image is actually the same as a 7th-magnitude Starlink satellite at 500 km.

What's more, OneWeb's higher altitude means a significant fraction of these satellites will remain visible throughout the entire night during summer months. Lower altitudes are therefore actually beneficial to professional astronomy, as they guarantee at least some unobstructed hours.

Despite the recommendation, OneWeb is unlikely to change altitude: It already has approval from the Federal Communications Commission to fly there. The company did, however, significantly reduce the total number of satellites it plans to launch, in part due to new ownership under the UK government following a Chapter 11 reorganization.

Besides OneWeb and Project Kuiper, which together with SpaceX could launch a combined tally of 54,000 satellites, smaller companies are also looking to edge in on the market. "We have dealt primarily with the big three constellations," Seitzer said. "But sliding under the telescope cover, so to speak, there are many smaller constellations of 30 to 50 satellites. My concern is that we will get blindsided by them as their numbers grow and grow and grow."

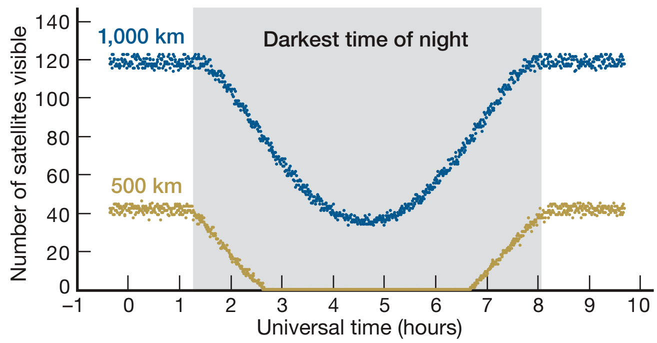
Astronomers and even satellite operators agree that depending on the goodwill of individual companies will not suffice in the long term. International regulations will be key, in part to prevent companies from moving operations to countries with more lax restrictions.

To that end, Connie Walker (NSF's NOIRLab) and colleagues have recently written up a report to be submitted to the United Nations Committee on the Peaceful Uses of Outer Space, outlining recommendations to protect dark skies and including guidelines for satellite operators. The UN is not a regulatory body, so if the plan is ultimately approved, it would then go to member nations for policy and enforcement.

While academia, federal agencies, and international bodies move along at an "Entish" pace, as panel participant Aparna Venkatesan (University of San Francisco) put it for Tolkien fans, the satellite-constellation industry continues to develop at a fast clip. SpaceX aims to provide near-global coverage by the end of the year, and OneWeb plans to have its first-generation network of 648 satellites aloft by mid-2022.

Also in 2022, the Rubin Observatory is due to start full operations, beginning the observations intended to generate a decade-long movie of the night sky. But it will have to do so while dealing with satellites too numerous to dodge and as yet too bright to completely remove from observations.

At the AAS session, Tyson took umbrage at the idea that observatories can take actions now to protect themselves in the future as near-Earth space becomes more crowded. "This notion of future-proofing is a charming idea," he said. "But very frankly, we did a lot of simulations and found that there is no combination of mitigations that we know of that can correct for the lost science — particularly the discovery of the unexpected."



▲ **NIGHTTIME VISIBILITY** This illustrative plot shows satellites' visibility throughout a summer night at 30° latitude depending on their distance above Earth's surface. At each altitude, the calculations divide 10,000 satellites amongst 100 orbital planes with orbital inclinations of 53°. Observed altitudes are assumed greater than 30°. The gray area marks when the night is darkest, between the hours of astronomical twilight.

■ **ANTHONY MALLAMA** is a retired astronomer working with the American Astronomical Society to measure satellite brightness. **MONICA YOUNG** is *Sky & Telescope*'s news editor.

▶ **UNDER CONSTRUCTION** The Telescope Mount Assembly has been assembled inside the Vera Rubin Observatory in Cerro Pachón, Chile. A sliver of blue sky peeks through the dome above.

VISIBILITY COMPARISON: PATRICK SEITZER (UNIVERSITY OF MICHIGAN, ANN ARBOR); VERA RUBIN OBSERVATORY: RUBIN OBSERVATORY / NSF / AURA

 by Nola Taylor Redd

The Magellanic

The Large Magellanic Cloud is a fuzzy smear in the Southern Hemisphere sky, a target for early humanity's myths. Over time, astronomers determined that it and its companion, the Small Magellanic Cloud, were two separate, smaller galaxies near the Milky Way. By the 1990s, they thought that the pair had spent several billion years making loops around our galaxy.

But in the last decade or so, we've realized that this, too, is likely a myth. Our understanding of these neighboring galaxies has undergone a revolution, one that has changed not only what we thought we knew about the Magellanic Clouds but also about our very own Milky Way.

Although not a large galaxy, the Large Magellanic Cloud (LMC) shows signs of structure. It has at least one spiral arm, but interactions with its neighbors have deformed the galaxy, creating a more irregular object. It and its partner are also the only star-forming satellites of the Milky Way.

In 2006, Nitya Kallivayalil (now University of Virginia)

P. HORÁLEK / ESO

GALACTIC TAGALONGS? The Milky Way arches above Paranal Observatory in Chile, accompanied by the Large and Small Magellanic Clouds (fuzzy objects at center, below galactic disk). The view is deceptive: Recent research has revealed that the Large Magellanic Cloud is more massive and more influential on our galaxy than previously thought.

Giant

A combination of new data and tenacity has upended our understanding of the Milky Way's largest companion.

and others used new data from the Hubble Space Telescope to calculate how fast the LMC was moving by tracing its path across several background quasars over the course of four years. To their surprise, they found that the galaxy was not lazily falling toward the Milky Way — it was rushing past it. A year later, Gurtina Besla (now University of Arizona), Kallivayalil, and their collaborators combined the observations with simulations to argue that the LMC was likely falling toward us for the first time, rather than making its fifth or six passage, as previously supposed (*S&T:* Oct. 2012, p. 28). Later work also suggested that the LMC must be far more massive than scientists had long believed.

A heftier cloud should do more damage to the Milky Way;

Say What?
perigalacticon: the closest approach to a galaxy

after all, at just over 160,000 light-years away, the LMC is already inside our galactic borders. The revision did not bode well for our galaxy.

Although scientists were initially reluctant to completely revise their understanding of the LMC's history, research over the past decade is proving Kallivayalil and Besla's interpretation correct.

"So many parts are coming together," says Besla. "It's a global effort."

Not Boring After All

The finding that the LMC was a new neighbor to the Milky Way made waves in the community. But initial studies were insufficient to cause most researchers to abandon the multiple-passage argument. At times, Besla felt at odds with the community, giving talks at conferences where people told her later that her conclusions were wrong.

"I've been yelling about this for a really long time," she says.

Understanding the situation has been stymied by the fact that such a giant companion is hard to find among galaxies. Observations indicate that only 12% of Milky Way–like galaxies have an LMC-like companion at a similar distance. The new models suggest that the LMC made its closest approach to the Milky Way roughly 50 million years ago, an eyeblink in astronomical time. Such close LMC-like neighbors are hard to spot. Those with an additional companion like the Small Magellanic Cloud are even rarer, and less than 1% of Milky Way–LMC/SMC analogs lie as close together as our pair.

12%
Fraction of Milky Way–mass galaxies with a companion of similar mass and proximity as the Large Magellanic Cloud

Besla and other scientists who study the Local Group — the collection of the Milky Way and its neighbors — realized that a new arrival would also be more massive and thus have a completely different effect on the region than a smaller, ancient companion.

Astronomers had assumed that frequent passages around the Milky Way would have stripped the LMC of its dark matter, leaving a galaxy dominated by visible stars and gas. "The classic picture was that the LMC was not massive enough to affect the stellar disk," says Jorge Peñarrubia (University of Edinburgh, UK). But if the LMC is coming in for the first time, then it should still have the bulk of its initial dark matter, with a correspondingly stronger gravitational effect on our galaxy.

A more massive LMC would also merge faster with the Milky Way — too fast to still be around today if it had made multiple passes already. So if astronomers could measure the mass and confirm that it's as high as theorists inferred, then they would know the galaxy is a newcomer.

All of this has contributed to a major rethink of our galactic neighborhood. "I remember when I was doing my PhD, people thought the Milky Way was a really boring place. Nothing had happened in the last 10 billion years," says Peñarrubia. "We're now realizing that was completely and absolutely wrong."

Some of his colleagues actually laughed in surprise at the results.

Weighing Galaxies

One of the first important steps was to confirm the LMC's predicted higher mass. But there is no scale large enough to weigh a galaxy. Counting stars is insufficient, because most of a galaxy's mass is hidden in its dark matter halo.

Instead, astronomers must measure how galaxies interact with each other and other objects to determine their mass: The orbital speed of two objects depends on their relative masses. So astronomers turned to the skies to "weigh" the LMC.

In 2016, Peñarrubia worked with Besla and others to model 35 nearby galaxies, along with the LMC and the Milky Way, to help nail down the dwarf galaxy's mass. The results suggested that the LMC was 250 billion times the mass of the Sun, roughly a fourth the size of the Milky Way. This value lay within the error bars suggested in earlier theoretical work and was 10 times higher than estimated in previous decades.

Some of his colleagues actually laughed in surprise at the results, Peñarrubia says. "They thought it was crazy that the LMC was so massive."

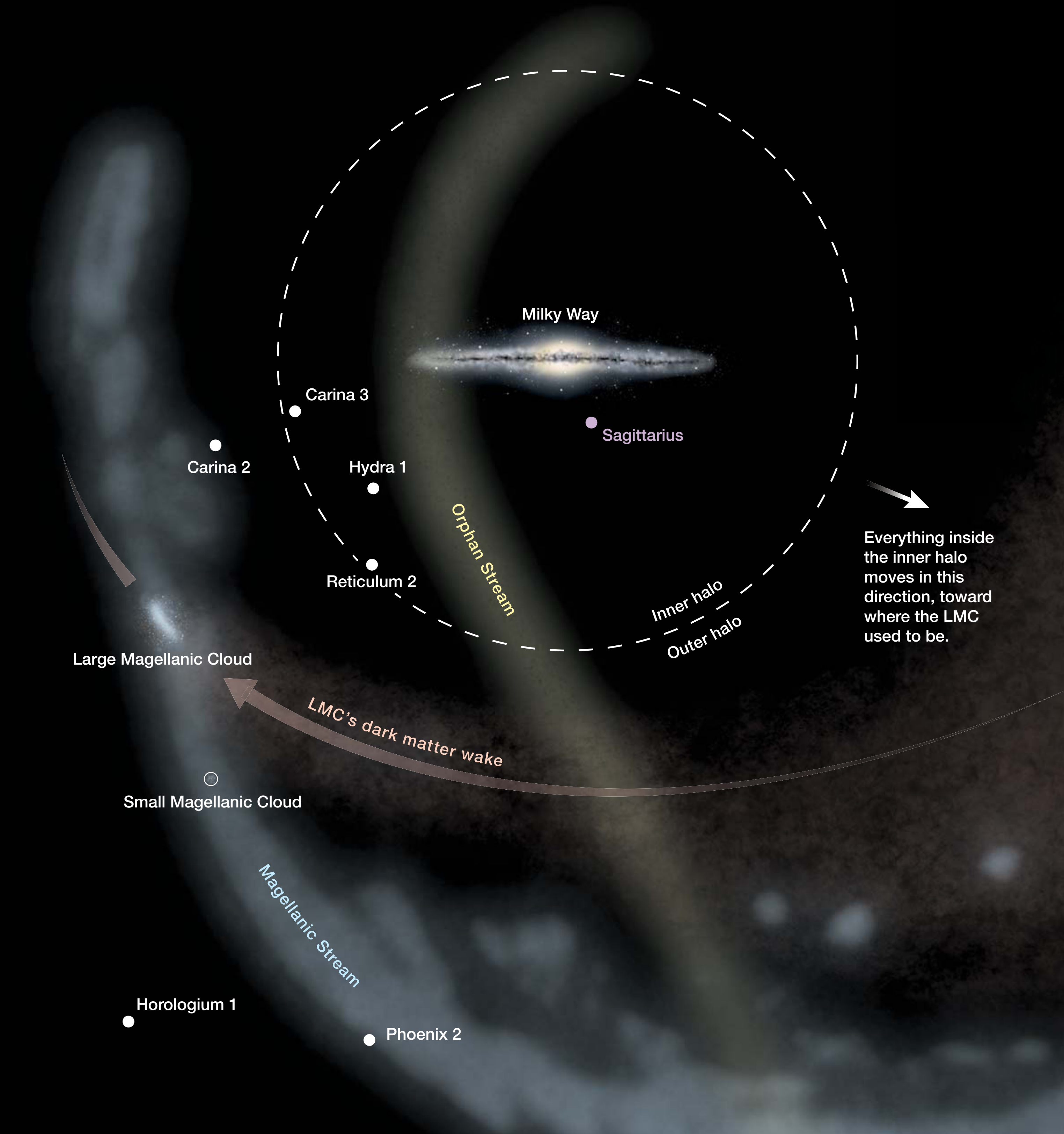
But Peñarrubia himself wasn't shocked — before the 2016 results, he says he was "agnostic" when he heard Besla's initial results. What convinced him was the realization that a larger LMC solved another problem that Local Group researchers had long struggled with. Historical measurements using similar methods had suggested that the Andromeda Galaxy was as much as three times larger than the Milky Way, but Peñarrubia says he was always wary of so much hidden mass having to be in Andromeda. Given the interactions among the three objects, a larger LMC suggests that Andromeda is closer in size to the Milky Way, a finding later supported with independent observations.

"It was another sign that the LMC was having a big effect," says coauthor Denis Erkal (University of Surrey, UK) about the 2016 mass measurement. "I think the community took a while to warm up to [a large LMC] because there wasn't a smoking gun."

Erkal himself managed to help change that.

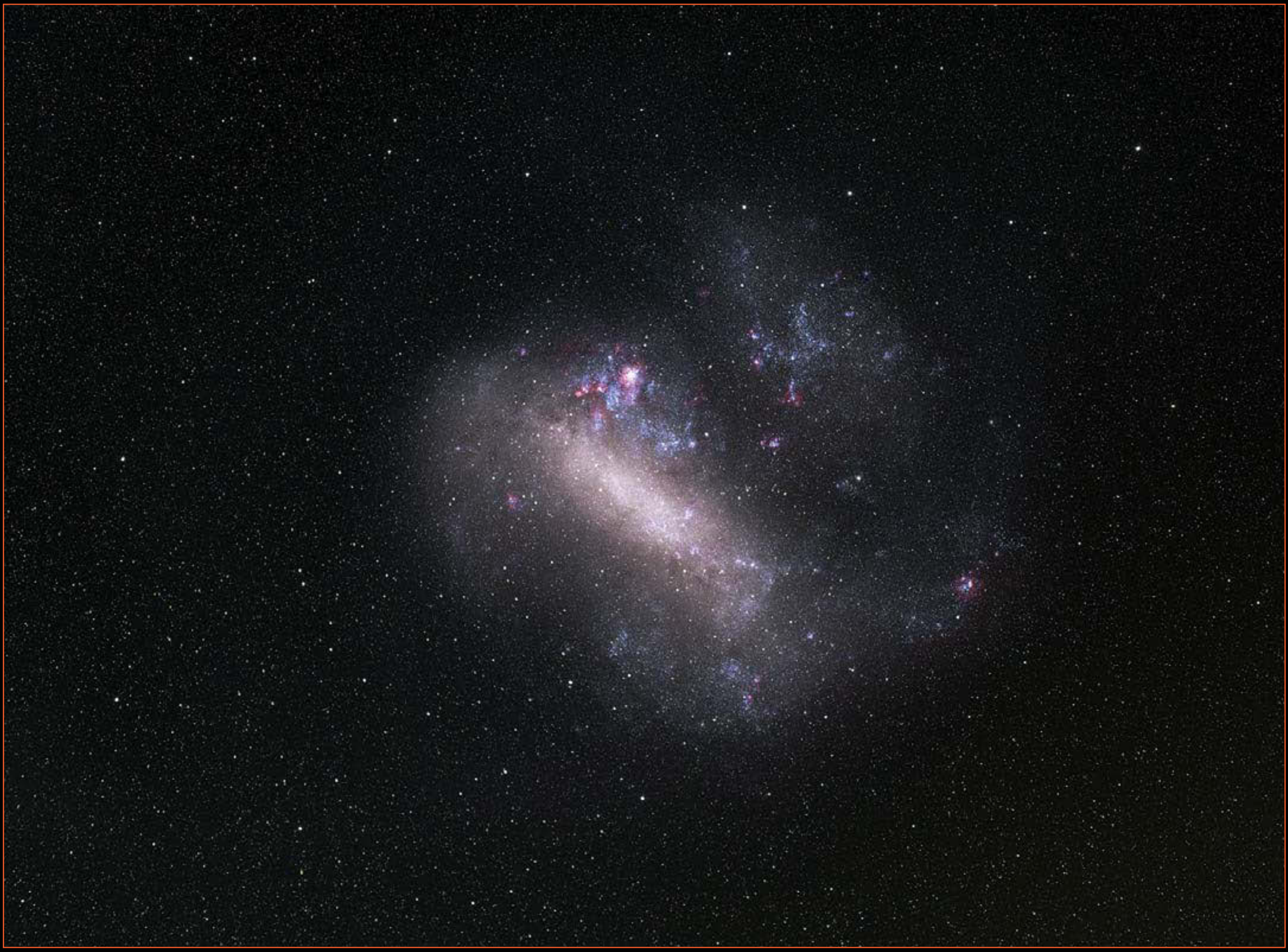
"Smoking Gun"

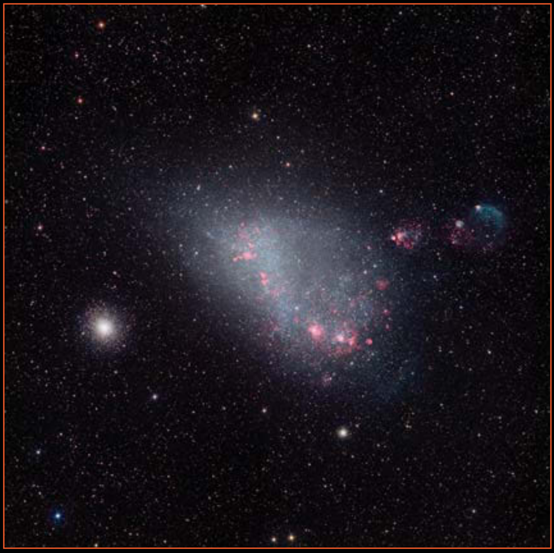
The Milky Way is surrounded by thin lines of stars that are remnants of destruction. As smaller galaxies move closer to the Milky Way, their stars and gas are stretched into long "strings of pearls" by the more massive giant. These stellar



GALACTIC ENCOUNTER As the Large Magellanic Cloud makes its first pass by the Milky Way, it's carrying along with it several satellites (white dots), including the Small Magellanic Cloud, out of which it has torn a rivulet of gas called the Magellanic Stream. The LMC has also put a kink in stellar debris streams (including the Orphan Stream, shown), left a wake in the Milky Way's dark matter halo, and even pulled the Milky Way itself off-center. The Sagittarius Stream comes out of the page from this perspective. Diagram is approximately to scale.

GREGG DINDERMAN / S&T, SOURCES: GURTINA BESLA, N. GARAVITO-CAMARGO ET AL. / ARXIV 2010.00816, PUTNAM ET AL. / *ARAA* 2012, D. ERKAL ET AL. / *MNRAS* 2019, M. S. PETERSEN & J. PENARRUBIA / *NATURE ASTR.* 2020





▲ **GIANT DWARF** The Large Magellanic Cloud has a clear central bar and one of the most prolific star-forming regions in the Milky Way system: the Tarantula Nebula, the bright pink region perched on top of the LMC's bar in this DSLR image.

▶ **SMALL MAGELLANIC CLOUD** This composite image of the SMC shows details that are often lost in the galaxy's fuzzy smear, including H II regions (pink), clouds of ionized gas created by young stars. Two foreground globular clusters also appear: NGC 362 (just below the SMC) and 47 Tucanae (left).

LMC: ZDENĚK BARDON / ESO; SMC: MARCO LORENZI streams not only probe our galaxy's past but can also reveal ongoing interactions (*S&T:* Mar. 2020, p. 34).

Enter the Orphan Stream, a collection of stars whose origin remains uncertain. Erkal and his colleagues used data from the European Space Agency's Gaia spacecraft to trace the motion of the stream's RR Lyrae stars. As standard candles, these variable stars do double duty, revealing not just motions but also distances to different parts of the stream. While those far from the LMC move along the path of the stream, the researchers found that stars closer to the LMC had changed direction, veering toward the incoming galaxy.

After using simulations to rule out influences within the Milky Way, Erkal and his colleagues determined that a more massive LMC could be responsible for the sudden change in the stars' direction.

"The LMC today is behaving as if it has the dark matter that it started with," Erkal says. "It's behaving like it's still huge."

Despite its name, the Orphan Stream is not alone. Erkal's team has identified several other streams with similar shifts — in fact, he says that almost all the streams visible in the Southern Hemisphere are showing effects from the LMC. The masses captured from those stellar collections all lend credence to a far more massive LMC.

"We're getting the same mass over and over again with different streams," he says.

The Orphan Stream provided concrete proof that the LMC is indeed massive. Erkal's collaborator Vasily Belokurov (University of Cambridge, UK) called the study a "drastic and clear" signal of the higher mass of the LMC.

Almost all the streams in the Southern Hemisphere are showing effects from the LMC.

Moving the Milky Way

When the LMC was considered a chewed-up satellite of the Milky Way, its correspondingly small mass was insufficient to cause much damage to our galaxy. However, as it became clear that a giant dwarf was taking its first spin around the Milky Way, researchers began to hunt for ways that our galaxy had begun to change.

In 2015, Facundo Gómez (University of La Serena, Chile), Besla, and their colleagues predicted that the Milky Way should react differently if pulled by a more massive LMC. If the LMC were small, the center of gravity of the two galaxies would fall near the Milky Way's center. A more massive LMC would push that center of mass to our galaxy's outskirts. But because the Milky Way is so large, different parts would respond independently to the LMC, with stars in the extended halo reacting at a different rate than the central regions. The Milky Way's inner regions should have shifted significantly in the last 300 to 500 million years as the LMC drew closer.

▼ **GAIA'S MAGELLANIC VIEW** These false-color images color-code the Magellanic Clouds' stars by age: Blue is younger (but does include some evolved stars) and red is older (generally older than 2 billion years). The older stars are everywhere in the LMC's disk, central bar, and spiral arms, as well as in the SMC. The intermediate-age stars (green) are more common in the spiral arms, while the younger stars appear mostly in the inner spiral structure and the Magellanic Bridge between the two galaxies.

Meanwhile, all the changes would have also affected the Sagittarius Stream — the largest and brightest stream mixed up in the Milky Way — and might potentially explain some oddities observed in its shape.

Those predictions panned out in 2020 and 2021, when three papers were released testing those predictions. In October, Erkal and Belokurov were part of a preliminary study that detected "sloshing" caused by the LMC in the inner halo of the Milky Way, starting roughly 98,000 light-years from the galactic center. "That means the galaxy is really out of equilibrium," Erkal says.

A month later, Peñarrubia and his Edinburgh colleague Michael Petersen announced that the LMC had pulled the disk of the Milky Way toward itself as it breezed by. Both studies require that LMC be massive and on its first orbit in order to recreate the observations of our galaxy.

The sloshing spotted by both teams is the result of a great galactic struggle. As the LMC falls into the Milky Way, it feels the pull of our galaxy's gravity. But even as the Milky Way pulls at the LMC, the LMC pulls back at the Milky Way, resulting in *reflex motion*.

A third result, published by Eugene Vasiliev (University of Cambridge, UK), Belokurov, and Erkal in February 2021, revealed that the Sagittarius Stream has an Orphan-like kink due to the LMC's pull. Sagittarius also has more subtle signs of interactions, including a slow unbending of its leading arm. The arm was not uncurled by the LMC, but rather by the Milky Way's motion: As our galaxy lurched toward its satellite, it shifted the direction of the stream.

As they come closer together, the LMC and the Milky Way will play tug of war with the small satellites.

"We have uncovered smoking-gun observational evidence," the authors write.

Together, all three papers reveal that the LMC is not just a minor passerby. "The LMC has a huge effect on the Milky Way," Erkal says.

Backed by the mass measurements, today most researchers accept that the LMC is new to the neighborhood. While some still argue that it could be on its second approach, the growing body of research is making that scenario less likely.

"I think now the evidence is there," Erkal says. "Gurtina was right to push on it so long ago."

Satellites of Satellites

The LMC isn't traveling alone. As it falls into the Milky Way, it's bringing its own collection of sycophants: satellite galax-

▼ **ANOTHER NEWCOMER?** The spiral galaxy M33 (lower right) might also be on its first pass by its larger neighbor, the Andromeda Galaxy (upper left). Like the LMC, M33 contains a lot of star-forming gas and has roughly 10% the mass of its host galaxy. It lies four times farther from Andromeda than the LMC does from the Milky Way, a distance appreciable in this mosaic.

ROGELIO BERNAL ANDREO

ies attracted by its gravity. Chief among these is the Small Magellanic Cloud (SMC), also visible to the naked eye in the Southern Hemisphere.

For decades, scientists have known that the LMC and SMC were bound together, slowly spiraling into the Milky Way. The pair come with an enormous stream of gas, and many astronomers thought that the Milky Way had stripped this Magellanic Stream from one or both dwarf galaxies. Some researchers still point to the stream as an argument against a first-pass scenario. "If the clouds are just coming in for the first time, there's not enough time for the Milky Way to really strip the gas from the clouds and create [the Magellanic Stream]," says Elena D'Onghia (University of Wisconsin, Madison).

But instead of the Milky Way being the culprit, Besla counters, a high-mass LMC tore the stream from the SMC before their first infall. In 2018, researchers confirmed that the composition of the stream bears a stronger resemblance to the SMC than to the LMC, supporting that scenario.

"If you want a system where the Magellanic Stream formed because of interactions between the LMC and SMC, then this has to be a first infall," Besla says. "There is mounting evidence that they have some shared history."

Conversely, if the SMC had followed the LMC around the Milky Way multiple times, it would have lost its gas to our greedy galaxy ages ago, and neither the stream nor the satellite would look the way they do — for example, today's SMC has more of its mass in gas than in stars.

Although the most dominant, the SMC isn't the only satellite trailing after the LMC; a number of newfound ultrafaint dwarf galaxies are caught up in the mix. With the second release of Gaia data, Ekta Patel (University of California, Berkeley), Besla, and others set out to hunt for the LMC's satellite galaxies. Of the roughly 60 dwarfs surrounding the Milky Way, the team selected 18 that are in the right place to be connected to the LMC. By tracing their orbits, the researchers found that six of those are likely tied to the incoming cloud, consistent with previous studies. That's also consistent with a higher-mass LMC taking its first turn around the Milky Way, as a smaller galaxy (or one having made multiple passes) would have a hard time holding onto so many companions.

As they come closer together, the LMC and the Milky Way will play tug of war with the small satellites. "Those satellites are coming along for a ride [with the LMC], but that does not necessarily guarantee they will stay on the same orbital path," Patel says. The Milky Way may tear away some of the satellites, sending them off on their own paths before they merge with our galaxy. Others might continue to ride with the LMC around the Milky Way, ultimately merging with the Milky Way at the same time as their leader.

Magellanic Stream

The leading and trailing parts of the Magellanic Stream together stretch more than 200° across the sky. You'd need 20 fists held at arm's length to cover that span.

Slow Changes

The Large Magellanic Cloud has already invaded the Milky Way's halo, and its intrusion will continue to be felt as it sinks toward the center of our galaxy. When the pair collides in about 2.5 billion years, the number of stars in the Milky Way's halo will grow significantly. The fresh influx of gas will also fuel starbirth and feed the Milky Way's central supermassive black hole, which may grow to be nearly 10 times its current mass. There's even a very small chance that the merger could slightly shift the Sun's orbit around the galactic center. "It's going to change the night sky if that happens," says astronomer Marius Cautun (Leiden University, The Netherlands).

At somewhere between a tenth and a fourth the mass of the Milky Way, the LMC will be an important merger in the life of our galaxy. But it pales in comparison to another expected impact. When the Andromeda Galaxy collides with the Milky Way some 2 billion years later, it will do a more thorough job of shaking things up. Andromeda will destroy the disk of stars orbiting the heart of the Milky Way, a far more dramatic blow than the LMC's effect on the halo of stars on its fringes. Ultimately, the LMC will fold into the Milky Way with some violence, but it will not completely disrupt our galaxy as thoroughly as the larger Andromeda will.

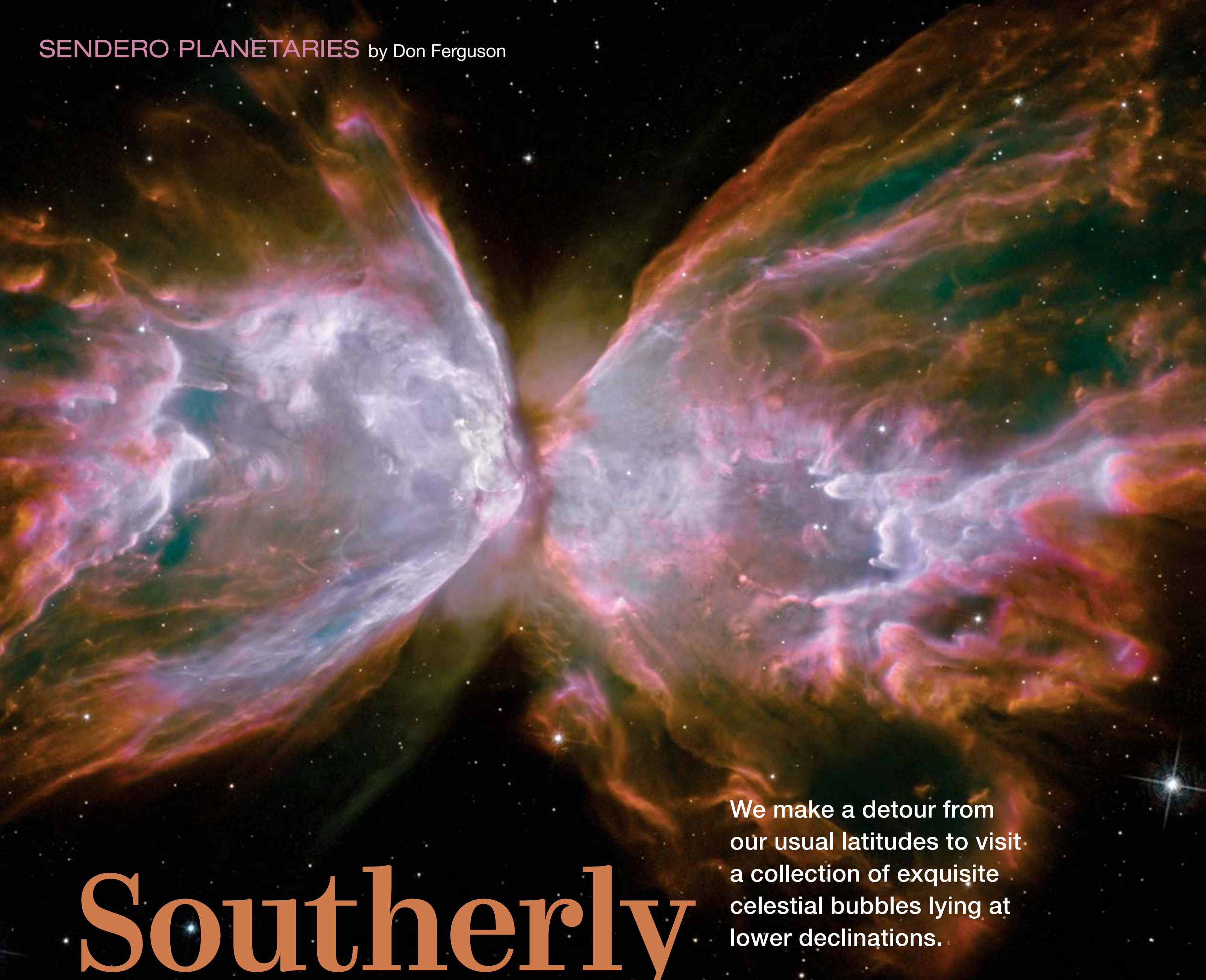
In fact, the LMC may stave off the destruction to be wrought by Andromeda down the road. Previous predictions of the crash's outcome relied on the masses of the LMC and the Milky Way to determine the tug on the incoming galaxy. But a more massive LMC will pull more significantly on Andromeda. Instead of heading directly for the Milky Way, Andromeda is swerving slightly toward the LMC, making the collision with our galaxy less head-on. That deviation also changes the deadline for the impending collision, setting it about 5½ billion years from now, or 1 billion years later than predicted by small-mass LMC models (*S&T:* June 2019, p. 12).

New instruments will help nail down just how the LMC is affecting the Milky Way. The European Southern Observatory's 4-metre Multi-Object Spectrograph Telescope (4MOST) is anticipated to begin observations in Chile in 2023, and the recently built Dark Energy Spectroscopic Instrument (DESI) at Kitt Peak National Observatory in Arizona should soon begin its survey of the sky. The pair will precisely measure the movement of stars in our galaxy, revealing how they are responding to the LMC.

"Probably in a few years, we'll have [measured] thousands and thousands of stars out there," Erkal says, "which we can use to really see what the LMC has done to the Milky Way."

■ **NOLA TAYLOR REDD** is a freelance science journalist who can be a bit spacey — literally. She writes about space and astronomy from Atlanta, where she lives with her four children.

 by Don Ferguson



Southerly Planetary Nebulae

We make a detour from our usual latitudes to visit a collection of exquisite celestial bubbles lying at lower declinations.

In Texas, where I live, pipelines are laid down in clear-cut corridors through the brush country. Called *senderos* (Spanish for "paths") by the workers who initially cleared the way, these pipeline passages deliver their product across the U.S., although I doubt they're called senderos elsewhere.

This observing project began to take root while I was examining Minkowski 3-6, a planetary nebula in Pyxis, when the telescope tracked into the foliage of my magnolia tree. After venting my initial displeasure, I noticed a southerly corridor — a sendero! — in the sky on the other side of the magnolia, resulting from the recent removal of a neighbor's tree. The opening was about 20° wide and reached from the top of the tree line to at least –45° in declination. Would it be possible to view some southern planetary nebulae through this gap?

▲ **BUG NEBULA** A dying star in Scorpius that was once five times as massive as the Sun is now spewing its innards out at nearly 800 times the speed of sound. NGC 6302's "butterfly wings" stretch out for more than two light-years on either side of the central object.

NASA / ESA / HUBBLE SM4 ERO TEAM

I realized then that planning on working up and down by right ascension and timing my observations for when the objects are in the sendero — my window — would make more sense than sticking to a particular constellation or working west to east. Maybe you can apply this approach to other views restricted by buildings or trees or the like.

I consulted Steven J. Hynes's *Planetary Nebulae: A Practical Guide and Handbook for Amateur Astronomers* and identified several objects that would pass through my sendero — all had magnitudes suitable for moderate-size telescopes (between 9 and 13). The only drawback was their southerly declinations (as low as −44°), which might render them difficult to see because of atmospheric extinction, sky glow, and murk when viewed in Houston skies. I nevertheless decided to pursue this project — here was an opportunity to see some planetaries possibly neglected by some observers.

Equipment and Protocols

I used my 7-inch Questar Maksutov-Cassegrain telescope to view the nebulae presented here. I was unable to sit during observing sessions because of the low declinations of my chosen targets, but the pier for the telescope elevates so I could stand comfortably with the eyepiece within easy reach. The only restriction was that the fork-mounted Questar in equatorial mode could only be aimed to about −45° declination before the tube collided with the base of the mount.

I selected four different eyepiece setups for these observations. They were as follows: I used a 34′ eyepiece field at 80×; a 25′ eyepiece field at 106×; a 17′ eyepiece field at 160×; and a 13′ eyepiece field at 212×.

A O III narrowband filter is necessary for enjoying most planetary nebulae — and I used one at some point for each of the objects discussed here. When I use the filter, I pre-focus on a nearby brighter star for the sharpest image possible. This way, I can evaluate any disk the nebula may present. Another tool is an eyepiece equipped with an occulting bar, which I made by affixing a very thin strip of aluminum foil across the field stop. The bar can be rotated to any position.

The most important pieces of observing "equipment" I have are my eyes. In 2008, I had cataract surgery in both eyes and had acrylic lenses implanted. Along with greatly improved visual acuity, another noticeable difference is that many planetaries, which I previously described as greenish-gray or green, now appear to be blue. Indeed, the Ghost of Jupiter (NGC 3242) presented an electric-blue disk one evening. By the same token, though, the star Beta (β) Librae still seems a benign green to me, implying that the yellowing of my cataracts probably caused the greenish colors of the nebulae.

Years ago, I noticed that light pollution worked in concert with atmospheric pollution. When weather conditions scoured the sky of smog, haze, and particulates, often a period of relatively good seeing and transparency followed. Picking those rare nights to observe improved the odds for locating and viewing faint nebulae near the southern horizon, but of course the targets have to appear in the sendero in order for me to spot them.

Most of the planetary nebulae observed in this exercise are relatively bright (for this class of objects) and associated with micro-asterisms and/or brighter stars, which made them easier to locate. On the negative side, it required patience to wait for the nebulae to clear the foliage and enter the sendero. Moreover, once diurnal motion carried the object out of the corridor, it was generally lost for the year.

From Vela to Hydra via Pyxis

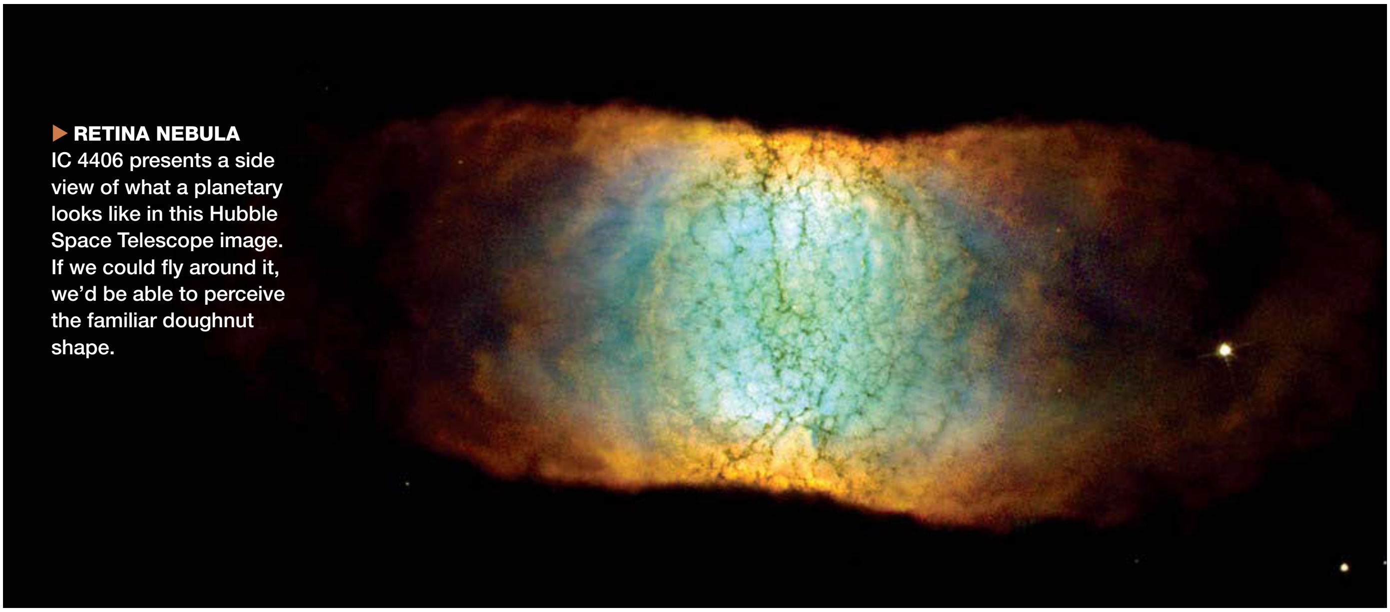
For a few evenings in May, **NGC 2792** culminates in my sendero about 18° above the southern horizon for a few minutes. This 11.6-magnitude planetary in Vela is around 13′ southwest of a 6.3-magnitude star. At 80× I positioned the star in the northeastern quadrant of the field, installed an O III filter, and was rewarded by a small (5″ to 8″) gray form near the center. With the filter and at 160× the view in the eyepiece improved, revealing a small, round, whitish disk. I didn't see the central star nor any evidence of annularity. After I removed the filter and refocused, I could still see the nebula with averted vision.

Shifting north in declination, I popped into Pyxis to view the planetary nebula **NGC 2818**. It's associated with an open cluster that — depending on source — carries the same designation as the planetary (see *S&T:* Mar. 2021, p. 61). On setting the coordinates for NGC 2818, I immediately saw a suspicious area at 106×, along with a few stars of the open cluster. Switching to 160× with filter, I confirmed the 11.6-magnitude planetary. I saw it as a gray-white puff but didn't make out its bipolar structure.

Heading back into Vela, I searched for **NGC 3132**, or the Eight-Burst Nebula as it's also known. A relatively bright magnitude of 9.2, large diameter, and high surface brightness facilitate its detection. At 160× with the O III filter in place, I saw the nebula as bluish-white with irregular edges. The disk was elongated in the northwest-southeast direction, and I suspected annularity. When I removed the filter, I noted the displaced 10th-magnitude central star.

▲ **SOUTHERN OWL NEBULA** You can find this ethereal bubble, also known as Kohoutek 1-22, in the southern reaches of Hydra. This image was captured with the European Southern Observatory's Very Large Telescope in Chile.

ESO



▶ **RETINA NEBULA** IC 4406 presents a side view of what a planetary looks like in this Hubble Space Telescope image. If we could fly around it, we'd be able to perceive the familiar doughnut shape.

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

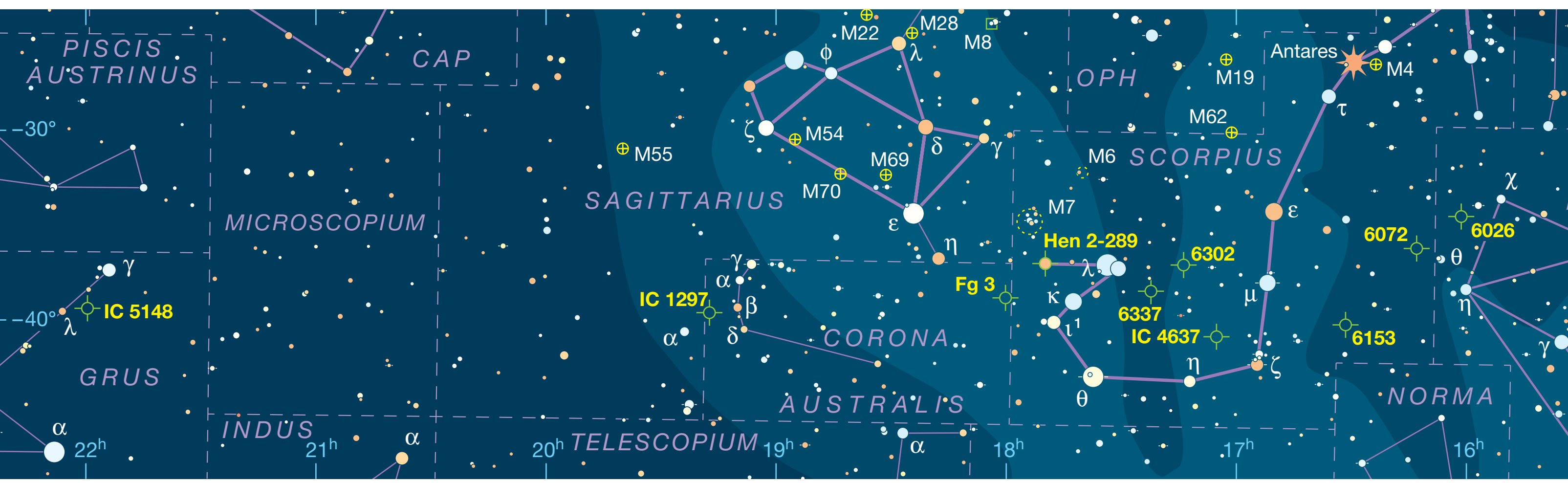
Kohoutek 1-22 is located in Hydra about 12′ south-southeast of the 8.5-magnitude star HD 99463. At 80× I located both HD 99463 and, about 2′ to the star's north-northwest, 8.7-magnitude HIP 55828. With the filter and averted vision I saw a dim, gray, amorphous entity perhaps 2′ across. Upping to 160× I couldn't detect the nebula, but a subsequent observing session with better sky transparency yielded a whitish image at 80×, always using averted vision and filter. With its very low surface brightness, K 1-22 is the second most difficult planetary nebula to bag in my skies.

Looping to Lupus

The 10.2-magnitude planetary **IC 4406** has a declination that's very nearly at the southern limit for my telescope's mount. I located the object by offsetting from Psi (ψ) Centauri, a 4th-magnitude star with a similar right ascension to IC 4406, but at higher altitude. I saw a fuzzy white ball about 20″ in diameter at 80×. A filter at 160× amplified the image, but I didn't see a rectangular shape or the central star, nor did I detect any pattern resembling blood vessels in one's retina, as its nickname suggests. The nebula soon disappeared behind my patio roof, as the viewing time of an object culminating only 16° above the southern horizon is very limited in the narrow sendero. So limited, in fact, that a week of summer thunderstorms delayed my sighting of IC 4406 for an entire year.

Examining the area at the coordinates of **NGC 5873** at 106× revealed two prominent 9th-magnitude stars some 17′ apart in a northeast-southwest line. The nebula is around 5′ southwest of the northernmost of the two stars. Returning to this at 160× I immediately saw a tiny, deep-blue object, which seemed almost as bright as the aforementioned 9th-magnitude stars. Once located, I could see the planetary without the filter. It grew in size at 320×, indicating it was an extended object. I didn't see a central star, but I did note its erose edges.

NGC 6026 lies 7′ northwest of the 7.4-magnitude star HD 143462. I manipulated the star to just outside the 13′



field of view to approximately center the 40″-diameter planetary nebula. With a filter and a black drape over my head and eyepiece to block out stray light, I could see the nebula (I estimated it to be 20″ wide) as it flickered in and out of averted vision.

This was a bonus. I didn't expect to spot this planetary due to its magnitude — at 12.9 the faintest on my list — plus atmospheric extinction at its –34° declination. Thankfully, on that evening the seeing and transparency were exceptional. Earlier in the day there were several rain showers in the area, which had apparently scrubbed and stabilized the atmosphere.

Sliding into Scorpius

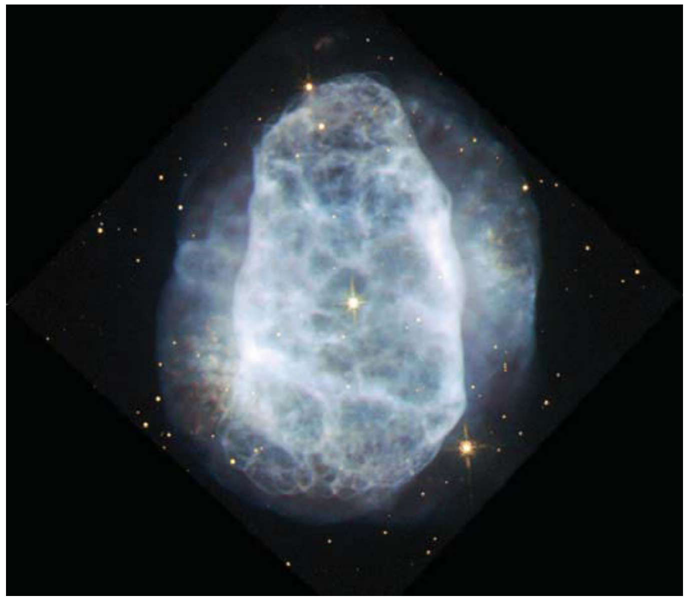
At the site of **NGC 6072**, the solitary 8.6-magnitude star HD 145538 is visible at 106×, lying 7′ north of the 11.7-magnitude planetary nebula. I examined the area at 160× with filter and noted a large, almost Jupiter-size nebula, best viewed with averted vision. The southern edge of the planetary appeared irregular, and I didn't detect a central star.

The color of this nebula was unique: I saw it as grayish tan. I could have called it taupe, but in deference to the Royal Navy officer and astronomer Admiral William Henry Smyth (known for his florid descriptions of double star colors), I'll stick with my initial impression. I suspect the color was the result of atmospherics at declination –36°, because when I checked the area the following night the nebula was a sedate bluish gray.

Near the coordinates for **NGC 6153** in Scorpius, 9th-magnitude HD 148705 and two 10th-magnitude stars form a flattened triangle about 4′ wide and 1′ high, pointing almost north. When I examined the triangle at 160× with an eyepiece fitted with a filter, it became a regular rhombus with NGC 6153 forming the southern vertex. I saw the planetary as a pale blue disk that seemed to brighten towards the center, but I didn't notice a central star. The edge of the disk was sharply defined. To me, this nebula and its micro-asterism are "eye candy."

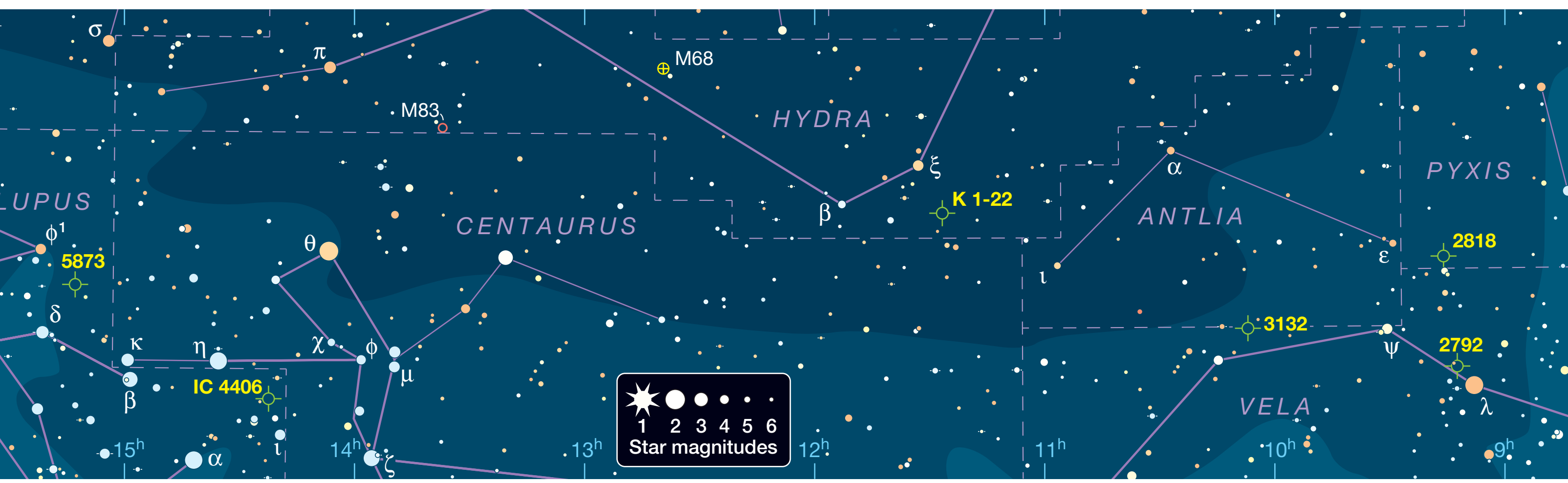
IC 4637 is a 12.5-magnitude object that doesn't compare with some of the showier planetary nebulae in Scorpius,

▲ **NGC 6072** You'll find this interesting-looking planetary nebula in western Scorpius, almost on the border with Lupus. Distance estimates place it at around 3,300 light-years from Earth.



▲ **NGC 6153** This Hubble Space Telescope image reveals the elliptical shape of this planetary, as well as an intricate spiderweb of tendrils and filaments. The object resides in the southwesternmost corner of Scorpius, just north of the border with Norma.

NGC 6072: JOSEF PÖPSEL / BEATE BEHLE / STEFAN BINNEWIES / CAPELLA OBSERVATORY; NGC 6153: ESA / HUBBLE / NASA / MATEJ NOVAK



▶ **CHEERIO NEBULA** This pretty planetary, whose official designation is NGC 6337, floats near the Scorpion's stinger.

since it's dim, inconspicuous, and located in an area devoid of brighter stars and micro-asterisms. Nevertheless, I was determined to spot it, and I saw it using averted vision at 160× with a filter. It was a grayish, somewhat circular mass about 10″ in diameter and showed no evidence of its unusually bright 12.5-magnitude central star (HD 154072) even without the filter.

My first glimpse of 9.6-magnitude **NGC 6302** was at 80× aided by a filter. Its disk was elongated almost in an east-west direction and was a brilliant bluish-white. The best view of the nebula was at 160× always with the filter, which enhanced its spattered appearance and hinted at its bipolar nature. When I removed the filter, I could still see the filament extending from the western end of the nebula. Did I mention that this nebula wins Best in Show?

NGC 6337 is in a rich but dim star field, about 4′ northwest of 9.9-magnitude HD 323131 and about 9′ east-southeast of 9.1-magnitude HD 156849. This object was difficult to locate, but I finally managed to coax out a hazy gray disk seen intermittently at 212× using a filter and averted vision. I didn't see the annulus or the stars superposed thereon.

Concluding in Corona Australis and Grus

Heading to the Southern Crown, **Fleming 3** is located around 7′ south-southwest of 7.8-magnitude HD 163941. At its coordinates, I saw a suspicious area at 106× alongside the nearby 10.4-magnitude star HD 324715; adding a filter at 160× revealed the nebula. It was slightly larger than stellar, bluish, and showed no evidence of annularity or a central star. The image grew in size at 320×.

At the site of **IC 1297** a magnification of 80× shows a pair of 7.4- and 7.8-magnitude stars about 20′ apart on the eastern side forming the base of an acute triangle, with 9.1-magnitude HD 180115 at the western apex. This latter star lies about 7′ southwest of the planetary. I glimpsed the tiny grayish nebula at 160× only a few days before IC 1297 exited the sendero. However, I never observed the 12.9-magnitude variable central star, RU CrA.

Spotting **IC 5148** in Grus from my location was an iffy proposition. Nonetheless, on a clear November night, I used a magnification of 80× to find HD 208677, an 8.4-magnitude star 11′ southwest of the planetary. Switching to an eyepiece at 160× and fitted with a filter, I began searching northeast of the star and encountered the round, grayish, 1′-wide nebula, which winked in and out of averted vision. Subsequent observations on a night with better transparency with the same setup showed the nebula directly, but I didn't see annularity or the central star. When I removed the filter, I noted the 10.3-magnitude star CD–40 14582 about 2′ south-southwest

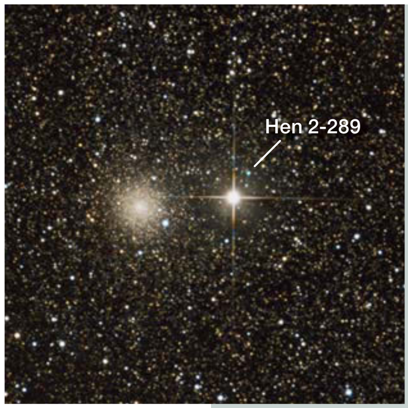
▲ **SPARE TYRE NEBULA** Another ethereal bubble, IC 5148 is at a distance of around 3,500 light-years in Grus, the Crane. It's one of the fastest expanding planetaries known.

NGC 6337: JOSEF PÖPSEL / BEATE BEHLE / STEFAN BINNEWIES / CAPELLA OBSERVATORY; IC 5148: ESO of the nebula. Larger planetaries with low surface brightnesses such as this one and K 1-22 require much larger telescopes to be visually appreciated.

Summary

When I was an acolyte of the chemical industry, we once had a corporate R&D director who spoke in parables and used inspirational catch phrases. One such was "Strive to pluck the low-hanging fruit first." There wasn't all that much fruit left on the chemical tree, but his precept prompted me to pursue this project: plucking low-hanging southern planetary nebulae from the murky skies of Houston. Although you could say these targets are low-hanging, they were certainly not easy to pluck.

But the fact that I cataloged all 15 planetary nebulae (plus one symbiotic star) detailed here suggests that neither my latitude nor atmospheric conditions or even light pollution are detrimental to viewing these southerly nebulae. Granted, the planetaries for the most part aren't ultra-faint fuzzies, and I viewed most of them on the rare nights of optimal seeing and transparency. However, I feel that I must apologize for always panning Houston skies, for even if it is one of the worst light-polluted cities in the U.S. there are still small jewels to be found.



Bonus Target

I decided to throw in the *symbiotic star* (binary system consisting of a red giant and a white dwarf) **Henize 2-289** because prior to my knowledge of its reclassification, I had previously scheduled to observe its alter ego, Haro 1-36. Since I was in the neighborhood. . . . Hen 2-289 is located 1.3′ north-northwest of G Scorpii, a 3.2-magnitude yellow star about 4′ west of the 7.2-magnitude globular cluster NGC 6441. Star and globular make a charming pair in a 13′ eyepiece field at 212×, but the glare of G Scorpii precluded any identification of the 12.1-magnitude symbiotic star either with or without the O III filter. Only when I placed an occulting bar in front of the bright star with the filter in the optical train did Hen 2-289 emerge as a blue point.

DON FERGUSON has cataloged 124 planetary nebulae (and one symbiotic star), uncounted double stars, and many other things good and proper for an amateur astronomer while living at this location. He can be contacted at **dferg28571@aol.com**.

FURTHER MATERIAL: Finder images for these targets can be downloaded at **https://is.gd/Sendero_Finders**.

Planetaries in the Sendero

Object	Constellation	Mag(v)	Mag(*)	Size	RA	Dec.
NGC 2792	Vela	11.6	17.2	21″	$09^h\ 12.4^m$	–42° 26′
NGC 2818	Pyxis	11.6	19.5	93″	$09^h\ 16.0^m$	–36° 38′
NGC 3132	Vela	9.2	10.0	88″	$10^h\ 07.0^m$	–40° 26′
K 1-22	Hydra	~12.1	17.4	180″	$11^h\ 26.7^m$	–34° 22′
IC 4406	Lupus	10.2	17.4	106″	$14^h\ 22.4^m$	–44° 09′
NGC 5873	Lupus	11.0	15.5	13″	$15^h\ 12.9^m$	–38° 08′
NGC 6026	Lupus	12.9	13.2	40″	$16^h\ 01.3^m$	–34° 33′
NGC 6072	Scorpius	11.7	19.3	98″	$16^h\ 13.0^m$	–36° 14′
NGC 6153	Scorpius	10.9	16.1	24″	$16^h\ 31.5^m$	–40° 15′
IC 4637	Scorpius	12.5	12.5	22″	$17^h\ 05.2^m$	–40° 53′
NGC 6302	Scorpius	9.6	21.1	89″	$17^h\ 13.7^m$	–37° 06′
NGC 6337	Scorpius	12.3	14.9	51″	$17^h\ 22.3^m$	–38° 29′
Fg 3	Corona Australis	11.2	14.3	2″	$18^h\ 00.2^m$	–38° 50′
IC 1297	Corona Australis	10.7	14.2	24″	$19^h\ 17.4^m$	–39° 37′
IC 5148	Grus	~11	16.5	132″	$21^h\ 59.6^m$	–39° 23′
Hen 2-289	Scorpius	12.1	—	—	$17^h\ 49.8^m$	–37° 01′

Mag(*) is the magnitude of the central star. 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.

WOLFGANG PAECH / FRANZ HOFFMANN / CHAMÄLEON OBSERVATORY

WORLDS ALIGN by Joe Rao

A fortunate few get to enjoy the first solar eclipse viewable from North America since 2017's epic event.

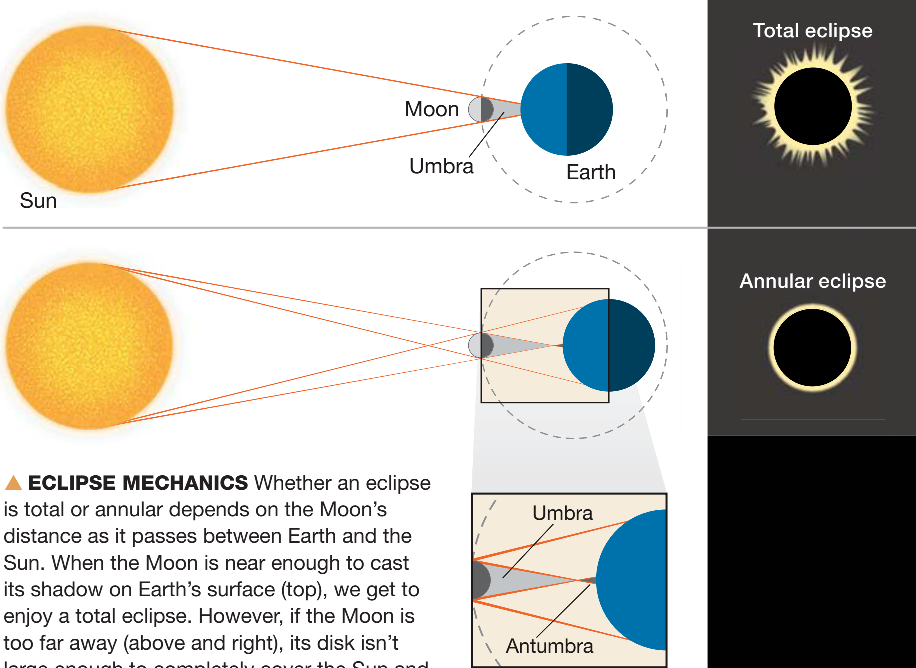
On Thursday morning, June 10th, the shadow of the Moon will brush parts of North America and Asia, allowing observers to witness a most alluring celestial event: a solar eclipse. On that day, the Moon will pass squarely in front of the Sun, yet will not totally cover it. Instead, some observers will see a ring of sunlight thanks to the fact that the Moon is far enough away (404,300 km or 251,200 miles) that it will appear somewhat smaller than the Sun — 5.6% smaller, to be exact.

This event is known as an *annular eclipse*, derived from the Latin "annulus" meaning "ring-shaped." Some also call it a "penny-on-nickel effect" with the nickel representing the Sun and the penny the Moon. The resultant shadow that reaches Earth's surface is not the dark umbra associated with the grand spectacle of a total eclipse. Instead, during an annular eclipse, the Moon's umbra falls short of Earth, producing what is called an *antumbra* or *negative shadow*, as shown in the diagram below. This feature is an extension of the umbra projected onto the Earth's surface.

The Strange Tale of the Shadow

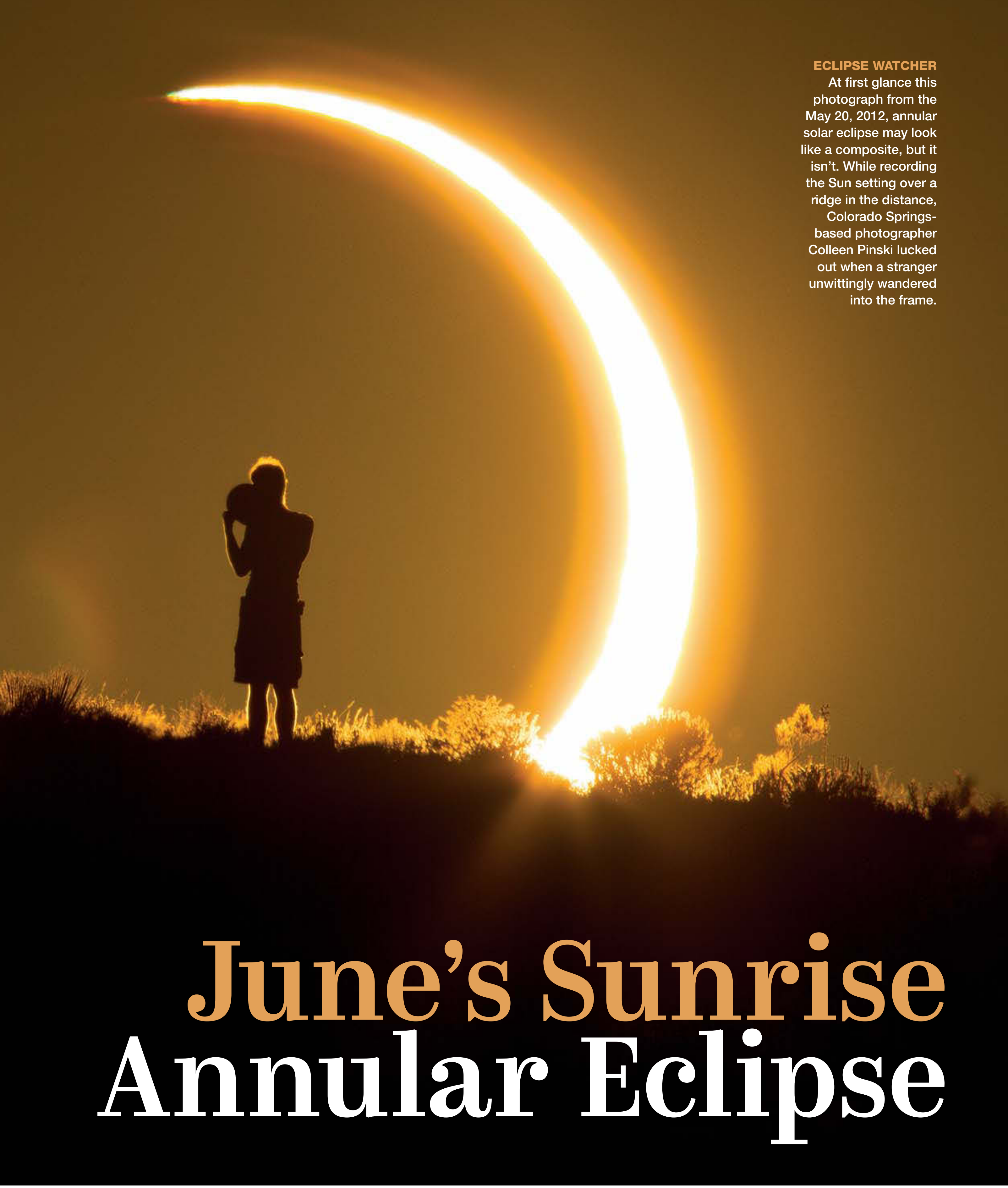
For observers along the path of the antumbra the eclipse appears as a brilliant ring of sunlight surrounding the Moon's dark silhouette. Outside the antumbra, within the much larger outer shadow called the *penumbra*, the eclipse is partial.

The June 10th event will be rather unusual in that the



▲ **ECLIPSE MECHANICS** Whether an eclipse is total or annular depends on the Moon's distance as it passes between Earth and the Sun. When the Moon is near enough to cast its shadow on Earth's surface (top), we get to enjoy a total eclipse. However, if the Moon is too far away (above and right), its disk isn't large enough to completely cover the Sun and an annular eclipse results.

ANNULARITY DIAGRAM: GREGG DINDERMAN / S&T



ECLIPSE WATCHER At first glance this photograph from the May 20, 2012, annular solar eclipse may look like a composite, but it isn't. While recording the Sun setting over a ridge in the distance, Colorado Springs-based photographer Colleen Pinski lucked out when a stranger unwittingly wandered into the frame.

June's Sunrise Annular Eclipse

path of annularity behaves in an apparently strange manner. For someone examining the eclipse path from the perspective of Europe or Asia, the lunar shadow sweeps across Earth in a typical fashion, from west to east. But for observers in North America, the shadow appears to move north-northeast, then north, before finally curving northwest through central and northern Canada, northwest Greenland, and on past the North Pole.

This seemingly odd behavior occurs because the Moon's shadow is directed toward the north polar region at the same time Earth is only 10 days removed from the June 20th solstice, when the North Pole leans most sunward. Consequently, the Northern Hemisphere's sunward tilt causes the Moon's shadow to trace a path across an area located well beyond the North Pole. If this eclipse had occurred at another time of year — around the equinoxes or the winter solstice — the eclipse path would track sunward of the North Pole in a normal fashion.

Additionally, because the Moon's shadow strikes Earth at such an oblique angle, the antumbral shadow path is abnormally wide: averaging about 600 km across. In fact, when it's first projected onto Earth's surface at the start of the eclipse, its outline will resemble a cigar, with its dimensions measuring 250 km by 1,375 km!

Ground Truth

As shown in the map on the next page, the path of annularity begins in the province of Ontario. Visitors to Wabakimi Provincial Park (known for its walleye and northern pike fishing) will be able to see the rising Sun transform into a ring of light. After passing over James Bay and southern and eastern portions of Hudson Bay, the path of annularity moves across northern Quebec and, after crossing the Hudson Strait, arrives in the northern territory of Nunavut. The Inuit hamlet of Pangnirtung, on Baffin Island, played host to a total eclipse in 1979 and is in line for another solar spectacle. This time, the location's 1,500 inhabitants have an opportunity to see 2 minutes 38 seconds of annularity, beginning at 6:10 a.m. EDT.

The point of greatest eclipse occurs not far from Hans Island, a tiny, uninhabited barren knoll located off the northwest coast of Greenland in Kennedy Channel of Nares Strait — the body of water that separates Ellesmere Island from Greenland and connects Baffin Bay with the Lincoln Sea. It's here that the ring phase will last longest: 3 minutes 51 seconds. About 20 minutes later, the shadow sideswipes the North Pole, then turns northwest and leaves Earth's surface a little more than half an hour later over the Kolyma region of Russian East Asia.

For observers in New York State, New England, and most of southeastern Canada (including the Maritime Provinces),

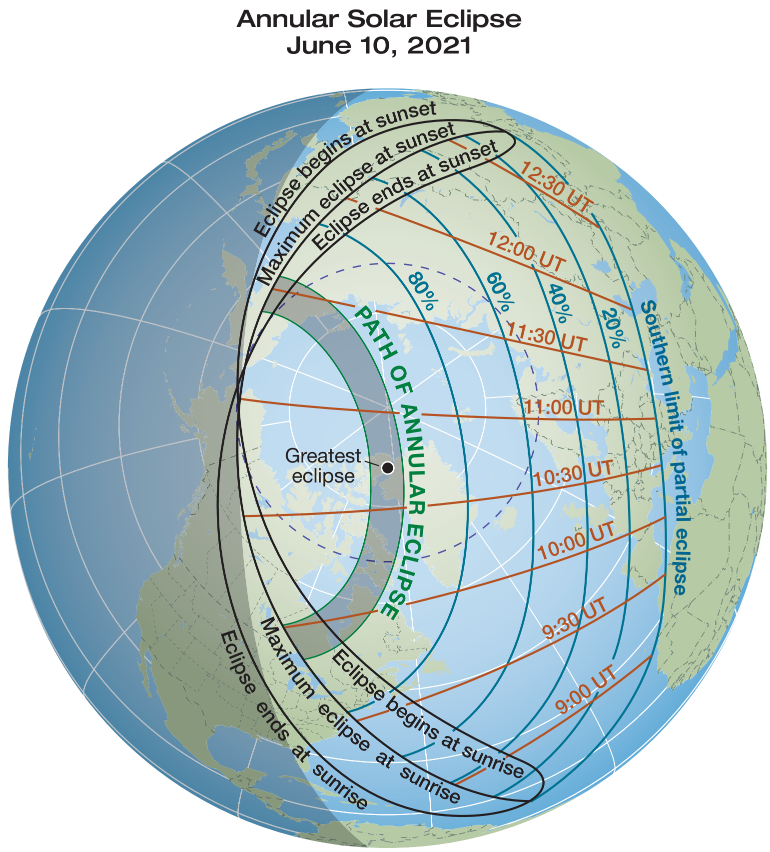
◀ **VERY LARGE ANNULAR** *Sky & Telescope* Senior Contributing Editor Dennis di Cicco photographed the May 2012 annular eclipse in the late afternoon from the Karl G. Jansky Very Large Array near Socorro, New Mexico. The June 10th annular eclipse is the first one visible from North America since 2012.

a most unusual spectacle will occur if skies dawn clear. As indicated in the map at right, the Sun will rise already deep in partial eclipse, with most of these regions seeing at least 80% of the Sun's diameter covered at, or shortly after, sunrise. The farther north and west one is located, the greater the percent eclipsed. Rather than seeing the usual solar disk rising on the east-northeastern horizon, eclipse watchers will instead enjoy either an elongated crescent or scimitar-shaped Sun.

The crescent Sun will rise cusps up, and over a span of roughly 10 minutes the cusps will appear to pivot 90° to the left as the moment of maximum eclipse passes and the Moon drifts eastward. Within an hour after sunup, the lunar disk will have completely exited the Sun, putting an end to the show. The table below details the partial phases from 14 select locations.

The Eclipse Outside Annularity

No place in the United States will see the complete annular "ring of fire." However, parts of Minnesota, Wisconsin, North Dakota, and a slice of southeast Manitoba and southwest Ontario are within the *negative path of annularity* — an imaginary southwest extension beyond the sunrise contact line, as shown on the map on page 38. The table at the top of page 39 provides specifics for five locations very near or within the negative path of annularity. These are places where maximum eclipse occurs around *civil twilight*, defined



June 10 Annular Solar Eclipse Timings

Location	Time zone	Sunrise	Maximum eclipse Time	Mag	Obs	Alt	Last contact
Providence, RI	EDT	5:10	5:32:47	0.795	0.723	2.8°	6:31:48
New York, NY	EDT	5:24	5:32:49	0.797	0.725	0.6°	6:30:55
Boston, MA	EDT	5:07	5:33:20	0.800	0.729	3.3°	6:32:37
Hartford, CT	EDT	5:15	5:33:25	0.802	0.731	2.0°	6:32:09
Manchester, NH	EDT	5:06	5:34:27	0.809	0.740	3.6°	6:33:53
Portland, ME	EDT	4:59	5:34:46	0.810	0.741	4.7°	6:34:42
Syracuse, NY	EDT	5:25	5:37:12	0.837	0.773	1.0°	6:35:39
Burlington, VT	EDT	5:08	5:37:31	0.837	0.773	3.6°	6:37:04
Rochester, NY	EDT	5:30	5:38:13	0.846	0.783	0.7°	6:36:23
Montreal, PQ	EDT	5:05	5:39:10	0.850	0.788	4.2°	6:38:58
Quebec City, PQ	EDT	4:51	5:39:56	0.850	0.788	6.4°	6:40:41
Toronto, ON	EDT	5:36	5:40:05	0.862	0.802	0.6°	6:38:02
Ottawa, ON	EDT	5:14	5:40:13	0.861	0.801	3.0°	6:39:31
Yarmouth, NS	ADT	5:42	6:33:03	0.786	0.713	7.2°	7:33:58

The amount of the Sun's disk covered by the Moon is expressed by the magnitude (Mag), which is the fraction of the diameter, and obscuration (Obs) is the fraction of the area. All times are local and a.m. Over large metropolitan areas, last contact may differ by up to half a minute from the time listed.

GREGG DINDERMAN / *S&T*

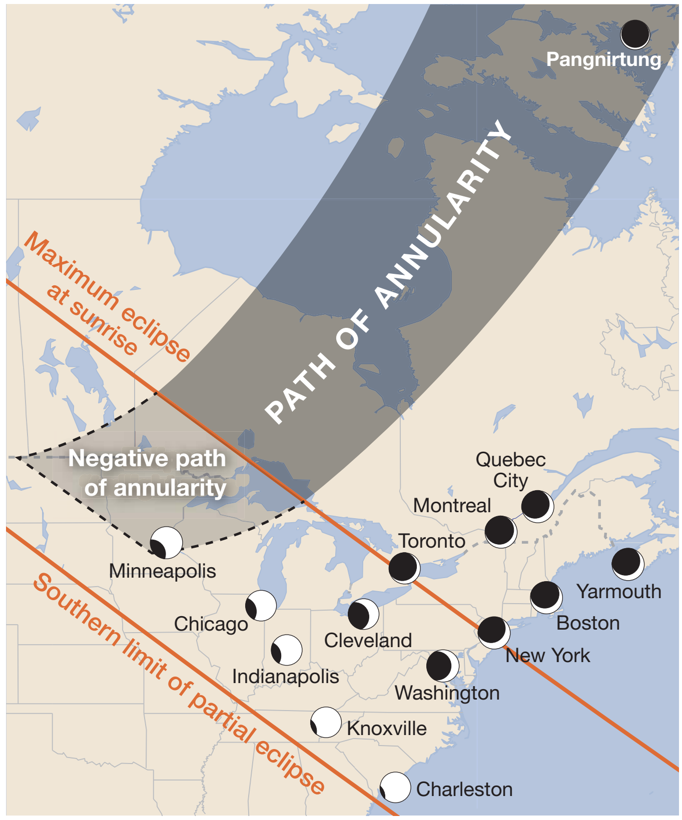
as when the Sun is 6° or less below the horizon and the sky is bright enough for motorists to turn off their headlights.

From Duluth, Minnesota, for example, the ring forms at 4:51:04 a.m. CDT and lasts almost three minutes. Unfortunately, the Sun will be about 4° below the east-northeastern horizon. By sunrise, at 5:18 a.m., the eclipse magnitude is only +0.52 (the Sun is 52% covered) with the Moon egressing the solar disk.

Those living in this region should pay extra attention to morning twilight on the 10th, which may be quite subdued due to the eclipse. If any cirrus clouds are present along the eastern horizon, the sky may look especially unusual. Depending on transparency and the amount and type of local cloud cover, the antumbra itself may be evident, projected low on the eastern sky.

Most likely any darkening you see will have no discernible shape or outline. You could try visually comparing the appearance of the horizon on the 10th to the mornings before and after. Better yet, at dawn on eclipse day, try capturing a series of photos with a wide-angle lens or a video sequence. The results could prove to be quite dramatic.

In locations where the rising Sun will be reduced to a crescent, observers may wonder if there will be a noticeable change in daylight illumination. Since maximum eclipse occurs in New York State, New England, and the Canadian Maritimes, with the Sun very low, the difference might not be great enough to dim the landscape appreciably. Then again, with so much of the Sun covered, perhaps the effect won't be to diminish the brightness of sunlight so much as to alter its quality: Scenery may appear strangely dusky and yellower than usual.



▲ **IN THE PATH** This close-up map of the path of annularity shows the local circumstances for a number of key locations. (The small icons indicate the amount of eclipse visible from each marked location.) Also illustrated is the negative path of annularity, where maximum eclipse occurs before sunrise. Observers at locations within this zone should be alert for unusual morning twilight illumination.

ECLIPSE RISING: ARMAN MOHAMMADY; PATH OF ANNULARITY: GREGG DINDERMAN / S&T

ECLIPSE SUNRISE Like the June 10th event, the most recent annular eclipse (December 26, 2019) also took place at sunrise from some locations. This striking photo was captured from Hengam Island, Iran, looking east across the Persian Gulf.

Locations Near or Within the Negative Path of Annularity

Location	Time zone	Maximum eclipse	Dur	Alt	Sunrise	Mag	Obs	Last contact
Minneapolis, MN	CDT	4:51:19	—	–5.7°	5:29	0.304	0.188	5:46:53
Duluth, MN	CDT	4:52:30	2:52	–3.8°	5:18	0.522	0.407	5:48:42
Fargo, ND	CDT	4:56:06	3:34	–5.7°	5:36	0.265	0.154	5:51:24
Winnipeg, MB	CDT	4:59:42	2:11	–3.3°	5:24	0.543	0.430	5:55:48
Minot, ND	CDT	5:01:00	2:21	–6.3°	5:20	0.627	0.525	5:55:54

For these locations, maximum eclipse occurs around the time of civil twilight, when the Sun is 6° or less below the horizon. Also provided is the duration of "faux annularity" (Dur) in minutes and seconds, the time of sunrise, and magnitude and obscuration values, along with the time of the Moon's last contact with the solar disk. (Minneapolis lies just outside the southern limit of the negative path of annularity.)

left provides local circumstances in 11 select cities.

Of course, all the usual eclipse-viewing precautions must be taken when observing this event. Even when the Sun is close to the horizon, it's still potentially blindingly bright. For telescopic or naked-eye viewing, a safe solar filter must be used.

If you still have your eclipse glasses from 2017, be sure to inspect them carefully beforehand to ensure that no tears or pinholes have appeared, or that any other damage has occurred in the intervening years.

The safest method is to avoid looking at the Sun directly and instead project its image onto a screen either through a pinhole or by using binoculars or a small telescope. You can review eclipse safety information at *Sky & Telescope*'s website: **https://is.gd/eclipsesafety**.

For a deep partial solar eclipse occurring at sunrise, the usual ground rules might be fraught with uncertainty. What if, for example, a thick layer of horizon haze significantly attenuates the Sun's light, dimming and reddening it to such a degree that you're tempted to look directly at it? After all, just about everyone has watched sunrises (and sunsets) under such conditions. While it's true that the Sun's visible rays may be significantly diminished, its infrared rays can still freely penetrate horizon haze, however thick it may be.

Damage to your retina can happen without any sensation of pain. So, even if the Sun is low and dimmed by haze or thin clouds, use discretion, and err on the side of caution. Take only brief looks and don't stare long enough for infrared rays to build up heat on your retina. Under no circumstances should you use binoculars or a telescope without full-aperture filters covering the objective lenses.

While a partial or annular eclipse is certainly no match for a total one, it's nonetheless a most interesting sight. And this one, occurring around sunup, will certainly be all the more dramatic, with the possibility of unusual twilight effects. The Sun's low elevation also means your photos can include beautiful foreground scenery to spice them up. If the weather doesn't cooperate, or if you live outside the eclipse zone, don't despair. Another annular eclipse is due in October 2023 — and its path will cross much of the Americas, providing viewing opportunities to more observers.

In the meantime, good luck and clear skies on June 10th!

Take a Bite, But Be Careful . . .

As the map on page 37 shows, there will be no eclipse for places southwest of a line running roughly from Edmonton, Alberta to Savannah, Georgia. But eclipse watchers just a little north and east of this boundary will get to see a brief glimpse of the Moon retreating from the solar disk, though the size of the bite will be very small. For example, in Charleston, South Carolina, there will be just eight minutes between the time the Sun is completely above the horizon and last contact. At most, the Moon will cover less than 5% of the solar disk. Conversely, for locations farther north of this line (such as Buffalo, New York, and Philadelphia), the eclipse magnitude will be considerably larger, with about four-fifths of the Sun's diameter hidden by the Moon. The table below

Maximum Eclipse Before Sunrise

Location	Time zone	Sunrise	Mag	Obs	Last contact
Chicago, IL	CDT	5:18	0.356	0.236	5:39:06
Philadelphia, PA	EDT	5:34	0.792	0.719	6:30:00
Buffalo, NY	EDT	5:40	0.847	0.785	6:36:24
Washington, DC	EDT	5:45	0.686	0.594	6:29:06
Manchester, NH	EDT	5:06	0.809	0.740	6:33:53
Cleveland, OH	EDT	5:55	0.660	0.563	6:35:24
Detroit, MI	EDT	5:58	0.651	0.552	6:37:24
Charlotte, NC	EDT	6:11	0.236	0.130	6:25:30
Charleston, SC	EDT	6:14	0.117	0.046	6:21:12
Indianapolis, IN	EDT	6:19	0.294	0.162	6:35:18
Knoxville, TN	EDT	6:21	0.123	0.050	6:28:24

This table provides local circumstances for 11 select cities where maximum eclipse occurs before sunrise. The magnitude and obscuration figures are the greatest amount of the Sun that will be covered at the time of sunrise. Sunrise is normally defined as the time when the uppermost limb of the Sun first appears above the horizon — for this table, the value given is for when the entire solar disk is above the horizon.

■ Contributing Editor **JOE RAO** witnessed his first solar eclipse in 1963. He has seen 12 total solar eclipses, two annular eclipses, and seven partial solar eclipses.

Radio Astronomy Grows Up

OPEN SKIES: *The National Radio Astronomy Observatory and Its Impact on U.S. Radio Astronomy*

Kenneth I. Kellermann, Ellen N. Bouton, and Sierra S. Brandt
Springer, 2020
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FROM THE BIRTH of radio astronomy in the early 1930s until today, the sensitivity of radio telescopes has increased by a factor of about 100 million. This is just one of many fascinating facts revealed in *Open Skies: The National Radio Astronomy Observatory and Its Impact on U.S. Radio Astronomy.*

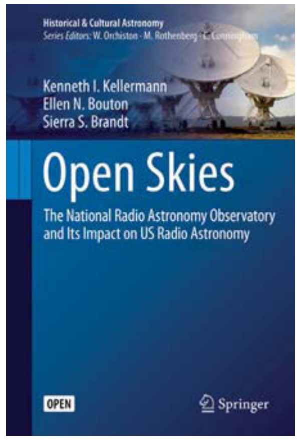
This meticulously researched and smoothly written history focuses on the construction and operation of increasingly larger and more expensive radio telescopes under the umbrella of the NRAO, whose creation revolutionized all of astronomy. For the first time, the government, rather than private donors, funded a major observatory. NRAO also pioneered the Open Skies policy, which allows anyone in the world who submits a successful observing proposal to use its telescopes.

Open Skies offers something for everyone as it chronicles the blossoming field's hurdles, successes, and failures. Those interested in history will delight in early chapters describing how large radio telescopes came into being (although the list of the myriad characters involved may become overwhelming to some readers). Political junkies will revel in going behind the scenes to witness in graphic detail how individuals battled to have their voices heard during countless committee and planning meetings, and how the interests of small radio observatories vied with the might of the ever-growing NRAO.

Others can enjoy eavesdropping on the battles between project managers and contractors as they argued about meeting stringent design specifications, which, in some cases, led to lawsuits. On the road to a new project's completion, disastrous setbacks were known to occur, as with the 140 Foot Radio Telescope in Green Bank, West Virginia. But other initiatives met with brilliant success, such as the Very Large Array in New Mexico, which, by contrast, was built on schedule and within budget.

The book has rich fodder, too, for techno-geeks with an interest in hardware and software. They can follow along as very creative people solved difficult and constantly evolving engineering and computational problems en route to realizing their combined visions. For true aficionados, the book includes extensive notes, references, further reading suggestions, and a lengthy index.

The underlying moral of the story is that large radio telescope projects usually cost a lot more — in time, effort, aggravation, and money — than originally anticipated. Beyond the U.S. experience, readers can also learn much about radio astronomy's development in more traditional settings in England, The Netherlands, Australia, Japan, and now in South Africa, the site for the high-frequency segment of the enormous Square Kilometer Array.



One aspect of the growing field that stands out starkly in *Open Skies* is how overwhelmingly male-oriented radio astronomy (and all astronomy) once was. In the book's numerous historical photographs, about 260 men appear to just eight women, at least four of whom were wives or administrative personnel. In the early 1960s, we could count the number of female radio astronomers on one hand. It's greatly to be hoped that future histories of astronomy will reflect broader diversity across the spectrum, not only in gender but in race and other underrepresented spheres.

While the nitty-gritty behind the advent of the large NRAO ventures makes for compelling reading, the authors didn't give the NRAO 140 Foot its due. They imply that it was a very expensive failure. It was expensive but not a failure. After all, in 1968 it saw the first measurement of the interstellar magnetic field strength and discovered the first organic interstellar molecule, formaldehyde, plus several more within a few years.

All in all, however, *Open Skies* is worth soaking in in its entirety. Interested readers will emerge at the end feeling that they just went on a remarkable adventure.

■ **GERRIT VERSCHUUR**, best known for his work in radio astronomy, pioneered the measurement of the interstellar magnetic field using the 21-cm Zeeman effect technique. He has published 13 books and dozens of popular astronomy articles.

1 DAWN: Look to the south-southeast before sunrise to see the Moon with Jupiter about 5° above it. Saturn sits around 18° right of the pair.

2 DAWN: The last-quarter Moon, Jupiter, and Saturn now form a shallow arc.

10 NEW MOON (6:53 AM EDT) An annular solar eclipse will be visible along a track that stretches from Ontario, Canada, across the Arctic, and ends in northeastern Russia. Large swaths of northeastern North America and Europe will witness partial phases (turn to page 34 for the full story).

13 DUSK: The thin lunar crescent is in Cancer, a mere 3° separating it from Mars, with the Beehive Cluster (M44) a bit more than 4° left of the Moon.

15 DUSK: In Leo, the waxing lunar crescent and the Lion's lucida, Regulus, sit some 4° apart.

19 EVENING: After rolling into Virgo, the waxing gibbous Moon gleams almost 5° from Spica.

20 THE LONGEST DAY OF THE YEAR in the Northern Hemisphere. Summer begins at the solstice, at 11:32 p.m. EDT.

21 DUSK: Very low on the west-northwestern horizon Venus blazes about 5° from Pollux. Catch the pair before they set (go to page 47 for details).

22 EVENING: The Moon, two days from full, is in Scorpius, around 3½° separating it from Antares. Watch as the pair climb in the south-southeast.

23 DUSK: Mars pops into the Beehive Cluster (see page 47).

27 DAWN: The waning gibbous Moon hangs above the southern horizon, with Saturn a bit less than 5° above it. Jupiter is left of the pair.

28 DAWN: The Moon has parked itself between the two gas giants, and the trio forms an eye-catching triangle before the Sun rises.

30 DAWN: The month closes as it opened, with the Moon, Jupiter, and Saturn adorning the southern horizon in a graceful arc.
— DIANA HANNIKAINEN

▲ Astronauts aboard the International Space Station photographed the Moon through the topmost layers of Earth's atmosphere. When the Moon comes between Earth and the Sun, we witness an eclipse. NASA / JSC GATEWAY TO ASTRONAUT PHOTOGRAPHY OF EARTH

JUNE 2021 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart

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

NASA / LRO

MOON PHASES

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

LAST QUARTER

June 2
07:24 UT

NEW MOON

June 10
10:53 UT

FIRST QUARTER

June 18
03:54 UT

FULL MOON

June 24
18:40 UT

DISTANCES

Apogee	June 8, 02^h UT
406,226 km	Diameter 29′ 25″
Perigee	June 23, 10^h UT
359,957 km	Diameter 33′ 12″

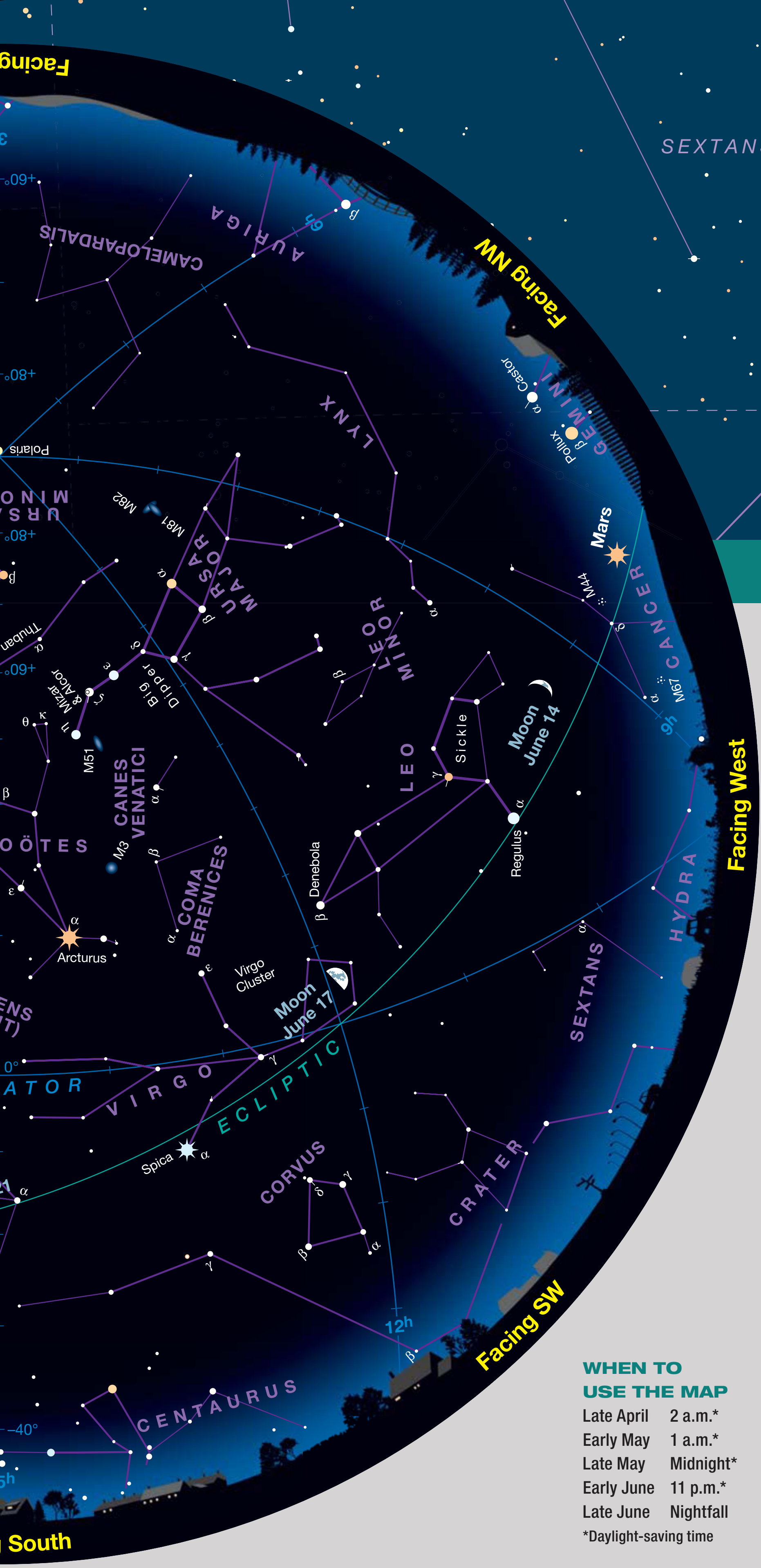
FAVORABLE LIBRATIONS

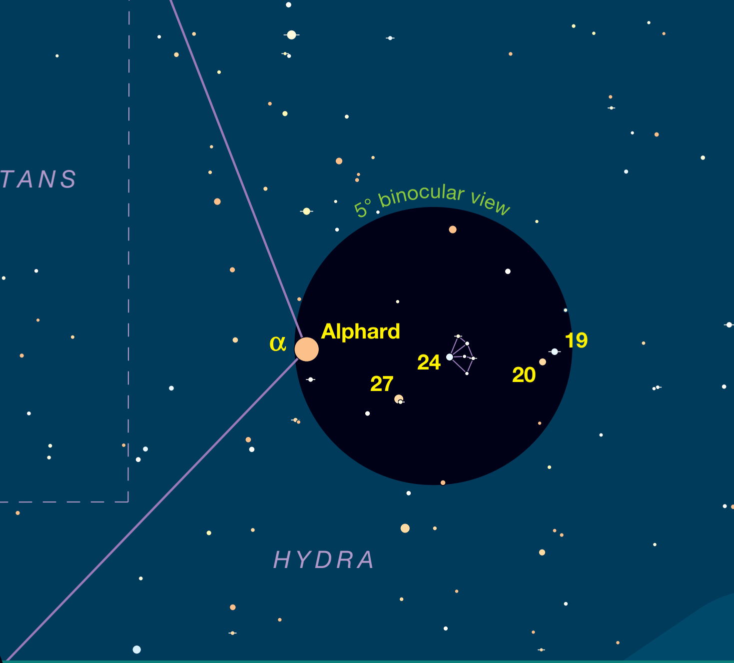
- Boss Crater — June 24
- Zeno Crater — June 25

Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

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





Binocular Highlight by Mathew Wedel

Treasures of the Southern Seas

This month we visit sprawling Hydra, the Water Snake. Let's start our voyage with **Alphard**, Alpha (α) Hydrae, the brightest star in the constellation. Alphard, about 23° south-southwest of Regulus in Leo, is an easy find because it has so little competition: At 2nd magnitude, it's brighter by far than any other star in its vicinity. In fact, the name Alphard comes from the Arabic Al-Fard, meaning "the Solitary One." But as we shall see, Alphard has plenty of company for alert binocular observers.

About 4½° to the west of Alphard you'll find **19** and **20 Hydrae**. The pair make an easy binocular double, with a separation of almost ⅓°. See if you can detect any color difference between 19 Hydrae, a 5.6-magnitude *B*-type blue-white giant, and 20 Hydrae, a 5.5-magnitude *G*-type yellow-orange giant. There's another attractive binocular double in the same field. With a separation of 229″, 4.8-magnitude **27 Hydrae** forms a nice, wide pair with 7th-magnitude HD 80550.

Smack in the center of the field between 19 and 20 Hydrae and Alphard is the object that first caught my attention when I was passing this way a couple of years ago. Fifth-magnitude **24 Hydrae** has an arc of dimmer stars about half a degree to the west. Together they make an asterism in the shape of a scallop shell. That fits with the marine theme of the constellation and with the more famous seashell at the other end of Hydra: M83, the Seashell Galaxy.

Like the ocean, this expansive stretch of sky might seem empty at first glance, but it has plenty to reward the intrepid mariner. What other treasures can you find in these dark depths?

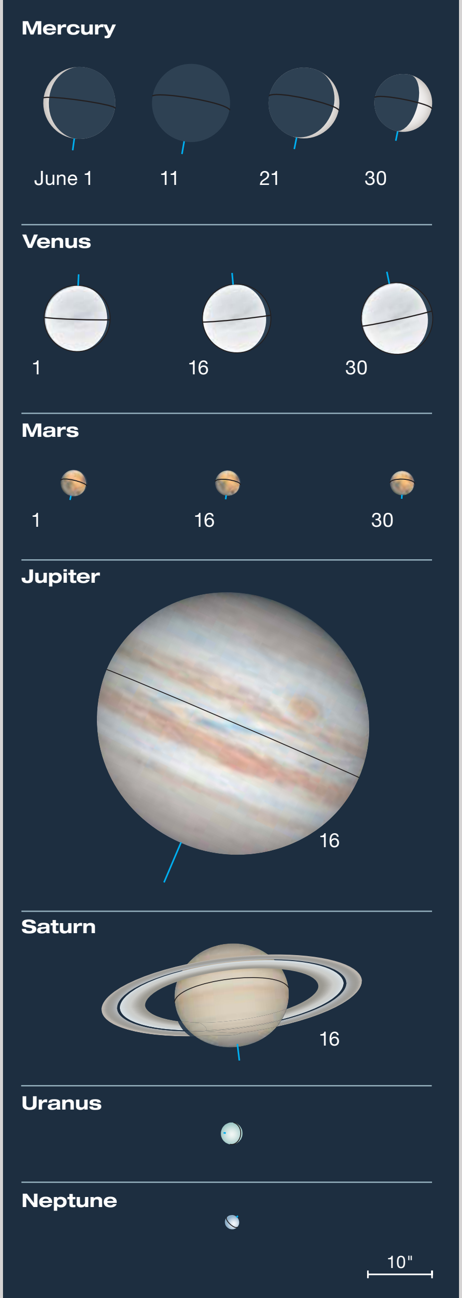
■ **MATT WEDEL** enjoys fishing, he's just not very good at it. But he never gets skunked when he dips a line in the cosmic ocean.

WHEN TO USE THE MAP

Late April	2 a.m.*
Early May	1 a.m.*
Late May	Midnight*
Early June	11 p.m.*
Late June	Nightfall

*Daylight-saving time

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** is hidden in the Sun's glare all month • **Venus** is visible at dusk all month • **Mars** is visible at dusk and sets in the late evening • **Jupiter** and **Saturn** rise around midnight and are visible through dawn.



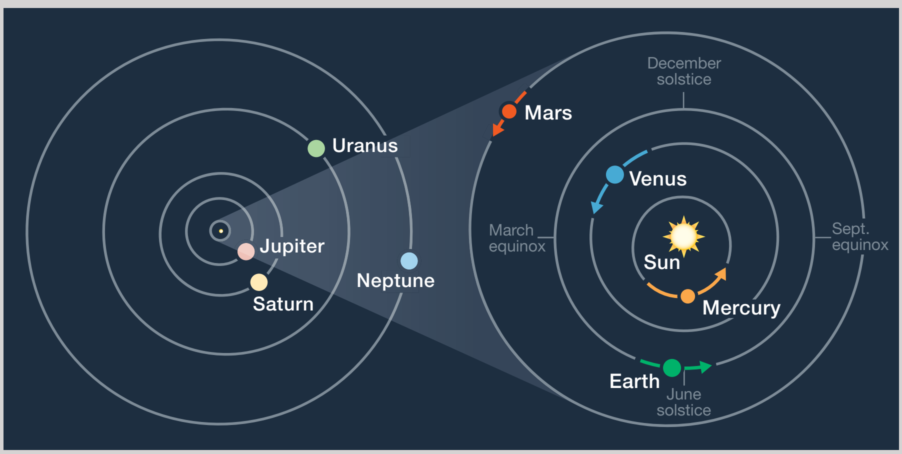
▲ **PLANET DISKS** have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

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

June Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$4^h\ 35.3^m$	+22° 01′	—	–26.8	31′ 33″	—	1.014
	30	$6^h\ 35.5^m$	+23° 11′	—	–26.8	31′ 28″	—	1.017
Mercury	1	$5^h\ 35.1^m$	+22° 57′	14° Ev	+3.0	11.2″	8%	0.599
	11	$5^h\ 17.9^m$	+19° 57′	3° Ev	—	12.2″	0%	0.551
	21	$5^h\ 01.0^m$	+18° 15′	14° Mo	+2.9	11.0″	8%	0.611
	30	$5^h\ 08.5^m$	+19° 01′	21° Mo	+1.0	9.0″	25%	0.746
Venus	1	$5^h\ 50.4^m$	+24° 18′	17° Ev	–3.8	10.3″	95%	1.619
	11	$6^h\ 44.0^m$	+24° 17′	20° Ev	–3.8	10.5″	94%	1.582
	21	$7^h\ 36.9^m$	+23° 04′	23° Ev	–3.8	10.8″	92%	1.540
	30	$8^h\ 23.3^m$	+21° 02′	25° Ev	–3.8	11.1″	90%	1.497
Mars	1	$7^h\ 41.2^m$	+22° 47′	43° Ev	+1.7	4.2″	95%	2.251
	16	$8^h\ 20.1^m$	+20° 53′	38° Ev	+1.8	4.0″	96%	2.346
	30	$8^h\ 55.6^m$	+18° 38′	33° Ev	+1.8	3.9″	97%	2.423
Jupiter	1	$22^h\ 14.5^m$	–11° 50′	99° Mo	–2.4	41.2″	99%	4.786
	30	$22^h\ 16.5^m$	–11° 48′	126° Mo	–2.6	45.1″	99%	4.369
Saturn	1	$21^h\ 03.3^m$	–17° 29′	117° Mo	+0.6	17.6″	100%	9.456
	30	$20^h\ 59.2^m$	–17° 51′	146° Mo	+0.4	18.3″	100%	9.097
Uranus	16	$2^h\ 42.2^m$	+15° 19′	42° Mo	+5.8	3.4″	100%	20.494
Neptune	16	$23^h\ 35.6^m$	–3° 51′	92° Mo	+7.9	2.3″	100%	29.873

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 Many Distinctions of Arcturus

The leading light of Boötes rides high in the June sky.

Arcturus, plainly visible high in the south on June evenings, may be the most distinctive of all the sky's bright stars. That's a big claim. But given the star's characteristics, I think it holds up.

The star's name means "the Bear Watcher," which is apt considering its relationship to Ursa Major, the Big Bear. The well-known "arc to Arcturus" curves from the Big Dipper's handle and leads right to Arcturus. That arc can be extended onward from Arcturus with a straight line to "spike to Spica." You can continue even farther with "the curve to Corvus." I made up that last one, but try it yourself — it works nicely.

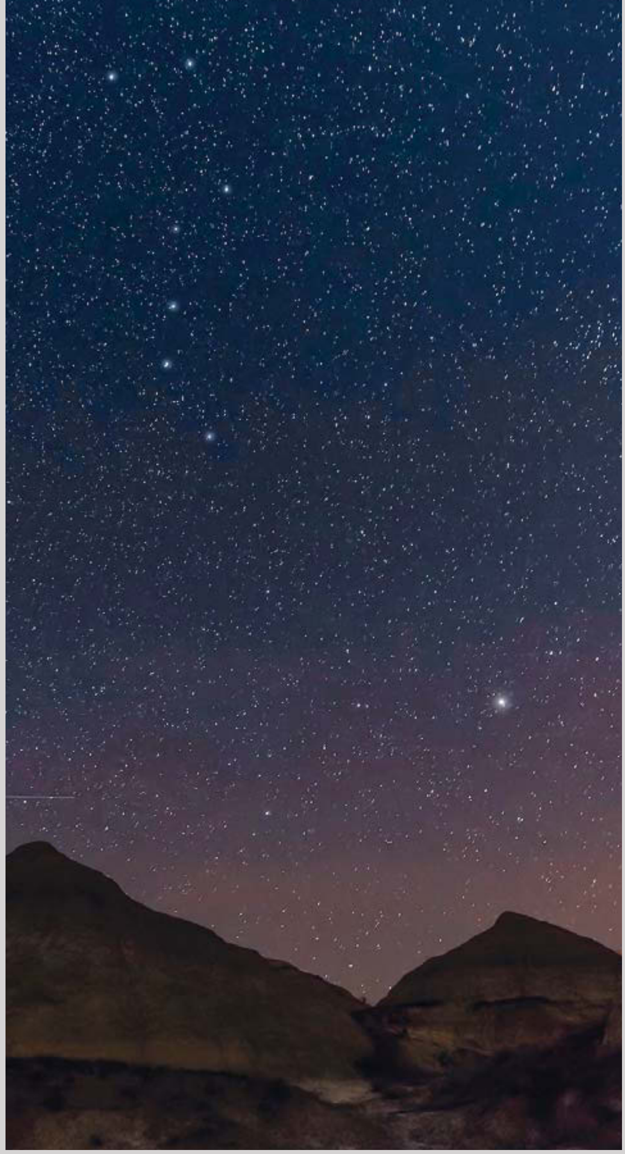
Arcturus gleams at magnitude –0.05, making it the fourth-brightest night-time star in all the heavens. However, sitting at number three is Alpha Centauri, which shines with the combined light of its two component suns of magnitude –0.01 and 1.35. If you treat the Alpha Centauri pair individually, Arcturus rises to number three on the list. For observers at mid-northern latitudes, however, Arcturus is second only to the brightest star in the night sky, Sirius (magnitude –1.44). Arcturus rules the evening sky from late spring to mid-autumn — the time of year when Sirius is absent in the evening hours.

A further remarkable indicator of Arcturus's brightness is its daytime visibility. A keen-eyed friend of mine, Chuck Fuller, reported seeing Arcturus with the naked eye right at sunset. More impressive was the sighting by the great 19th-century German visual observer J. F. Julius Schmidt, who glimpsed Arcturus without optics 24 minutes *before* sunset. And which star (other than the Sun) was the first viewed in a telescope in daytime? Arcturus. It was observed by French astronomer Jean-Baptiste Morin, in 1635.

For skywatchers at mid-northern latitudes, Arcturus crosses the meridian at an altitude of roughly 65°. However, the star passes just about overhead as seen from Honolulu, Hawai'i. That made Arcturus an important navigational aid to early Polynesian sailors, who determined their latitude by noting which stars appeared at the zenith. Between about AD 1219 and 1266 some of these South Pacific sailors crossed Earth's equator and happened upon the Hawaiian island chain. They noted Arcturus as the most prominent zenith star — one that could be used to guide a return visit to these new lands. (They found their way back home to Tahiti by sailing south to where Sirius appears overhead.)

It's not just Arcturus's brightness that stands out — it also has a distinctive color. The difference in brightness between starlight measured through filters that isolate the blue light, B, and visible (yellow-green) light, V, gives the *B-V color index*. The higher the resulting value, the redder a star appears. Arcturus's B-V color index of +1.23 lies in a big gap between slightly orange Pollux (+1.00) and more deeply orange Aldebaran (+1.54). But Arcturus is much brighter than those other stars, so its hue stands out more strongly.

Finally, Arcturus is also remarkable for its origin and age. Whereas our Sun is roughly 4.6 billion years old, astronomers estimate Arcturus to be 7.1 billion years old — more than half the age of the universe itself. And among the countless stars (including our Sun) that travel within the Milky Way in orbits tilted only slightly to the galaxy's equatorial plane, Arcturus (and perhaps only 52 other much dimmer stars) have orbits that are tilted out of the plane and elongated. This raises the distinct possibility that Arcturus (and the other 52 stars) are from another galaxy that collided with the Milky Way long, long ago.



▲ **ARCING TO ARCTURUS** Following the curve of the Big Dipper's handle leads the observer's eye to Arcturus, the brightest star in the constellation Boötes.

ALAN DYER

■ **FRED SCHAAF** first identified Arcturus when he was seven or eight years old. He's come to refer to it as "the great glad star of spring."

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

Venus and Mars Steal the Dusk Show

Two early-evening planets highlight an eventful month.

TUESDAY, JUNE 1

If you like to do your observing before sunrise, you'll be rewarded straightaway in June. Cast your gaze toward the southeast at the start of morning twilight to catch the (almost) last-quarter Moon hanging some 5° below right of **Jupiter**. This is a fine naked-eye sight. Jupiter gleams at magnitude –2.4, so it stands up well to moonlight and even bright twilight. As a bonus, Saturn is located about 18° to the right of the twosome.

FRIDAY, JUNE 11

Whenever **Venus** is favorably placed, skywatchers are treated to the monthly spectacle of a conjunction between the Evening Star and crescent **Moon**. Generally, only one such encounter happens each calendar month, though every couple of years we get two. Not this time. However, this month's lone Venus-Moon pairing is a nice one, featuring a very young (1.6-day-old, 2.3%-illuminated) lunar crescent sitting 3° lower right of the magnitude –3.8 planet at dusk. It's still early days in the current apparition, though, so Venus hasn't yet had the chance to climb very high yet. That means you'll need an unobstructed west-northwest horizon to see this Venus-and-Moon show.

If you use binoculars, you can seek them out only minutes after sunset, when they're at their highest, about 13° up. Because Venus maintains a nearly constant altitude after sunset over the next several months, its lunar meet-ups will continue to occur near the horizon. The main difference is the early-evening lunar crescent will be increasingly older (and fatter) as the year progresses.

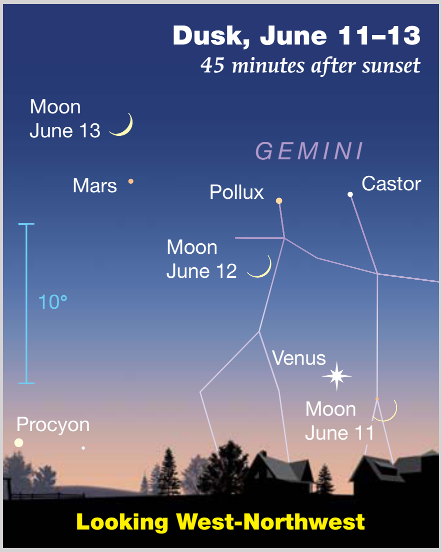
SUNDAY, JUNE 13

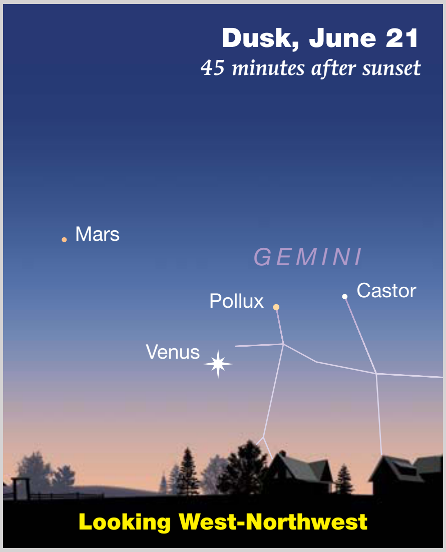
Echoing last month's sequence of events, after its encounter with Venus, the **Moon** next joins **Mars**. Thanks to Venus's relatively rapid eastward drift, the gap between it and the Red Planet is shrinking. As a result, early this evening the Moon pulls up alongside Mars only two nights after its meeting with Venus — compare that to May when there was a three-night gap. Come July, Venus catches up to Mars so that the Moon can visit both planets on the same night. On June 13th, however, the earthlit lunar crescent will be a little less than 3° above Mars, which shines at magnitude 1.8 — about half as bright as Pollux in Gemini, which is some 10° to the planet's right. In addition, if you get out your binoculars you should just be able to squeeze the Moon into the same view as the pretty open cluster M44, in Cancer. The cluster will also figure in one of June's more interesting sights on the 23rd (see next page).

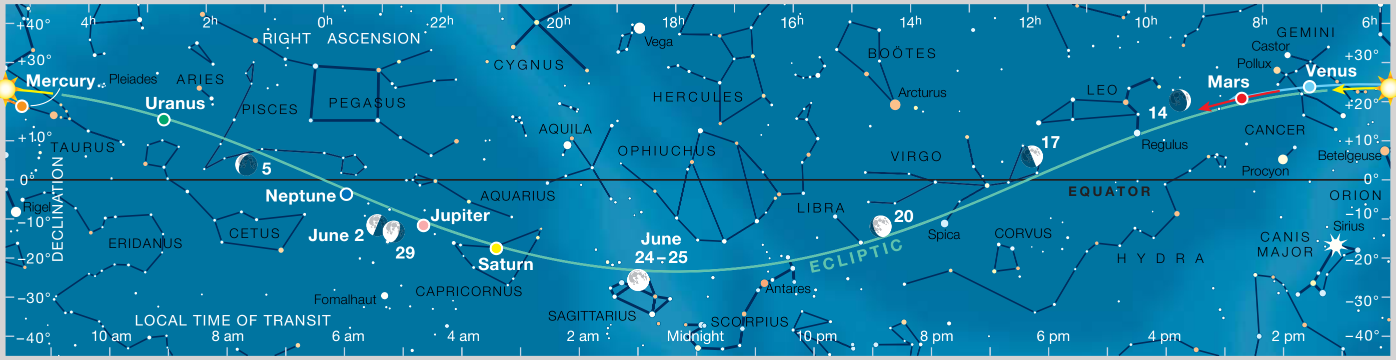
THURSDAY, JUNE 17

Asteroid hunters have a great opportunity to spot **Vesta** this evening. It's the brightest asteroid and currently shines at magnitude 7.6 — easily within reach of ordinary binoculars. What makes it an especially tempting target tonight is that it's found only 1.3° north-northeast of 4th-magnitude Iota Leonis and is positioned as the middle dot in a three-in-a-row configuration that includes stars of magnitudes 5.8 and 6.5. (Iota is shown — though not labeled — on our center star chart, below and right of Denebola.) A finder chart for Vesta appeared in the March issue (page 48), which plots Iota and the two fainter stars. The best way to be sure you're

▼▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west). European observers should move each Moon symbol a quarter of the way toward the one for the previous date; in the Far East, move the Moon halfway.







▲ The Sun and planets are positioned for mid-June; 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.

seeing the asteroid tonight is to note its position relative to the nearby stars, then view the field again a night or two later. Vesta's eastward motion will be obvious relative to the background stars.

MONDAY, JUNE 21

As **Venus** marches along the ecliptic, it approaches 1.2-magnitude **Pollux** in Gemini. At dusk today, the two will be closest, with about 5° separating them. But sometimes, closest approach doesn't yield the most striking configuration. For those who enjoy tidy alignments, the evenings of the 24th and 25th may well offer a more enjoyable arrangement. That's when Castor, Pollux, and Venus will form a line spanning 12° parallel to the west-northwest horizon.

TUESDAY, JUNE 22

The **Moon** encounters only a small handful of bright stars as it makes its monthly journey along the ecliptic through the zodiacal constellations. **Antares**, in Scorpius, is the third brightest of these stars and the most southerly. This month it's also the brightest star the Moon gets closest to, though it did pass nearly as close to Regulus on the evening of the 15th. As the night of the 22nd transitions into the morning of the 23rd, the nearly full Moon sits about 3½° above Antares. The star's orange hue contrasts nicely with the lunar disk's silvery light.

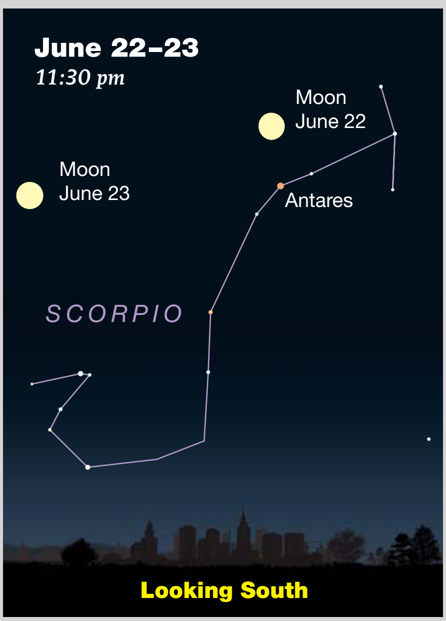
WEDNESDAY, JUNE 23

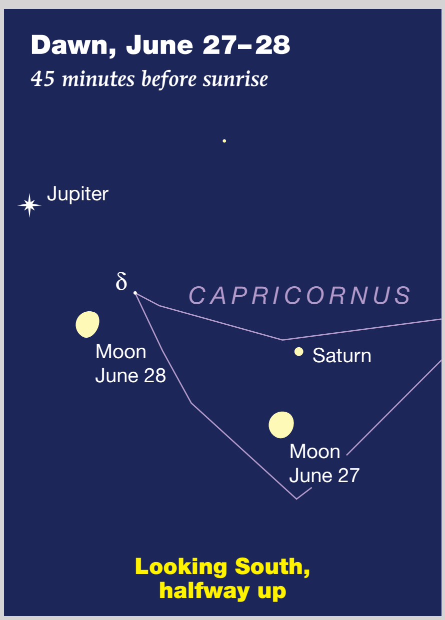
At dusk today **Mars** becomes an extra bee in the Beehive Cluster, **M44**. For details, turn to page 50.

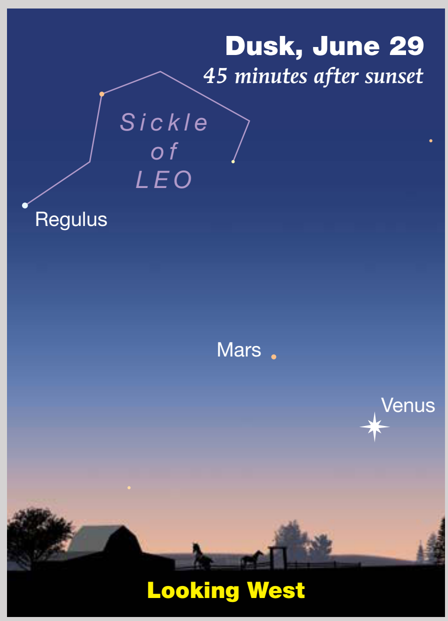
SUNDAY, JUNE 27

After opening the month by visiting Jupiter, the **Moon** this morning bookends June by closing in on **Saturn**. In the predawn hours, the waning gibbous is parked less than 5° below the +0.4-magnitude ringed planet. Both objects are found right in the middle of the squashed V-shape of Capricornus. Of course, the brilliant Moon will make it difficult to see most of the constellation's stars, which aren't exactly among the brightest in the sky.

■ Consulting Editor **GARY SERONIK** always thinks Venus and Mars are alright.







Enter the Twilight Zone

Enjoy dawn and dusk riches during the summer solstice.

The crescent Moon and Mercury adorned evening twilight last January when this photo was captured. The sky near the horizon appears much redder than higher up because we view through much more atmosphere, which scatters blue light, leaving only orange and red hues.

ALAN DYER

Dusk and dawn. Gloaming. Blue Hour. Eventide. All refer to twilight, that colorful and contemplative time after sunset and before sunrise. Light scattered off particles and dust in the air bathes the landscape in a soft, mellow light. I've always enjoyed the transition that dusk provides, especially in summertime when the end of the day brings relief from the heat. Dawn has a different feel. It's an awakening to the fresh possibilities that come with a new day.

But twilight can have a downside, too. Around the summer solstice — which this year occurs on June 20th at 11:32 p.m. EDT — skywatchers at mid-northern latitudes typically experience late sunsets, two hours or more of evening twilight, and very little true darkness. That puts a big crimp in the time available for spending at the telescope, not to mention how late nights can affect your attentiveness at work the next day.

The circumstances aren't so bad in the southern states where twilight is shorter, but in the northern U.S. and southern Canada it lingers an additional hour and kicks in again 2½ hours before sunrise. That makes for a short night. So why not spend an evening observing the twilight sky at dusk for its own charms?

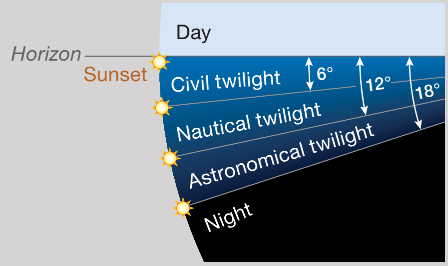
Let's start by looking at the three types of morning and evening twilight: *civil*, *nautical*, and *astronomical*. Civil twilight begins at sunset and ends when the center of the Sun is 6° below the horizon. During this period, you can still easily see your way around and recognize faces and landmarks.

Scattered light from the setting Sun colors the western horizon bright yellow at first, which deepens to orange and orange-red as the minutes pass. If mid- to high-level clouds are present, they catch the Sun's final reddened rays and glow vividly against the deepening blue sky. Watch for the purple light some 20° to 30° above the western horizon about 15 to 20 minutes after sunset. The effect is caused by sunlight scattered by dust and aerosols in the lower stratosphere mingling with the reds of the troposphere. Extra material injected into the air by volcanic eruptions and dust storms can intensify the phenomenon. Civil twilight is also the best time to spot the Earth's shadow rising in the eastern sky, opposite the sunset position. The shadow appears as a purple-gray band about 5° wide, fringed by a diffuse, pink glow. Known as the Belt of Venus, it's caused by reddened sunlight scattering off dust high in the atmosphere.

Nautical twilight covers the interval when the center of the Sun is between 6° and 12° below the horizon. During this time, sailors can still discern the horizon and make reliable readings of star positions at sea with a sextant. On terra firma, the brighter stars and constellations are visible, and most outdoor activities require artificial lighting.

The general public would consider the end of nautical twilight "night" — but not astronomers. For them, true night only arrives at the end of astronomical twilight, when the center of the solar disk has dipped 18° below the horizon. With all trace of twilight gone, observers far from city lights can seek the faintest deep-sky objects and comets. Of course, the night sky is never truly dark. Starlight, airglow, aurorae, and zodiacal light continue to provide feeble illumination, making it possible to see your hand silhouetted against the sky even from the darkest locations on Earth.

Nights around the solstice offer only a brief voyage into darkness before our craft arrives at dawn's shore, where each stage of twilight plays out in reverse before the Sun peeps over the horizon. How long twilight lasts depends on how quickly the Sun drops below the



▲ **DAY TO NIGHT** Twilight has three phases, each defined by the Sun's position relative to the horizon. The sky is only fully dark when the Sun's center lies 18° below the horizon at the end of astronomical twilight (evening) or before the start of astronomical twilight (morning).

horizon, which varies according to the season and your latitude. Dusk and dawn zip by in about 70 minutes at the equator, where the solar disk quickly drops to –18°. Northern visitors to the tropics are often shocked at how quickly darkness falls.

Not surprisingly, twilight lingers longest at the poles, where the Sun's path is nearly parallel to the horizon around the equinoxes. All of us have heard of the Land of the Midnight Sun, where daylight lingers continuously during the summer solstice for locations north of the Arctic Circle. However, you might be surprised to learn that if you live north of 48.5° the Sun's center never dips to –18° on the June solstice. As most Canadian stargazers are keenly aware, at least a trace of twilight lingers in the northern sky all night long.

The Sun's declination varies during the year from 23.5° north of the celestial equator on the summer solstice, to 23.5° south on the first day of winter. Near the equator, the Sun's path is almost perpendicular to the eastern and western horizons all year long. However, at mid-Northern latitudes in summer, the Sun intersects the horizon at a much shallower angle. That means the Earth has to spin longer for the Sun to sink to the requisite –18°, increasing twilight's duration by an hour or more.

June is, of course, the month of the summer solstice and brings a bounty of eventide. Use the time to relish the progression of colors and emerging stars as our planet languorously unfurls its shadow across the sky.

▲ **FADING LIGHT** The blue-gray band of Earth's shadow rises in the eastern sky beneath the rosy-hued Belt of Venus. Both features lie opposite the setting Sun and remain visible for 20 to 25 minutes after sunset.

DAY TO NIGHT DIAGRAM: GREGG DINDERMAN / *S&T*; TRAFFIC AT TWILIGHT: BOB KING

A Nunki Cover-up

The Moon eclipses 2.1-magnitude Sigma (σ) Sagittarii (better known as Nunki) 11 times in 2021. Nunki is the most northern star in the Handle of the Sagittarius Teapot and the brightest star the Moon will occult this year. (The star is shown on our Northern Hemisphere Map, near the "Facing SE" label.)

On the morning of June 25th, if you live in the western half of the U.S. or in Mexico, at last it will be your turn to see an occultation. From most of the western half of the U.S. and Hawai'i, the 15.5-day-old Moon will cover the star at its bright limb in a dark sky, while for locations farther east the event occurs in morning twilight or around sunrise.

A narrow slice of the far southern U.S., Central America, and northern South America will see the star disappear again behind the 11-day-old Moon on August 18–19. Additional information is available at **https://is.gd/2021occultations**.

Mars Bumbles Through the Beehive

WHILE YOU'RE ADMIRING the dusk sky, keep an eye on Mars. Even though it's currently just 3.9″ across and a relatively pale magnitude 1.8, Mars still knows how to get our attention.

On the evening of June 23rd, the Red Planet will shine near the center of the Beehive Cluster (M44) in Cancer. Use binoculars and look low in the west-northwest, starting about 90 minutes after sunset. From mid-northern latitudes the planet and cluster stand just 7° above the horizon as twilight deepens and set soon after. Mars will hover close to the cluster from June 22nd to 24th, so you have a couple of backup opportunities in case of clouds on the 23rd.

For a fun mental exercise, try to imagine the scene in 3D. Mars is practically under your nose at 358 million kilometers away, compared to the Beehive's 593 light-year distance — almost 16 billion times more remote.

▲ **BEEHIVE PLUS ONE** Because the Beehive Cluster (M44, in Cancer) lies just north of the ecliptic, the swarm of stars periodically welcomes the Moon and planets. Mars passes through the heart of the cluster on June 22nd, though both objects will be low in a twilight sky. This photo is from March 1995 and shows the Red Planet positioned well east of M44.

ALAN DYER

Selected Jupiter Mutual Satellite Events

Date	Time (UT)	Event	Mag change
June 1	11:06 – 11:13	Io eclipses Ganymede	0.3
June 10	7:58 – 8:05	Callisto eclipses Europa	0.9
June 18	5:26 – 5:55	Europa eclipses Callisto	0.6
June 21	6:13 – 6:17	Io eclipses Europa	0.8
June 28	8:33 – 8:36	Io eclipses Europa	0.9

Action at Jupiter

BY MID-JUNE JUPITER rises shortly after midnight local daylight-saving time and ascends to an altitude of nearly 34° in the south-southeast by the time morning twilight significantly brightens the sky.

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

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

May 1: 4:43, 14:39; **2**: 0:35, 10:30, 20:26 **3**: 6:22, 16:18; **4**: 2:13, 12:09, 22:05 **5**: 8:01, 17:56; **6**: 3:52, 13:48, 23:43 **7**: 9:39, 19:35; **8**: 5:30, 15:26; **9**: 1:22, 11:18, 21:13 **10**: 7:09, 17:05; **11**: 3:00, 12:56, 22:52 **12**: 8:48, 18:43; **13**: 4:39, 14:35; **14**: 0:30, 10:26, 20:22 **15**: 6:17, 16:13; **16**: 2:09, 12:04, 22:00 **17**: 7:56, 17:52; **18**: 3:47, 13:43, 23:39 **19**: 9:34, 19:30; **20**: 5:26, 15:21; **21**: 1:17, 11:13, 21:08 **22**: 7:04, 16:59; **23**: 2:56, 12:51, 22:47 **24**: 8:43, 18:38; **25**: 4:34, 14:30; **26**: 0:25, 10:21, 20:17 **27**: 6:12, 16:08; **28**: 2:04, 11:59, 21:55 **29**: 7:51, 17:46; **30**: 3:42, 13:38, 23:33 **31**: 9:29, 19:25

June 1: 5:24, 15:19; **2**: 1:15, 11:11, 21:06; **3**: 7:02, 16:58; **4**: 2:53, 12:49, 22:45; **5**: 8:40, 18:36; **6**: 4:32, 14:27; **7**: 0:23, 10:19, 20:14; **8**: 6:10, 16:06; **9**: 2:01, 11:57, 21:53; **10**: 7:48, 17:44; **11**: 3:39, 13:35, 23:31; **12**: 9:26, 19:22; **13**: 5:18, 15:13; **14**: 1:09, 11:05, 21:00; **15**: 6:56, 16:52; **16**: 2:47, 12:43, 22:39; **17**: 8:34, 18:30; **18**: 4:25, 14:21; **19**: 0:17, 10:12, 20:08; **20**: 6:04, 15:59; **21**: 1:55, 11:51, 21:46; **22**: 7:42, 17:37; **23**: 3:33, 13:29, 23:24; **24**: 9:20, 19:16; **25**: 5:11, 15:07; **26**: 1:02, 10:58, 20:54; **27**: 6:49, 16:45; **28**: 2:41, 12:36, 22:32; **29**: 8:27, 18:23; **30**: 4:19, 14:14

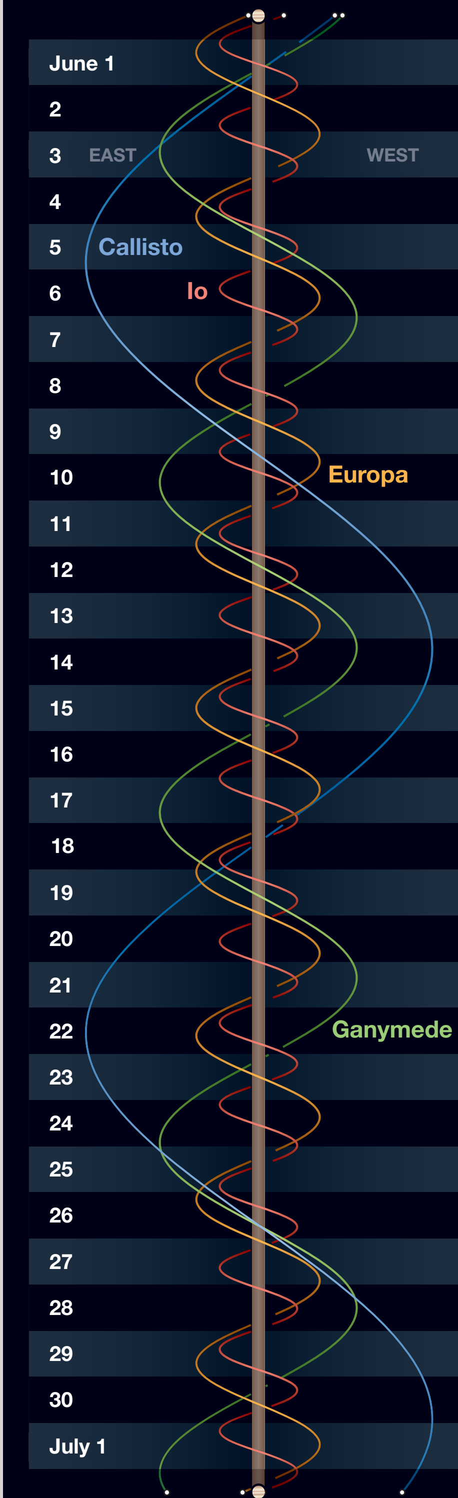
These times assume that the spot will be centered at System II longitude 0° on June 1st. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 0° and 1²/₃ minutes later for each degree more than 0°.

Phenomena of Jupiter's Moons, June 2021

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

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 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.

What's In a Name?

A lot, which led to the reclassification of lunar craters.

An early stage of science is classifying observed features to search for relationships between them. Carl Linnaeus started it in 1735 with his binomial nomenclature system for life forms, and in 1869 Dmitri Mendeleev brought order to chemical elements with his Periodic Table. Lunar observers faced similar challenges with our satellite's thousands of circular depressions of different sizes and morphologies. Astronomers began naming individual lunar features with the first detailed Moon maps starting in the 1640s. However, it wasn't until the 19th century that observers began classifying the different types of lunar craters.

In his 1876 book *The Moon and the Condition and Configurations of Its Surface*, Edmund Neison introduced English readers to the classification system of lunar craters found in Wilhelm Beer and Johann Mädler's *Der Mond* (1837). Their division of craters into nine classes generally ran from largest to smallest: walled plains, mountain rings, ring plains, crater plains, craters, craterlets, crater pits, crater cones, and depressions. Whew! Neison and later British selenographers' descriptions appear in the table below. These classifications appeared in many lunar books all the way up through the early 1960s.

There are three major problems with these classifications, which is why no one uses them anymore. First, they arose at a time when lunar craters were thought to be volcanic. The impact origin of craters wasn't widely recognized until the early 1960s. Second, only a few observers trying to understand craters knew anything about volcanoes.

The third problem was most important. Many 19th-century observers didn't appreciate that a majority of the differences they used to classify craters were actually due to subsequent modifications of a crater's original form. They didn't know that the dark material of the maria were lava flows that partially or completely covered craters, or that lavas could rise up from floor fractures to flood a crater's interior. More importantly, not until the 1960s was the existence of giant impact basins known and especially that their widespread ejecta deposits filled crater floors and gouged grooves through older craters' rims.

The modern understanding of impact-crater mechanics began in the 1960s, stemming from Canadian geologist Michael Dence's investigations of 10 ancient terrestrial features that he and other Canadian scientists recognized as impact craters. He identified two crater types, which he called *simple* and *complex*. Simple craters are less than 10 kilometers (6.2 miles) in diameter and appear as smooth-walled, circular depressions. Complex craters have diameters ranging from 20 to 65 km, with terraces and slumped-wall material that has collapsed onto their flat floors, and they often contain central mountain peaks. This simple and complex classification is still in use today, with different values for the simple-to-complex transition diameters on other planets and moons.

Since then, complex craters were further subdivided into two types. The smaller complex craters — typically less than 40 km wide — are characterized by large slumps of wall material that left a bite or "scallop" in the crater rim. Larger complex craters have terraces that faulted down the inner walls, and flat floors usually punctuated with a central mountain.

My goal here is to place the large variety of classical crater types into this modern simple/complex system. Ring plains like **Copernicus**, **Tycho**, and **Theophilus** are unmodified, complex-terraced craters. Neison's walled plains are older, complex-terraced craters whose rims, interiors, and exterior

Crater Categories (1837-1960)

Type	Walled plains	Mountain rings	Ring plains	Crater plains
Diameter (kilometers)	60-250	25-100	15-100	10-40
Description	Massive, broken walls with uneven heights; floors often flat, smooth, and level with surroundings or significantly depressed with hills or central mountains	Very low, incomplete rims; smooth, level floors; few central peaks. Often found in maria.	Continuous, circular terraced walls with peaks; deep floors, massive central mountains. Concentric or radial outer ridges and depressions	Resemble ring plains but with lower rims; steeper outer walls
Examples	Ptolemaeus, Clavius, Plato, Gassendi, Bailly, Posidonius	North of Flamsteed, South of Plato, surrounding Torricelli, Fra Mauro, Fracastorius	Copernicus, Bullialdus, Theophilus, Tycho, Piccolomini, Bürg	Pallas, Colombo, Goclenius, Seleucus, Delisle

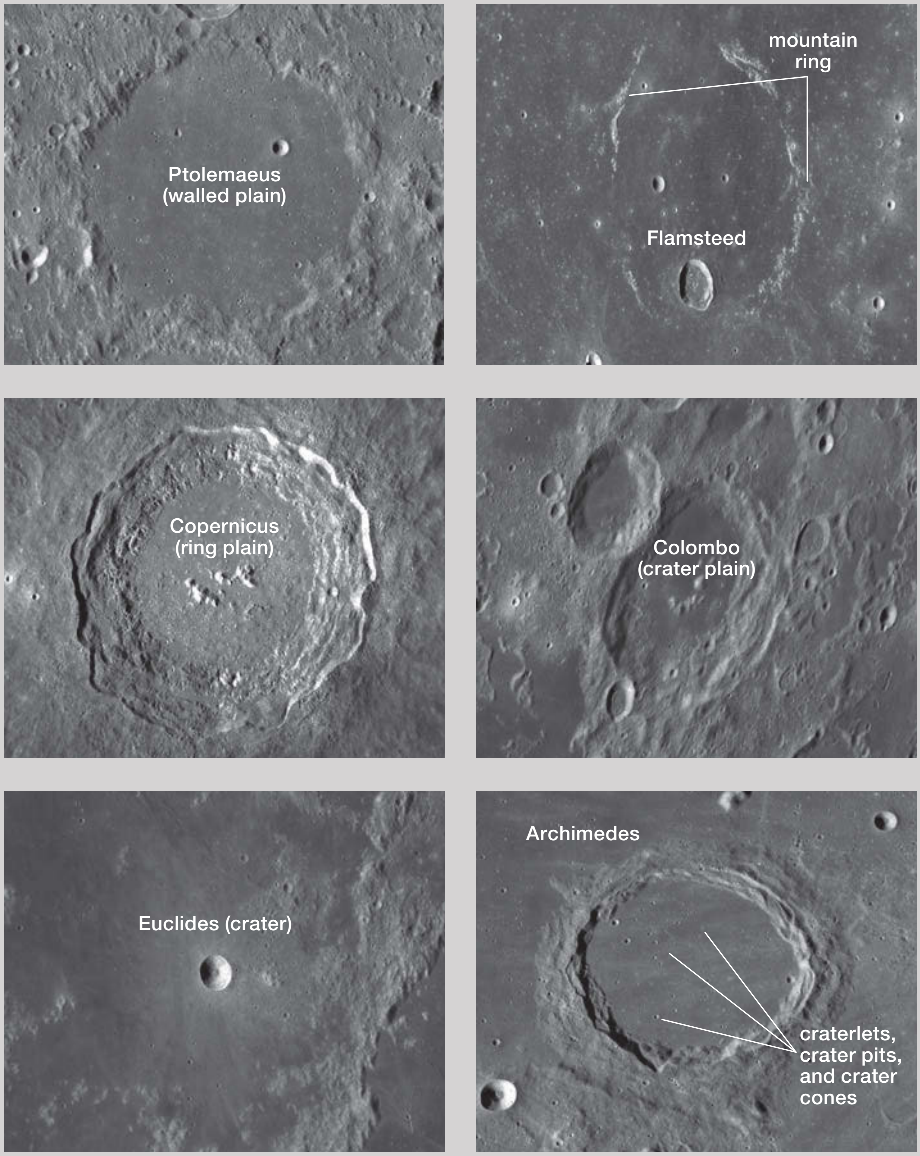
deposits were strongly modified. And mountain rings are complex craters almost completely covered by mare lavas, with only partial remnants of their original rims remaining. Crater plains of the past are mostly eroded complex craters.

Neison's "craters" are today's simple craters, as are craterlets, crater pits, and crater cones. These were too small for telescopic observers to clearly investigate; 19th-century observers thought they were different classes, but they were wrong. Finally, the 19th-century depressions included a mixture of craterlets and random spaces between craters — a grab bag of leftovers that are ignored today.

Today we're data-rich, thanks to the meter resolution of orbital images, our knowledge of terrestrial impact craters, and the thorough analyses of hundreds of lunar samples returned by Apollo astronauts. It's not surprising we know far more than any previous generation of lunar scientists.

Today, we can examine circular features on Pluto and on Saturn's moon Titan in images that have about the same resolution as those of the Moon taken before the Space Age. We know vastly more about impact and volcanic processes than scientists did from the 1830s to the 1960s. But like them, we don't know what we don't know.

■ Contributing Editor **CHUCK WOOD** looks back through observational history to reminisce about what we thought we knew about our nearest neighbor.



NASA / GSFC / ARIZONA STATE UNIVERSITY (6)

▲ In the 19th century, astronomers made the first attempt to categorize craters by their appearance but were heavily influenced by the idea that the features had volcanic origins. The images above from NASA's Lunar Reconnaissance Orbiter depict archetypes for eight of the now-obsolete classifications that persisted through the first half of the 20th century.

Craters	Craterlets	Crater pits	Crater cones	Depressions
5-15	up to 2	>1	>1	1-10
Steep, narrow outer walls falling smoothly to small deep floor, sometimes with small peaks; bright interior walls, craters located in bright material; often found in maria and highlands	Thousands of tiny caters everywhere with no central peaks or other details. Same as craters but smaller.	Shallow rimless craters, often with irregular shapes, like "froth"	Steep, conical hills, some with tiny summit pits; white spots on maria; commonly associated with light streaks (rays)	Irregular, often tiny "blow-holes". Broad, low areas between ridges.
Bode, Euclides, Bessarion, Thebit, Hortensius	Detectable on maria and smooth floors of Plato, Archimedes	Between Vendelinus and Lamé	Near Stadius, on floors of Plato, Archimedes, Copernicus H	No named examples

Working With What You Have

Before you purchase your dream astrophotography rig, consider what you can do with a basic setup.

Many would-be astrophotographers stay on the sidelines because they imagine good results can only be achieved with expensive, specialized equipment.

While it's true that better cameras and lenses generally yield better results, that doesn't mean you can't capture the night sky with gear you may have already. Let's say your main camera is a recent-vintage DSLR (or other interchangeable-lens camera) and the "kit" lens it came with. Could such a basic setup be a practical starting point? There's no harm in at least trying — and you'll probably be delighted by what you're able to capture.

▲ The author appears here with his Canon 80D camera and kit lens. The dark skies above the Painted Hills in central Oregon provided the perfect background to record the summer Milky Way. This 20-second exposure was captured by the author's good friend Chris Boar, who used a Nikon D750 camera set to ISO 2000 and equipped with a 20-mm lens at f/2.8 and a fixed tripod.

Soaking up Starlight

Kit lenses often feature lightweight plastic construction and offer a zoom range of around 18-55 mm. Night-sky photography is all about gathering as much light as possible, but these budget-friendly lenses usually have small-diameter optics, which limits their performance. And additional features like autofocus and image stabilization don't help when you're trying to photograph the night sky. Thankfully, with a few carefully chosen settings, you can still be in the game.

There are three main controls you'll need to adjust: ISO, lens aperture, and shutter speed. ISO affects the "gain" or sensitivity of your camera's sensor. Bumping up the ISO won't increase the actual amount of light captured, but it will produce brighter-looking images. Compared with older models, newer cameras will generally let you use higher ISO values before digital noise starts to spoil the image. You'll need to experiment with this setting to see what works best for your particular camera body, but I've found ISO 1600 is a good starting point.

Next, you'll want to set the lens to its widest aperture available to allow as much light to reach the camera's sensor as possible. The ratio between a lens's focal length and its diameter is called

ALL IMAGES BY THE AUTHOR UNLESS OTHERWISE NOTED the *f-stop* or *f-ratio.* The lower the f-stop number, the bigger the aperture opening and the brighter the image will be. Kit lenses typically have variable f-stops that range from around f/3.5 to f/5.6, with the largest aperture (lowest f-stop value) being at the wide-angle end of the zoom range, and the smallest opening (highest f-stop number) at the fully zoomed end. In other words, to capture the maximum amount of light, you'll want to zoom out so you can use the absolute widest aperture. One caveat here is that most lenses don't yield their sharpest images wide open. So, stopping-down slightly by choosing f/4 instead of f/3.5, for example, will often improve image quality, especially at the edges of the frame.

Finally, you'll want to adjust the shutter speed on your camera. Choose Manual mode (M) to dial in an exposure time of up to 30 seconds. As a starting point try an exposure of 10 seconds. Such a long exposure will require mounting your camera on a tripod to prevent vibration. You'll also need a way to trip the shutter without jiggling your camera. You can accomplish this by using either the camera's self-timer (check the owner's manual) or a shutter release cable. Either way, the idea is to make sure that once the exposure starts, there's no chance that camera motion will blur the image.

Since the auto-focus systems on most cameras can't cope with dim starlight, you'll probably need to switch your lens to manual focus mode and use "live view" (if your camera has that feature) to zoom in and focus on a bright star, planet, or the Moon. Even a very distant streetlight will do. Unfortunately, this is one area in which kit lenses fall down — their plastic construction can make manual focus extremely frustrating. Be patient and do your best. Even a small focus error will lower the overall contrast of your images and obscure faint stars.

▲ Even a basic DSLR camera and kit lens can produce some really pleasing night images. A crescent Moon helped illuminate one of the domes at Pine Mountain Observatory in Oregon in this 30-second exposure shot with a tripod-mounted Canon 80D DSLR set to ISO 3200 and a Canon kit lens zoomed to 20 mm and f/4.5.

▶ You can dramatically improve the quality of images you take with a kit lens by mounting it on a tracking platform such as the iOptron SkyTracker, shown here. Such a mount allows you to take long-exposure shots without the star trails that result from Earth's rotation.

Lastly, it's a good idea to set your camera to record RAW images instead of JPEGs. This will allow you greater flexibility later when it's time to make adjustments.

Try and Try Again

When everything is set, aim at your target and take a series of test exposures that vary from a few seconds up to 30 seconds long. Try different ISO settings, including the highest one your camera offers. You might be surprised how well it works. Next, try zooming your lens to a longer focal length (you'll need to refocus) and take another series of test shots. Finally, if you have a shutter release cable or wireless trigger, set your camera to Bulb (B) mode and lock the shutter open for exposures of one minute or even longer. No matter what kind of equipment you have, experimentation is always key to producing the best photos.

Once you're done shooting and have returned indoors, download the images onto your computer to evaluate what you've shot. You should certainly see some stars, but you might be a little underwhelmed by your initial results. This is normal since all astronomical images need some amount of post-processing to reveal everything you've recorded.

If you view your images at 100% you'll also notice that as your exposure times increase the stars go from tiny points to little lines. These "star trails" are caused by Earth's rotation, which always puts you in a race against time when taking astrophotos with a camera mounted on a stationary tripod. While you can't stop the world from turning, you can counteract its effect by attaching your camera to a motorized equatorial telescope mount or to one of the many inexpensive sky-trackers available. Without one of these options, you will be limited to exposures only a few seconds long if you want pinpoint stars with a kit lens.

Of course, you can embrace star trails rather than trying to fight them. It's fascinating to see the results you can get by aiming your camera at Polaris, the North Star. Exposures of several *hours* show wonderful concentric star trails and maybe even the occasional bright meteor.

Your test shots will reveal the challenges and limitations of your equipment. Generally, even inexpensive DSLR cameras are very capable — it's the kit lens that usually proves to be the weakest link in the imaging chain. That's the main reason a better lens is often among the first equipment upgrades most astrophotographers make.

Getting Better

If wide-field or landscape astrophotography with a fixed tripod is something you want to explore further, there are many lens options available. Generally, you'll want to look for lenses with lower f-stops and shorter focal lengths. The lower f-stop collects more light during a given exposure. For example, an f/2.8 lens gathers twice as much light as an f/4. And a wide-angle lets you shoot longer exposures before the stars start to trail noticeably. A lens that combines both of these features is ideal.

If you can mount your camera on a sky-tracking platform, then you may want to look at longer focal-length lenses that will offer more detailed views of individual deep-sky objects. Again, faster (lower f-stop) lenses are better, but this is less of an issue with a tracking mount since you can increase your exposure times dramatically without star trails appearing.

Although a new lens and a tracking platform are both worthwhile purchases, don't underestimate the value of stretching the equipment you already have to its limits. The lessons you learn by doing so will serve you well in future should you become more ambitious with your astrophotography. And you might find that for your tastes, basic is best.

■ **TONY PUERZER** is a full-time professional photographer and part-time amateur astronomer living on Vancouver Island, British Columbia, Canada.

▲ Even with relatively short exposures, stars near the celestial equator exhibit trails when shot with a camera on a fixed tripod. This 30-second photo was taken at Pine Mountain Observatory in Oregon using a Canon 80D DSLR set to ISO 3200 and a kit lens zoomed to 22 mm and f/4.5.

▲ When shooting long-exposure photos from a fixed tripod, stars near the celestial equator (such as those seen here in the constellation Orion) trace lines across the frame. For this shot, the author made a single, 240-second exposure with the same equipment and settings as above.

▲ This image shows what happens when you shoot a long-exposure photograph on a sky-tracker mount that compensates for Earth's rotation. The stars in this 240-second exposure are perfect points, but foreground objects are smeared out as the camera tracks the sky.

The Footprint, the Egg, and the Butterfly

You may need to stay up late to explore all of these summertime pre-planetary nebulae.

Before producing the beautiful glowing shells of planetary nebulae, low- to intermediate-mass stars (0.8 to 8 solar masses) eventually exhaust their core fuel supply of hydrogen and helium. The star then ascends the asymptotic giant branch (AGB) of the Hertzsprung-Russell diagram, where helium burning continues sporadically in a thin shell surrounding an inert carbon-oxygen core. Hydrogen also burns periodically in an outer shell. However, this double-shell configuration is thermally unstable. Helium ashes from the hydrogen shell build up, increasing the pressure and temperature of the helium shell. Then the AGB star experiences episodes of short but strong bursts of helium burning, known as a *thermal pulse* or *helium shell flash*.

Thermal pulses dredge up substantial amounts of carbon to the surface and trigger shock waves in the atmosphere. A significant outflow of gas and dust (stellar wind) escapes as an expanding circumstellar envelope, though the central star is too cool to ionize its surrounding envelope.

An ephemeral (a few thousand years) phase bridges the end of the AGB and an ionized planetary nebula. This poorly understood metamorphosis — a key link in late stellar evolution — produces a pre-planetary nebula (PPN). Of the hundred or so known PPNe, most are visible only in the infrared, but the summer Milky Way is home to three of the best targets for backyard telescopes.

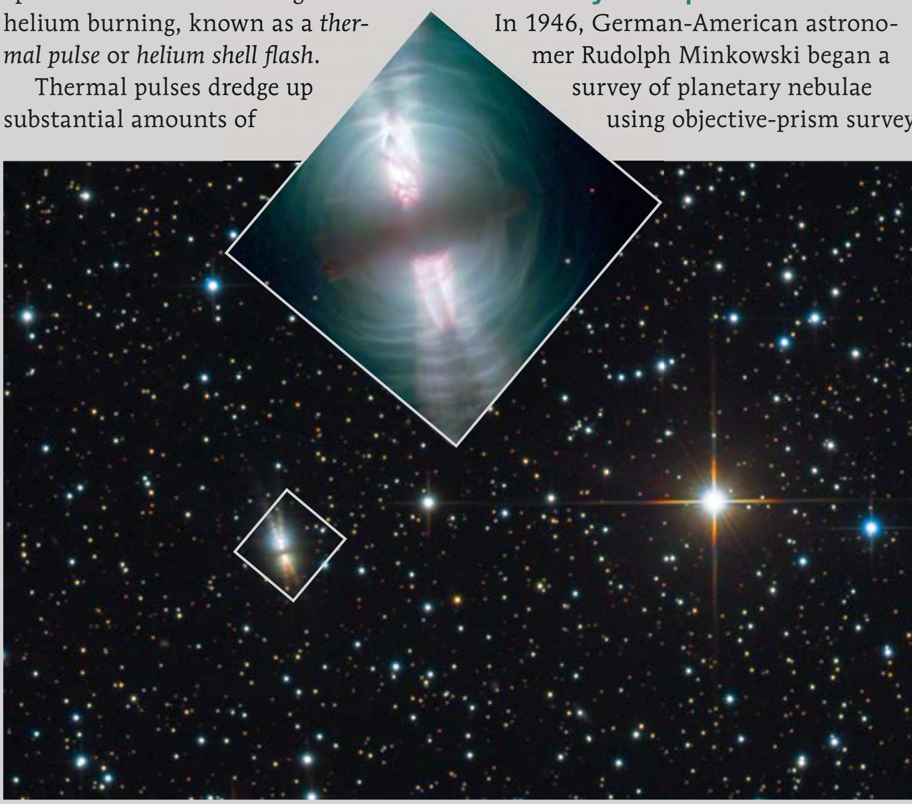
One Tiny Footprint

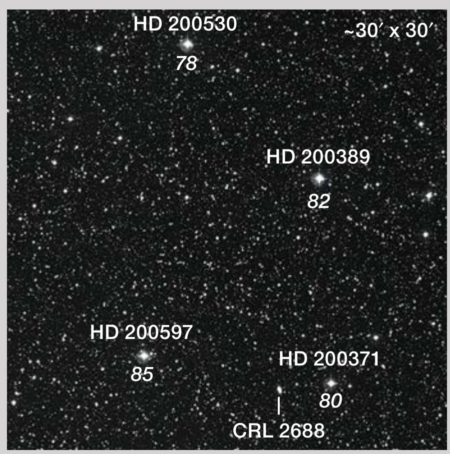
In 1946, German-American astronomer Rudolph Minkowski began a survey of planetary nebulae using objective-prism survey plates at Mount Wilson Observatory. He described **M 1-92** (the 92nd object on his first discovery list, see image p. 58) as follows: "Binuclear nebula without central star. The north preceding mass has a diameter of about 3″ and is separated from the south following fainter mass by a dark lane. . . . The nebula is probably not an emission nebula, but a reflexion nebula which obscures the peculiar star by which it is illuminated."

George Herbig, known for his spectroscopic studies of young stars and the discovery of Herbig-Haro objects, assigned the nickname Minkowski's Footprint in 1975. The footprint comprises two sections, the "sole" and "heel," divided by a slight gap. Herbig found both lobes exhibited a stellar continuum superposed by a variety of emission lines.

He proposed that a flattened dust disk or torus shrouded the central star and a much larger dust shell of low density surrounded this disk. The star illuminates the two lobes through transparent holes at the poles, though the disk partially obscures the southeastern lobe. Herbig speculated that certain emission lines formed near the star and scattered off dust in the lobes, while other lines resulted from photoionization.

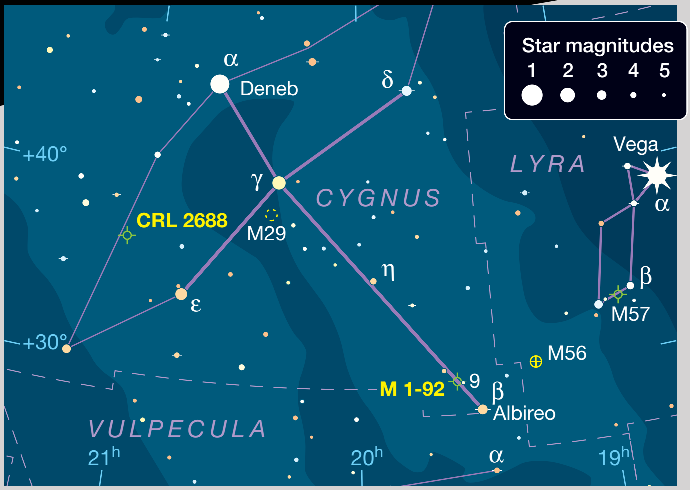
Ground-based telescopes have studied M 1-92 at optical, near-infrared,





◀▼ **EGG NEBULA** Hidden by the dusty disk is the star powering this nebula. We don't observe the star directly, but we see its light streaming through holes in the disk as "searchlight beams." Find this target in Cygnus at RA: 21^h 02.3^m Dec: +36° 42′.

EGG NEBULA AND STAR: BERND KOCH / STEFAN BINNEWIES / JOSEF PÖPSEL / CAPELLA OBSERVATORY; ZOOM: ESA / HUBBLE / NASA; DSS: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY



and radio wavelengths. The central star's temperature is currently 20,000 kelvin, indicating it's well on its way to forming a planetary nebula.

The brighter northwestern lobe (the sole) tilts 35° toward our line of sight and resembles a delicate water lily in the Hubble Space Telescope (HST) image below. The reddened central star peeks out just beyond its inner edge. Studies show a flow of gas and emission knots lie along the lobe's symmetry axis. Astronomers have proposed two sources for the knots: shock heating as a collimated outflow collides with the lobes, and direct formation within the bipolar flow.

A 2007 kinematics investigation, led by Spanish astronomer Javier Alcolea, studied the velocity of the molecular gas and concluded that the ages of the equatorial disk and the bipolar lobes are similar. This suggests a single, sudden mass-loss episode 1,200 years ago triggered the nebula's formation.

Search for Minkowski's Footprint 2° northeast of Albireo, Beta (β) Cygni, and 20′ east-northeast of 5.4-magnitude 9 Cygni. The nebula lies in a dense Milky Way field, but an orange 10th-magnitude star just 30″ to the west highlights the spot. M 1-92 has a high surface brightness and is visible in an 8-inch telescope. That may not sound too challenging, but its teensy disk is easily mistaken at high power for an out-of-focus 12th-magnitude star.

In my 18-inch scope at 565×, the brighter sole is nonstellar and elongated, though it spans only 4″ to 5″ in diameter. The Footprint's heel is a smaller and fainter extension to the southeast that sometimes appeared detached.

The Hard-to-crack Egg Nebula

In 1967, Caltech astronomer Fritz Zwicky happened upon a double blotch while scrutinizing *National Geographic Society – Palomar Observatory Sky Survey* (*POSS*) plates. Zwicky was searching for compact galaxies — eventually cataloging several thousand — and logged a "pair of blue fuzzy oval compacts" as IV Zw 67.

The Air Force Cambridge Research Laboratories rediscovered this object during an infrared, rocket-borne sky survey in 1971–72. Follow-up multi-wavelength studies identified it as an unusual pair of polarized reflection nebulae with a carbon-rich central star. Mike Merrill, a pioneer in infrared spectroscopy, coined the nickname based on its oval shape on the *POSS* plate. A 1975 article in *Sky & Telescope* magazine (page 21 in the January issue) informed readers of the "Mysterious 'Egg Nebula' in Cygnus."

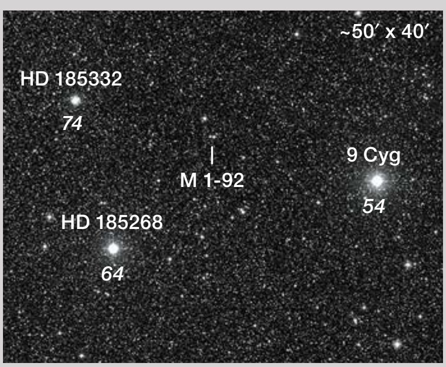
In 1998, NASA astronomer Raghvendra Sahai and colleagues imaged the **Egg Nebula** (CRL 2688) with the HST Wide Field Planetary Camera 2. The stunning high-resolution image (on page 57) shows a twin pair of narrow collimated "searchlight beams." These emerge from an equatorial dust cocoon that obscures a binary central star. In Sahai's model, an outflow of high-velocity gas carved a pair of annular holes or rings in the dust disk. Starlight shines through these polar holes then scatters off and illuminates the nebular dust, creating the searchlight-beam features captured by the HST.

A remarkable series of concentric arcs or incomplete shells crisscross the beams. Assuming a distance of 1,400 light-years, these shells span at least one-quarter of a light-year. According to a 2012 study led by Bruce Balick (University of Washington), the shells were ejected every century for the last 4,000 years, though the dual polar beams formed only during the past 250 years.

A 2003 radio-based investigation headed by Jamie Lee Highberger (University of Arizona) detected sodium chloride and sodium cyanide molecules in the circumstellar AGB envelope. The unusual discovery of sodium chloride inspired the paper's whimsical title: "The Salty Scrambled Egg."

The Egg Nebula lies 4.3° northeast of 2.5-magnitude Epsilon (ε) Cygni, the star marking the Swan's eastern wing. An 8th-magnitude star (HD 200371) just 4′ west helps pinpoint the location. This smudge shines at 12th magnitude, but because of its diminutive size, you'll need high magnification and steady seeing to resolve any detail.

With my 18-inch scope at 108×, the Egg mimics a fuzzy, unequal double star tipped to the north-northeast. At 450×, the northern lobe is a high surface brightness oval, perhaps 10″ in diameter, with a brighter spot at the center. A very dim extension (the base of the northern beams on images) fans farther north. The southern lobe, separated by a slight gap, is fainter and only half the size.



◀▲ **MINKOWSKI'S FOOTPRINT** The dot between the two onion-like lobes is a dying star that will soon become a white dwarf. Starlight is reflected off the nebula, which is why we can see it. RA: 19^h 36.3^m Dec: +29° 33′.

MINKOWSKI'S FOOTPRINT: ESA / HUBBLE / NASA; DSS: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

The polarization induced by aligned dust grains is nearly 50% over most of the nebula. This effect can be seen visually by inserting a variable polarizing filter into the light path. Experiment by slowly rotating the filter to different positions and look for changes in the nebula's brightness.

Wings of a Cosmic Butterfly

Minkowski's Butterfly (M 2-9), or the Twin Jet Nebula, is one of the most dramatic bipolar PPNe imaged by the HST. It displays a delicate axial symmetry on both sides of the nucleus and a dusty, pinched waist. Age estimates place it at around 2,500 years, which implies a distance of around 4,000 light-years.

Astronomers usually classify M 2-9 as a *symbiotic nebula*. In this scenario, the binary central star consists of a hot white dwarf and a Mira-type companion. The latter loses mass via its stellar wind or else transfers mass to the white dwarf when it overflows its Roche lobe. The white dwarf ionizes this gas, thus mimicking a young planetary nebula.

Balick and collaborators' recent model of M 2-9 using hydrodynamic simulations showed that a conical spray blasts out at an incredible 200 km/s (450,000 miles/hr) in the polar direction. The gas interacts with the pre-existing AGB wind that is slower and denser, forming and shaping a variety of features.

The Butterfly's "proboscis" or outer lobe extends 1′ in both directions, so the nebula's total size is 120″ × 12″. At the outer tips are blobs of compressed gas (N4 and S4; see the diagram below). The bright inner lobe is hourglass-shaped and nested with two separate shells: an inner "bulb" and a thin outer "sheath." Two brighter knots, N3 and S3, are near the tips of the inner lobes and appear flattened in HST images. In Balick's model, the knots formed in situ and were not ejected by the core.

A 2011 study by Romano Corradi (Instituto de Astrofísica de Canarias) and colleagues compared 12 years' worth of observations and found dramatic changes in the Butterfly's inner lobe. Hα and O III images showed the knot pairs S1/S2 and N1/N2 marching along the walls of the lobe from east to west. The knots rotate around the symmetry axis (the period is nearly one century) within a "lighthouse" jet from the central star. This pattern points to a symbiotic binary source, whose orbital period matches the rotation period of the knots. The phenomenon results from a collimated jet of high-velocity particles that shocks and excites the bulb walls on impact.

The thin equatorial region has two expanding, ring-shaped structures of molecular gas and dust with diameters of 2.5″ and 7″. A 2012 investigation headed by Arancha Castro-Carrizo (of the Institut de Radioastronomie Millimétrique in France) found these rings move in different directions, suggesting two mass-loss episodes occurred 900 and 1,400 years ago at distinct points in the binary star's orbit.

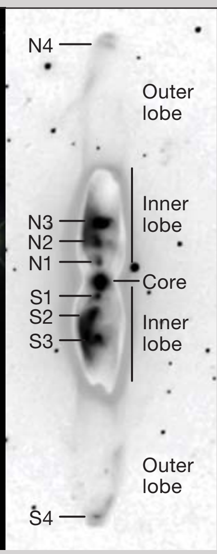
This Butterfly floats in central Ophiuchus: You'll find it 4.6° northwest of 4th-magnitude Nu (ν) Serpentis and a little more than 1° west-northwest of 5.4-magnitude HD 155078. My first observation of it was 35 years ago through a 13.1-inch reflector at 214×. M 2-9 appeared as a thin, 30″-long streak, bisected by a 14.5-magnitude central star. A narrowband filter produced a slight contrast improvement.

In my 18-inch scope at 435×, two thin wings, each 15″ to 20″ in length, extend north and south from the central star. The wings appear detached from the star, and the northern knot N3 occasionally pops into view. With exceptional seeing at 565× in my 24-inch scope, N3 morphed into a short bar perpendicular to the wing.

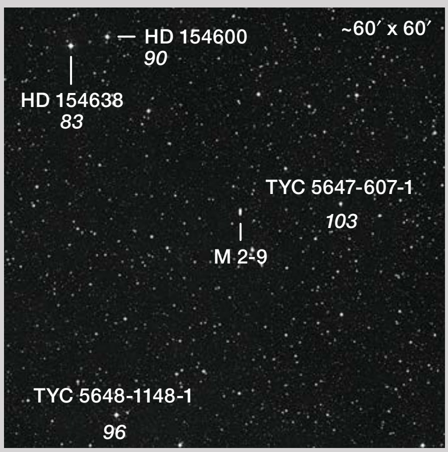
Despite their small angular size, pre-planetary or post-AGB nebulae are among the most mysterious and alluring objects captured by the HST. I hope the three I've highlighted here whet your appetite for more.

■ Even after observing the entire *NGC* (7,500+ objects), Contributing Editor **STEVE GOTTLIEB** still enjoys chasing exotic targets like pre-planetary nebulae.

ANIMATION: Go to **https://is.gd/butterfly_animation** to see the Egg Nebula's evolution between 1997 and 2010.



◀▼ **MINKOWSKI'S BUTTERFLY** The central object in this pre-planetary nebula is a binary star, which is responsible for the bipolar nature of the outflow. RA: 17^h 05.6^m Dec: –10° 09′.



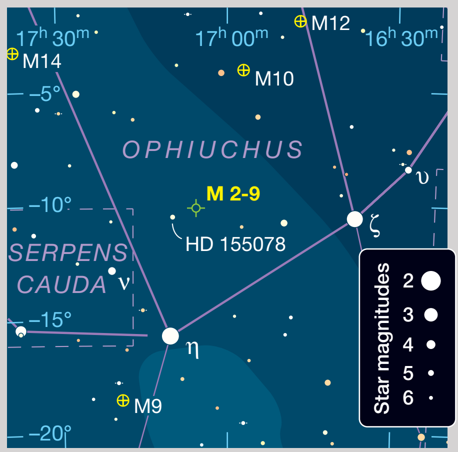
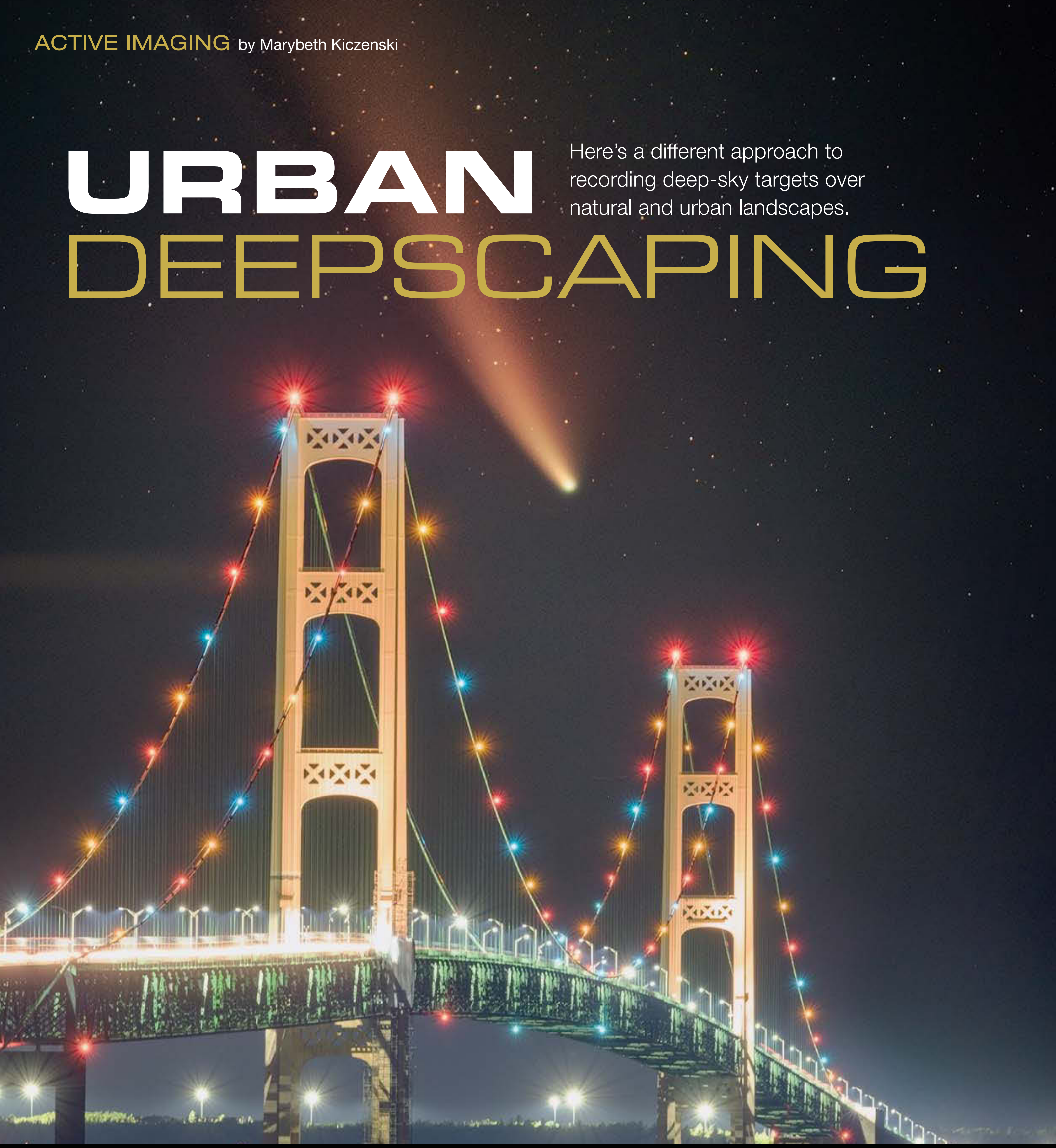


PHOTO: ESA / HUBBLE / NASA / JUDY SCHMIDT; DIAGRAM: ROMANO CORRADI ET AL. / *ASTRONOMY AND ASTROPHYSICS* 2011; DSS: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

URBAN DEEPSCAPING

Here's a different approach to recording deep-sky targets over natural and urban landscapes.



UP CLOSE AND PERSONAL Photographing deep-sky targets over terrestrial landscapes is an interesting challenge. Marybeth Kiczenski shares her tips for capturing deep images such as this shot of Comet NEOWISE (C/2020 F3) above the Mackinac Bridge, which connects the two parts of the state of Michigan. This image consists of six 2-minute, tracked exposures combined with a single 60-second image of the foreground, each recorded with a modified Nikon Z6 Mirrorless camera and 70-to-200-mm lens at 185 mm, ISO 250.

Who among us hasn't been inspired by the beauty of the Milky Way standing high above a picturesque horizon, or marveled at detailed close-up images of nebulae, galaxies, and other deep-sky objects? Both kinds of scenes have a wonderful appeal, but have you ever thought of what happens when you combine a close-up view of a deep-sky target with a photogenic landscape? This is the kind of imaging known as *deepscape* astrophotography.

Deepscapes blend detailed telephoto shots of deep-sky objects aligned with interesting subjects on the horizon. Ever stumble across one of those "big Moon" photos? This is essentially what a deepscape accomplishes. A telephoto lens exaggerates the size of the main subject compared to objects closer to the photographer — an effect known as *lens compression*. While some photographers prefer to shoot a single exposure to create a deepscape photo (*S&T:* Feb. 2020, p. 26), these shots can also be a mix of exposures in order to maximize detail while minimizing noise — much like more conventional deep-sky astrophotography. The technique described here is also helpful when shooting urban deepscapes under light-polluted conditions.

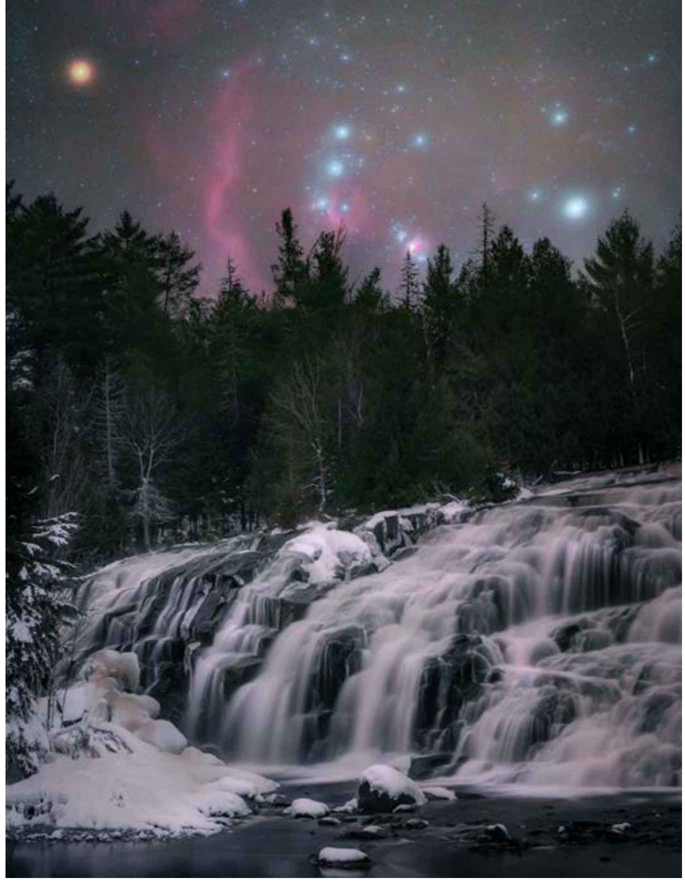
The difference between a deepscape and a fantasy image is that the scale and location of all elements in the finished photograph are true to that specific location and optic. In other words, all parts of a deepscape are shot with the same camera and lens at the same location, preferably on the same outing. The final result brings those distant objects closer to the viewer, creating an intimate connection between the land and sky.

However, when it comes to deepscapes that include faint nebulae, the process is a bit more involved than a snap of the Moon. Here's how I do it.

Tools of the Trade

In order to photograph your target and the landscape below, you'll need more than just a camera and a tripod. Recent model DSLR or Mirrorless cameras are recommended, though older units can work well too. Cameras that pick up emission nebulae are best suited to the task. My favorites are the Canon EOS Ra, Nikon 810a, or the newer Nikon D850. Other cameras modified for deep-sky imaging are also a good choice (like my Nikon Z6), though try to search for newer models, as they have much lower noise at high ISO settings than older ones.

In addition to a camera, you'll need a good, fast telephoto lens. The lens speed is important because you want to be able to capture as much nebulosity and as many stars as possible in a fairly short exposure. Fixed-focus lenses tend to perform best, though high-end zooms work great, too. Avoid cheaper zoom lenses, as they often are slow and become slower the more you zoom in (for example, a 75-300-mm kit lens ranges from f/3.5 to f/5.6), which requires more exposure to get a good result. I often shoot with a Nikon Z6 and Nikkor AF-S 70-200-mm f/2.8E FL ED VR lens, which retains its photographic speed throughout its zoom range. Additionally, this lens holds its zoom position nicely and does not slip.



▲ **DEEPSCAPE MOSAIC** You can create multi-panel mosaics that take advantage of the higher resolution of a telephoto lens with the expansive field of view typically seen with wide-angle lenses. This photo of Orion rising above Bond Falls in Michigan is the result of four frames shot with the same zoom lens at 70 mm and assembled in *Photoshop*.

Next, you'll need a good tracking mount and sturdy tripod. I prefer the Sky-Watcher Star Adventurer for its high-payload capacity compared to similar star trackers, though other models (like the latest Vixen Polarie) also work well. Having the ability to add a counterweight is beneficial, particularly if your lens is fairly heavy. Choose a sturdy tripod — don't skimp here, because you'll want your setup to hold steady even in a strong breeze. I use a carbon-fiber model from Sirui to keep down the weight, as I often hike some distance to my photo sites.

Other necessary gear includes a sturdy ball head so that you can compose your photo without being limited to the axis of your tracking mount. Since you'll be recording exposures of about a minute or more, you'll also need a shutter release cable

▶ **THE RIGHT TOOLS** In addition to a sturdy tripod, shutter release cable, and digital camera, deepscape astrophotography requires a fast, high-quality telephoto or zoom lens, a solid ball head, and a good star tracker.

ALL PHOTOS COURTESY OF AUTHOR

or even an intervalometer if your camera doesn't have one built in. The best option is a wireless intervalometer or cable release, so that you don't accidentally tug the camera while firing off your exposures.

It's All in the Plan

Once you have your gear, you need to plan your shots. You'll want to know where your chosen target will be relative to the landscape or structure you hope to record it with. For example, last July Comet NEOWISE (C/2020 F3) presented several great deepscape opportunities. Since the comet was passing through the north, low to the horizon late at night, I thought it would be pretty cool to capture it above the Mackinac Bridge, which connects the two parts of the state of Michigan. A shot like this requires careful planning, because it deals with a small field of view. Add in the ever-changing position of the comet, and it becomes even more challenging to compose the photo. Luckily, there are tools available online and smartphone apps to help pre-visualize your shot. I used the free online planetarium program *The Sky Live* (**theskylive.com**) to plan this image and figure out when the comet was lowest to the horizon from my chosen location.

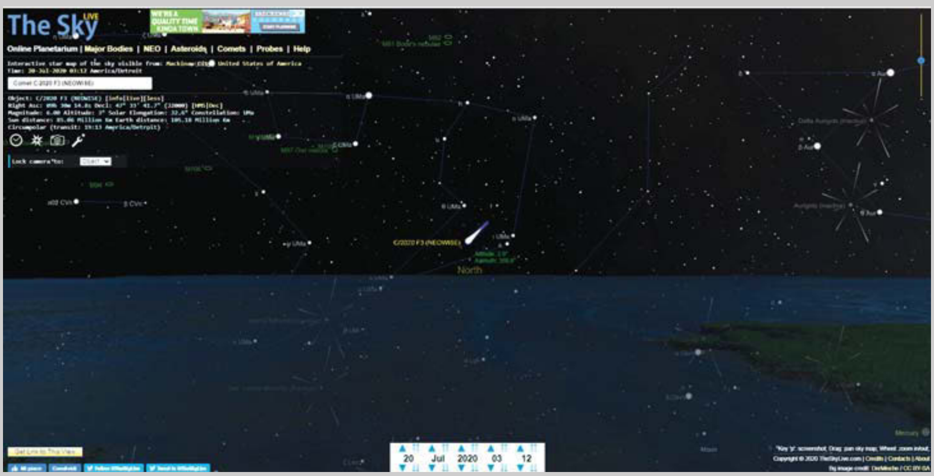
The Mackinac Bridge spans from north to south as seen from Mackinaw City, and I wanted to frame the comet between the towers of the suspension bridge. Additionally, I had to take into consideration the altitude of the comet from where I planned to photograph — I didn't want it too far below the bridge, or too high. According to the app, there were only a handful of days in which this alignment would be the best. I decided my best opportunity was on July 20th, when the comet would appear precisely due north at about 3:12 a.m.

Next, I had to figure out if the landscape portion of the scene worked compositionally. For this, I turned to the smartphone app *PlanIt Pro* (**yingwentech.com**). This fantastic tool lets you pre-visualize a shot with astonishing accuracy. The app features constellation overlays, which are invaluable for both nightscape and deepscape photography. And while the app doesn't include transient objects like comets, its star charts, combined with the position noted in *The Sky Live*, allowed me to know the comet's precise location. On this particular morning, NEOWISE was passing just below the Big Dipper, which was helpful because its stars are visible even with the bright lights of the Mackinac Bridge.

To use *PlanIt Pro*, you first have to "pin" the exact location where you plan to set up. Use the search feature to narrow down your area, then hold your finger on the spot until a red pin appears. Next, touch the camera icon, and you're ready to set the focal length of your lens so the app can display your camera's field of view. Do this by tapping the lens value under Focal Length and inputting your lens. Using my zoom lens, I start with the wide-angle number to get my bearings, then I "zoom in" to the focal length I plan to use in the next step.

With the lens set, tap the top left corner of the app to open the Ephemeris Features and select Night Photography > Stars

Planning Ahead



▲ **THE RIGHT TOOLS** Planning images that include a transient object like a rare bright comet requires finding its exact position in the sky on the evening you intend to photograph it. Most all planetarium programs offer updates to include new comets. This screen capture shows the view as predicted by the online app *The Sky Live* on the morning of July 20th, 2020.

▶ **FINDING YOUR SITE** Several apps are available in both the Apple and Google Play marketplaces to help you precisely identify your location to get the best image. This screenshot shows the view using *PlanIt Pro*.

▶▶ **LAND AND SKY REFERENCE** *PlanIt Pro* also includes an option to display the bright stars and constellation lines.

READY FOR A SHOOT Author Marybeth Kiczenski heads out for a night of deep-scape photography.

and Star-trails. The view will return to the overhead map view. Touch the name of a star at the top of the screen, and you can change the listing from Major Star to Constellations and activate the constellations you'd like displayed. After that, touch the bracketed box on the lower right of the screen and select Viewfinder (VR). You should now see the major constellations, which will help you pinpoint where your subject will be in relation to the horizon. You can zoom in by spreading apart two fingers on the screen — this changes the focal length setting. The app also will load elevation maps, so you can see if there's a tall hill or mountain in the way (not a problem in Michigan).

Once you're comfortable with the scene, continue to adjust the time setting to pinpoint the period with the best alignment between your target and foreground. Be sure to save your plan, as you'll need it to open it again when at your chosen location.

Executing the Plan

Now you can head out to take your photos. Be sure to leave plenty of time, because you'll need to perform an additional action with *PlanIt Pro* to nail your composition once you arrive on location.

Once onsite, open your saved plan to find your predetermined shooting spot (the app uses GPS to show you exactly where you are compared to your pinned location). Next, click on the bracketed box again and select Viewfinder (AR). This is the "augmented reality" function of the app, which first requires you to snap a picture in the direction of your composition. This will be overlaid on the view so you can refine the plan of when your target will be in the exact spot for your image. Follow the app's instructions to take the foreground image.

With the location shot in the app, simply scrub through the time and check the constellations that are projected into the view. Do they still line up as in your original plan using the Viewfinder (VR) setting? If so, then you're good to go! If not, you may have to adjust your location slightly.

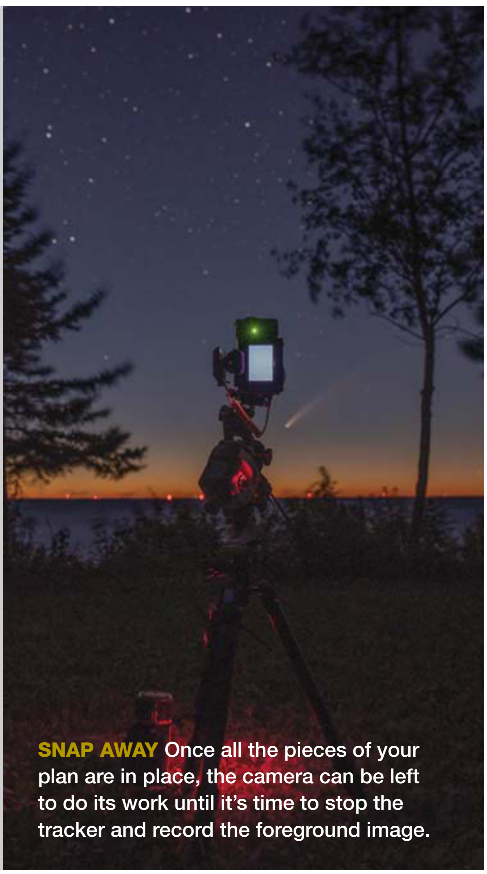
When you're satisfied with the view, set up your equipment, polar align your star tracker, and wait for the big moment. For NEOWISE, I fired off six 2-minute, tracked photos as the comet moved between the bridge's towers. Seeing that icy snowball show up on the camera's viewscreen was nothing short of amazing! After recording the tracked exposures, I turned the drive off and took a few stationary images of the bridge. This particular night was quite windy, so I took several frames to ensure at least one was acceptably sharp.

Putting It All Together

Once you're back home with all your photos, you can load them into your computer and combine them into your composition. In my workflow I utilize a few programs, including *Adobe Lightroom* and *Adobe Photoshop*, plus *PixInsight* for image stacking.

I begin by opening all the RAW images in *Lightroom*, where I perform initial adjustments, such as white balance, some exposure adjustments, and matching the color casts between each exposure as closely as possible so that they blend well. I then save each image as a 16-bit TIF file.

Next, I'll move on to the foreground picture. I process this in *Lightroom* the same way as with the tracked images, but depending on the lighting I may use a single shot or stack a few images to reduce noise in underexposed areas. In the case



SNAP AWAY Once all the pieces of your plan are in place, the camera can be left to do its work until it's time to stop the tracker and record the foreground image.

of my Mackinac Bridge photo, I only needed a single frame due to the bright lights on the structure, which permitted a good exposure.

With the basic adjustments completed, I then move on to combining the tracked shots. I open all the guided frames in *PixInsight* and align and stack them into the "master" deep-sky picture to be blended with the stationary foreground shot. Once completed, I then open both the master sky shot and the foreground in *Photoshop*.

There are several ways to align the tracked shot with the foreground. I usually try *Photoshop* first (File > Scripts > Load File into Stack . . .). This script saves the time of copying and pasting the stationary shot onto the tracked and stacked image. Next, the two layers need to be aligned. *Photoshop* has a script for this, too — Edit > Auto-Align Layers . . . , which often works well. But if it doesn't, I manually shift the stacked image into place by selecting the top layer in the Layers palette and nudging it into place with the arrow keys.

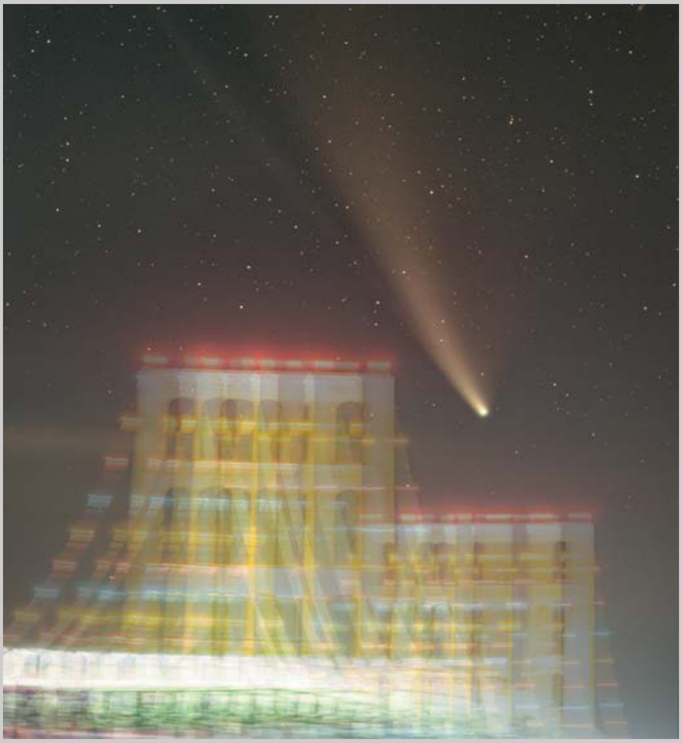
◀ **SCORPION AND RAPTOR** With these techniques, you can get creative and work most any foreground object into a deepscape composition. This image combines several exposures recorded at 70 mm and totalling 16.5 minutes.

Now that the two images are aligned, it's time to blend them together. I do this with a layer mask. At the bottom of the Layers window, I click the white square with the gray circle in the middle. I then select the Brush Tool from the tools palette (make sure your color is set to black) and then simply "paint" the area I want to mask out of the top layer. Adjust the hardness setting of the paintbrush tool to make a smooth transition from the top layer to the background. And voila! The tracked and stacked image surmounts the stationary landscape.

I may perform additional adjustments, such as matching the brightness and color along the border between the two layers. This is easy to do while the image still retains its individual working layers. Depending on how complex the foreground is, you may also need to spend a crazy amount of

Combining Tracked and Stationary Images

▲ **FOLLOW THE STARS** The advantage to tracking an exposure is evident in this single, 2-minute exposure showing Comet NEOWISE shining through the lights of the Mackinac Bridge — a scene that's practically impossible to capture in a short, unguided exposure.



▲ **DRIFTING BY** Stacking six 2-minute exposures recorded at f/2.8, ISO 250 dramatically increases the visibility of the comet's yellowish dust and bluish ion tails, while stationary objects in the foreground are significantly blurred.

▶ **TWILIGHT REFLECTIONS** Comet NEOWISE stands high over Lake Michigan on July 13, 2020. This composite consists of several 1-minute exposures recorded with a Nikon Z6 and zoom lens at 86 mm, ISO 800.

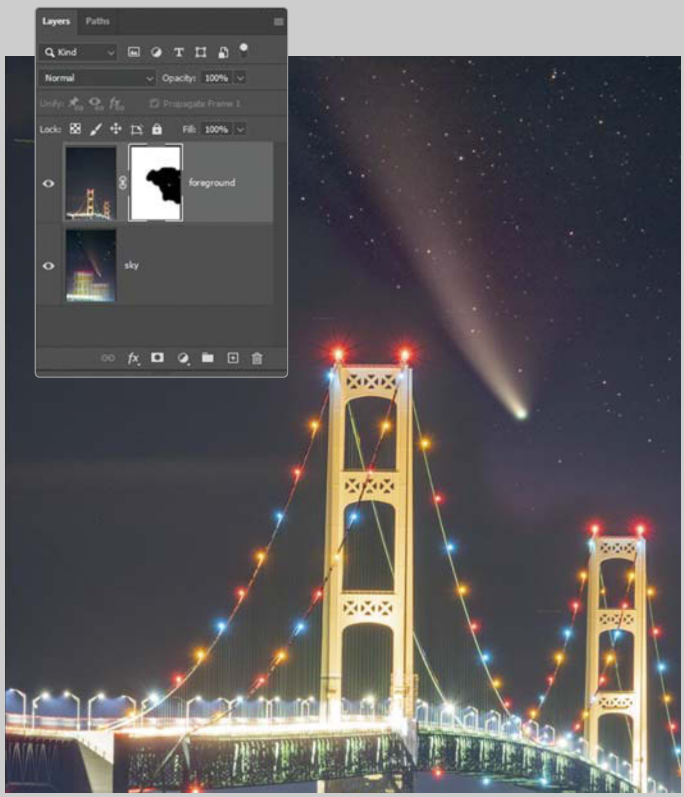
time masking, especially if there are lots of trees. These are the basic steps, but every deepscape tends to be a little different, requiring some modifications to the process.

The technique described here works just as well for multi-panel mosaics and panoramas, giving that wide-angle "nightscape" feel with more details than can be recorded in a single image captured with wide-angle lenses. Like most astrophotography, the sky and your creativity are the only limits.

With this basic technique, you can get out and deepscape most anywhere that presents interesting juxtapositions of large, bright nebulae, galaxies, star clusters, and the occasional comet above interesting foregrounds. Your subject matter is endless once you master these basic techniques and develop a workflow that works best for you. With today's equipment and the power of the digital darkroom, imaging the sky has never been easier — so get out under the stars and deepscape the world!

■ **MARYBETH KICZENSKI** photographs the night sky from rural and urban locations around the Great Lakes region.

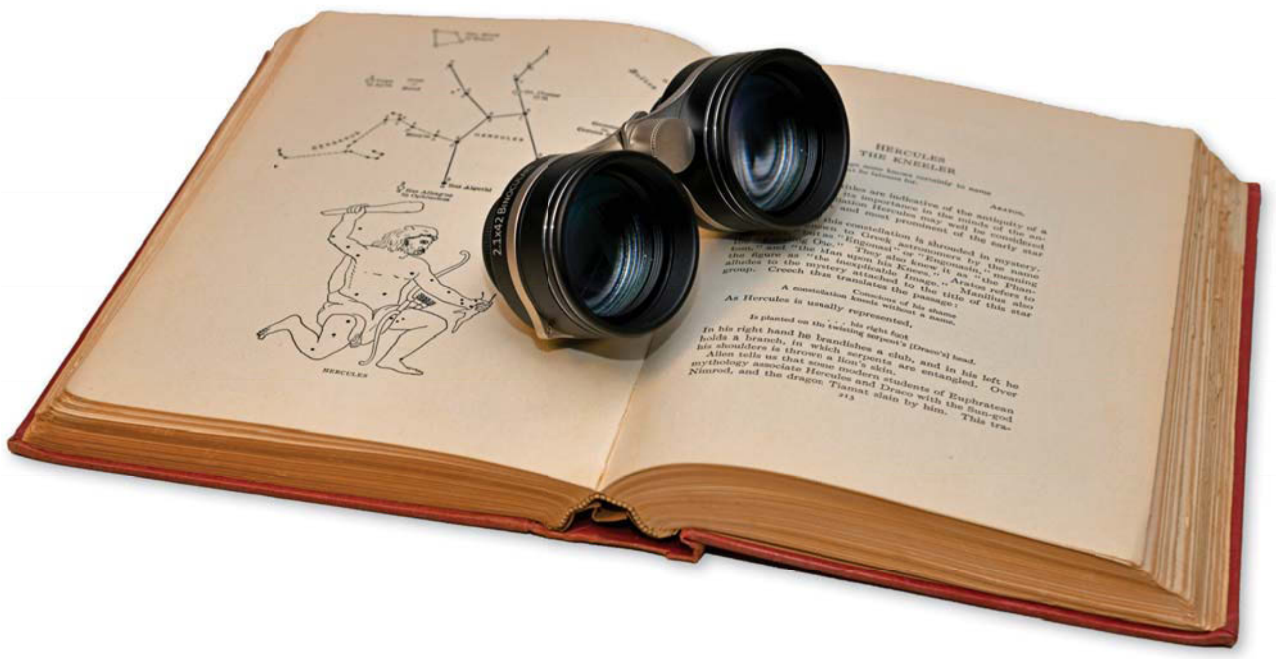
▲ **TRAILED STARS** Conversely, a single minute-long exposure taken through the same camera and lens captures the foreground nicely, though astronomical objects appear trailed.



▲ **UNMASKED RESULT** To get the best of both results, paste the stacked comet image over the foreground photo, and then a layer mask is created. The mask only reveals the comet and stars while blocking the blurred foreground, permitting the stationary foreground shot to be seen.

Omegon's 2.1×42 Wide-Field Binoculars

Sometimes dismissed by observers, these wide-field binoculars fill an unusual niche when it comes to viewing the night sky.



▲ The Omegon 2.1×42 Binoculars make the perfect optical aid for learning the constellations, especially from locations where light pollution has hidden many of the fainter stars that fill out the celestial patterns.

ALL PHOTOS BY THE AUTHOR

Omegon 2.1×42 Binoculars

U.S. Price: $149

Omegon.eu

What We Like

Very well made

Smooth, individually focusing eyepieces

Excellent aid for learning and enjoying the night sky under less-than-ideal conditions

What We Don't Like

Maximum field of view reduced for those who observe wearing eyeglasses

IF THESE UNUSUAL binoculars have caught your eye, but you've dismissed them as not being very useful for astronomy, you're not alone. But you're also not right. They offer a view of the starry sky unlike anything you'll see with typical binoculars and opera glasses — something that was dramatically apparent the moment I turned them skyward. Although I was well prepared for the advantages this type of optical system brings to viewing the night sky, I wasn't prepared for how instantly smitten I was with the views through the Omegon 2.1×42 Binoculars. Whether it was the views or my reaction to them I don't know, but either way it was a delightful introduction to astronomical observing with this pair of binoculars.

So why have some amateurs dismissed them? From chatter I've seen online there are two reasons. One is the low magnification, especially since most binoculars recommended for astronomy have magnifications of 7× and greater. It's true that 2.1× isn't a lot, but it is enough to split some double stars, identify a few lunar craters, and give an occasional glimpse of Jupiter's four Galilean moons. While most of us wouldn't consider that a big deal, I think everyone would agree that if nature had equipped us with eyeballs that could switch to 2×, we'd find it immensely useful for astronomical observing.

The other turnoff seems to be the objectives' 42-mm apertures, which

▶ The binoculars come with a carrying case, wrist strap, cleaning cloth, and a complete set of lens caps.

some people find misleading. The laws of optics dictate that all the light the 42-mm apertures collect cannot enter your eyes and much of it is thus wasted. Where you place your eyes in the light bundle emerging from the eyepieces of binoculars is called the exit pupil, and its diameter is equal to the binocular's aperture divided by its magnification.

For the Omegon 2.1×42 that's an exit pupil 20 mm in diameter — far greater than what can enter the dark-adapted eye's pupil, which is typically around 7 mm for young people and decreases with age. Indeed, at 2.1× the maximum aperture that can channel all the light it collects into an eye's 7-mm pupil is 14.2 mm. But the Omegon's twin 42-mm apertures are not a waste nor are they an attempt to mislead the consumer, but rather it is needed to create the binocular's very wide field of view. And it does this very well.

The Omegon 2.1×42 Binoculars are based on a Galilean optical design, which in its simplest form is a convex objective lens and a concave eyepiece (the Omegon is a more advanced version, with four lens elements). The field of view that you see with a Galilean system is governed somewhat by the diameter of your eye's pupil, and with my dark-adapted "senior" eyes it was a bit more than 25° — large enough to take in all of the Big Dipper from the end of the handle to the tip of the Pointer Stars. (This field is reduced for people who observe wearing eyeglasses and thus have their eyes farther back from the eyepieces.) Stars appeared sharp across more than half the field, but even those at the edge weren't objectionable given that I naturally concentrate my view toward the center of the field.

I was particularly interested in how much the Omegon 2.1×42 Binoculars improved the visibility of faint stars. Crunching numbers for the gain that an effective aperture of 14 mm provides versus the unaided eye's 7 mm suggests that the binoculars will show stars more than 1½ magnitudes fainter than the naked eye under a dark sky. This gain remains a constant regardless of your eye's maximum pupil diameter. And

▼ *Left:* The eyepieces individually rotate to achieve sharp focus. The mechanism is smooth and holds focus very well once set. The binoculars accommodate interpupillary distances between 55 and 75 mm. *Right:* The objective cells are threaded to accept filters made for standard 2-inch telescope eyepieces.

while it seems a bit counterintuitive, the gain is more pronounced in light-polluted skies because the binocular's 2.1× magnification darkens the background sky by a factor of more than four, thus improving the contrast with faint stars, which are not dimmed by the magnification. There were nights when I could almost convince myself I was seeing stars more than 1½ magnitudes fainter in my suburban sky. That adds a lot of stars to the view!

As mentioned above, I was familiar with the advantage this type of optical system brings to astronomy. My first 35-mm camera — a fixed lens, rangefinder model — had an accessory Tele Lens that is essentially a 1.8× Galilean telescope with a 57-mm aperture. Advertisements for low-power astronomical binoculars reminded me of my old Tele Lens, so I dusted it off and started using it as an astronomical monocular. The views it provided were interesting but not exceptional, which is why I was surprised by my immediate fascination with the view through the 2.1×42 Binoculars. Certainly, the natural sensation that comes from viewing with both eyes was a factor, but it took a bit of self-reflection to figure out why it seemed to be more than that.

◀ As mentioned in the text, the author used the Tele Lens accessory from his first 35-mm camera as a wide-field 1.8× astronomical monocular after being reminded of it by the first advertisements for the Omegon binocular. The lens and binocular are both based on a similar Galilean optical design.

▼ The binoculars' central pivot has a standard ¼-20 tripod socket. The author used it to attach a simple wooden stick that made it much easier to hold the binoculars for extended periods of observing.

As a pre-teen I taught myself the constellations using star charts in several library books, including those in William Tyler Olcott's *Star Lore of All Ages*. These simple star charts were a near-perfect match for my rural skies, and the learning experience provided one of the foundation blocks for my lifelong love of observing. Light pollution has continually taken its toll in eastern Massachusetts, and the naked-eye constellations of my youth no longer grace my backyard sky. But that first look through the 2.1×42 Binoculars showed they were still there and every bit as enchanting to me as they were at the dawn of the Space Age.

Regular binoculars reach fainter stars but can only show the smallest constellations in a single view. The 2.1×42s serve up the major outlines of Cygnus, Orion, Gemini, Auriga, the Square of Pegasus, and much more in one gulp. It's a great way for today's suburban observers to explore the constellations the way they appear above a rural landscape with the added benefit of 2.1× magnification. And the 2.1× helped me pick out occasional deep-sky objects that I've long remembered from Olcott's charts, albeit they were mostly faint but discernible smudges. Still, it was satisfying to find them.

The objective cells on the Omegon binoculars are threaded to accept standard 2-inch eyepiece filters, and there's a ¼-20 socket on the central pivot for use with tripod adapters. I fashioned a simple wooden handle that attached to the tripod socket so that I could comfortably hold the binoculars to my eyes with one hand for extended periods, much the way we think of people using opera glasses.

During the peak of last year's Geminid meteor shower I mixed naked-eye meteor watching with random intervals of scanning the sky with the Omegon binoculars and was struck with how often I caught sight of a meteor with them. I can't say that those meteors wouldn't have been visible to my unaided eyes, but the number did seem disproportionately high, especially given the smaller field of the binoculars.

The Omegon 2.1×42 Binoculars are definitely a joy to use, and I highly recommend them for anyone wanting to learn the constellations under less-than-ideal sky conditions. It was fun to look up from my back deck and see the Little Dipper as a complete dipper rather than just Polaris and a pair of stars in the dipper's bowl. And it was also nice using the binoculars to keep tabs on several well-known variable stars such as Algol in Perseus, where the wide field allowed having a complement of good reference stars in a single view. I started out with the thought that these binoculars would be interesting to test, and I ended up liking it way more than I ever expected.

■ **DENNIS DI CICCO** spends a lot of clear nights testing equipment from his backyard observatory in Boston's western suburbs.

▲ FLAT-FIELD EYEPIECES

Celestron introduces a series of eyepieces with excellent correction. The Ultima Edge series includes 10-, 15-, 18-, and 24-mm 1¼-inch eyepieces, as well as a 30-mm 2-inch version. The optical design uses between 5 and 9 multi-coated lens elements per ocular to produce sharp views from the center to the edge of the field. The series features apparent fields spanning 60° to 70°, and all models are parfocal, allowing users to quickly change magnifications without the need to refocus. Prices range from $89.95 for the 10-mm model to $239.95 for the 30-mm eyepiece.

Celestron
2835 Columbia St., Torrance, CA 90503
310-803-5953; celestron.com

▲ UNIVERSAL FINDER BASE

The Explore Scientific Hybrid Finder Scope Base ($39.99) is designed to accept all legacy Explore Scientific finderscope and mini dovetail brackets, including those manufactured by Celestron, Sky-Watcher, Synta, and many others. This black-anodized bracket attaches to your scope with an included pair of nuts and bolts, and it firmly holds finderscopes as well as most unit-power red-dot finders. The base includes three knurled thumb screws to secure your finder device, and threaded holes on both sides of the base allow you to connect your finder in the most accessible location on your scope.

Explore Scientific
1010 S. 48th St., Springdale, AR 72762
866-252-3811; explorescientific.com

◀ OBSERVING TENT

Explore Scientific now provides an observing tent for amateur astronomers. The Explore Scientific Two-Room Pop-Up Go Observatory Tent ($249.99) protects small telescopes from dust, wind, dew, and even stray light. The structure is manufactured with UV-resistant, black-out coated fabric with two 5-by-5-by-5-foot enclosures that can be set up in minutes without tools. The tent folds neatly into a 27-inch disk about 4 inches thick for convenient transportation and storage. Generously sized doors (3-by-3.5-foot) facilitate entering and passing through the two rooms. An over-sized, waterproof roof is included to cover your telescope during daylight and to protect your gear from rain showers. Each purchase includes cords and pegs to secure both the tent and its cover.

Explore Scientific
1010 S. 48th St., Springdale, AR 72762
866-252-3811; explorescientific.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.

Mark the Next Big Leap for Mankind
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Enhanced with selective color, it recalls the mission's launch, interplanetary journey and destination, Mars

Showcases an American Eagle and Mars above the Earth, inspired by the Apollo 11 mission patch

Richly plated in 24K gold

Shown larger than actual size of 38.6mm diameter

This fine collectible is not legal tender and bears no monetary face value. Design subject to change

KEY DETAILS

EVENT: Celebrates Mission Mars 2020 and the successful arrival of NASA's Perseverance Rover at Jezero Crater, Mars on February 18, 2021.

LIMITED AVAILABILITY: Issued to honor this historic step forward in mankind's exploration of Mars, editions are strictly limited. Due to the low quantity available, only the earliest applicants will be able to secure this tribute.

ORIGINAL DESIGN: Intended as a collectors' item, this non-monetary commemorative is offered in coveted Proof condition and richly plated with 24K gold.

SPECIAL ENHANCEMENTS: The front is enhanced with selective color and depicts the mission's launch, its interplanetary journey, and destination, Mars. An inset portrays the Perseverance Rover and its landing site. The back showcases an American Eagle and Mars, inspired by the design of the historic Apollo 11 Moon Landing mission patch.

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Richly plated in 24K gold

Richly plated in 24K gold, this thrilling tribute's front recalls the mission's launch on July 30, 2020, its interplanetary journey, and its destination, selectively enhanced with vivid color. An inset depicts the Perseverance Rover at its landing site. The back showcases an American Eagle and Mars above the Earth, inspired by the historic Apollo 11 Moon Landing patch. Proof quality coining dies create this non-monetary coin's polished, mirror-like fields and raised, frosted imagery. It arrives secured for heirloom preservation in a crystal-clear capsule.

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Replicating the Great Quadrant

History repeats itself, beautifully!

▲ Jon Voisey and his friend Meg Cassidy take a measurement with Jon's replica of Tycho Brahe's Great Quadrant.

WHEN YOU THINK OF medieval recreation, you probably think of Renaissance clothing, feasts, calligraphy, and swordfights. All of these, and more, are the sorts of things that members of the Society for Creative Anachronism (SCA) engage in. It's a group dedicated to understanding history through engaging in it. But one area that's often overlooked is astronomy.

When you think of scientists, you often think of researchers breaking new ground with new discoveries, but one of the most important things a scientist can do is to replicate the methods and the results of a previous experiment. Understanding how it was done is both personally satisfying and scientifically (and historically) important.

Enter Jon Voisey, known in the SCA as Lord Jon Chesey of the Barony of Three Rivers in the Kingdom of Calontir, who also holds a degree in astronomy. He fused these two passions after becoming interested in how Johannes Kepler worked out his elliptical heliocentric model of planetary motion before the invention of the telescope. Jon wanted to recreate Kepler's discovery, using Kepler's methods. So, Jon, like Kepler, turned to Tycho Brahe, whose instruments measured the night sky with a precision unmatched in his time (the second half of the 16th century) and whose data laid the foundation for Kepler's work.

To take his measurements, Jon decided to build a replica of Tycho's Great Quadrant, one of the instruments with which Tycho measured the position of the stars and planets. Using observations from this instrument, Jon intends to collect sufficient data of his own to follow Kepler's methodology and derive the orbits of the naked-eye planets. Because Kepler used measurements taken at opposition, and planetary oppositions are relatively rare events, this will take many years. So he's also using the quadrant in the meantime to plot the position of hundreds of stars as Tycho did as well, leading to the first accurate star map, Johannes Bayer's *Uranometria*, in 1603.

Jon's father is a contractor and carpenter, so he helped Jon build the Quadrant over the weekends of almost two months. They started with the curved arc, which they drew on a sheet of plywood and cut with a jigsaw. Then they made the internal lattice, ripping 2-by-4s down to 1½″ × 1½″ and making cross-lap joints with a dado blade. They built the 5″-square central column out of plywood and the base out of plywood and 4″ × 4″ posts. They then made an axle out of ½″ iron pipe and hung the quadrant from the axle. A plumb bob also hangs from the axle and is used to level the instrument as well as take the reading where the plumb line crosses the scale.

Drawing that scale was the killer. Tycho boasted that his instrument was accurate to ⅙ of one minute of arc. Jon's replica is smaller, so his scale is smaller as well, but he wanted it to at least be accurate to within a few arcminutes. Unfortunately, the period methods used to create accurate scales proved elusive, so Jon made the scale in the drafting software program *AutoCAD*. After printing, he transferred the scale to the wood by cutting through the drawing with a razor knife, then enhancing the marks with a Sharpie. The scale zigzags to provide greater

▶ The lattice was made with 1.5″ wooden strips bearing cross-lap joints.

GREAT QUADRANT REPLICA: WILL DAY; ORIGINAL QUADRANT: *ASTRONOMIAE INSTAURATAE MECHANICA*; LATTICE UNDER CONSTRUCTION: JON VOISEY separation between points, making it easier to read.

Tycho's instrument lacked an azimuthal scale, so Jon initially tried following suit, observing objects only as they crossed the meridian, but that proved too restrictive. So he installed an azimuth scale and takes his measurements in both altitude and azimuth, which are converted to RA and declination for comparison to modern values.

The finished quadrant is, of course, a hit at SCA events, but on clear nights Jon can often be found under the night sky, patiently collecting data on his own. Why does he do it? Jon says, "The big reason is the sense that I'm doing something important. While this path has certainly been walked before, it's so rare that anyone has done it that the path is overgrown."

Jon is certainly clearing that path here, with a beautiful melding of science, history, craftsmanship, and art.

For more information about the Great Quadrant, visit Jon's website at **jonvoisey.net/blog**.

■ Contributing Editor **JERRY OLTION** has made a replica of Galileo's telescope and used it to confirm that Jupiter's moons do indeed orbit the gas giant and not Earth.

▼ The plumb bob's fine brass wire and the staggered scale allow measurement accuracy of about three arcminutes.

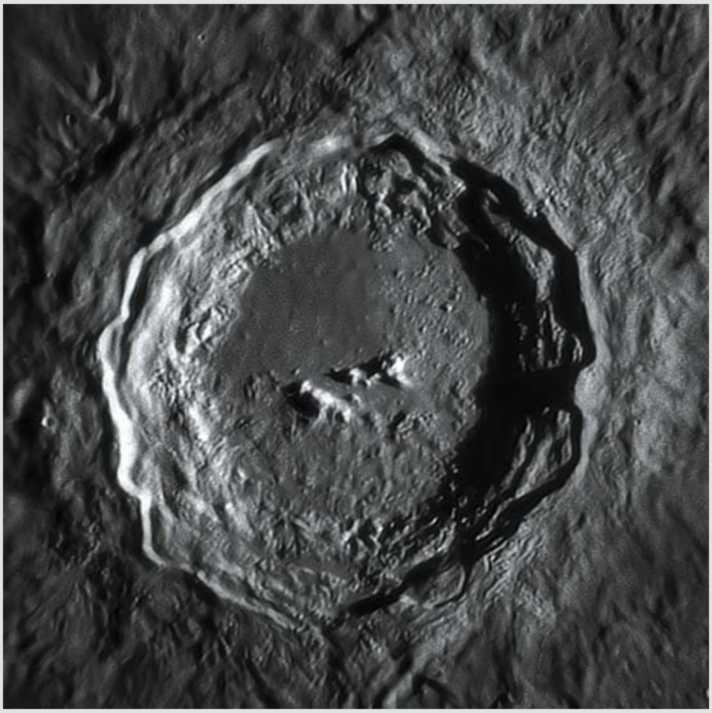
JON VOISEY

▷ CRATER CLOSE-UP

Scott Gauer

Copernicus is one of the youngest large craters visible on the Moon, having formed less than a billion years ago. Several peaks protrude from its center, the tallest rising roughly a kilometer above the crater floor.

DETAILS: *Celestron EdgeHD 14-inch Schmidt-Cassegrain with ZWO ASI290MM CMOS video camera. Stack of 3,000 video frames.*

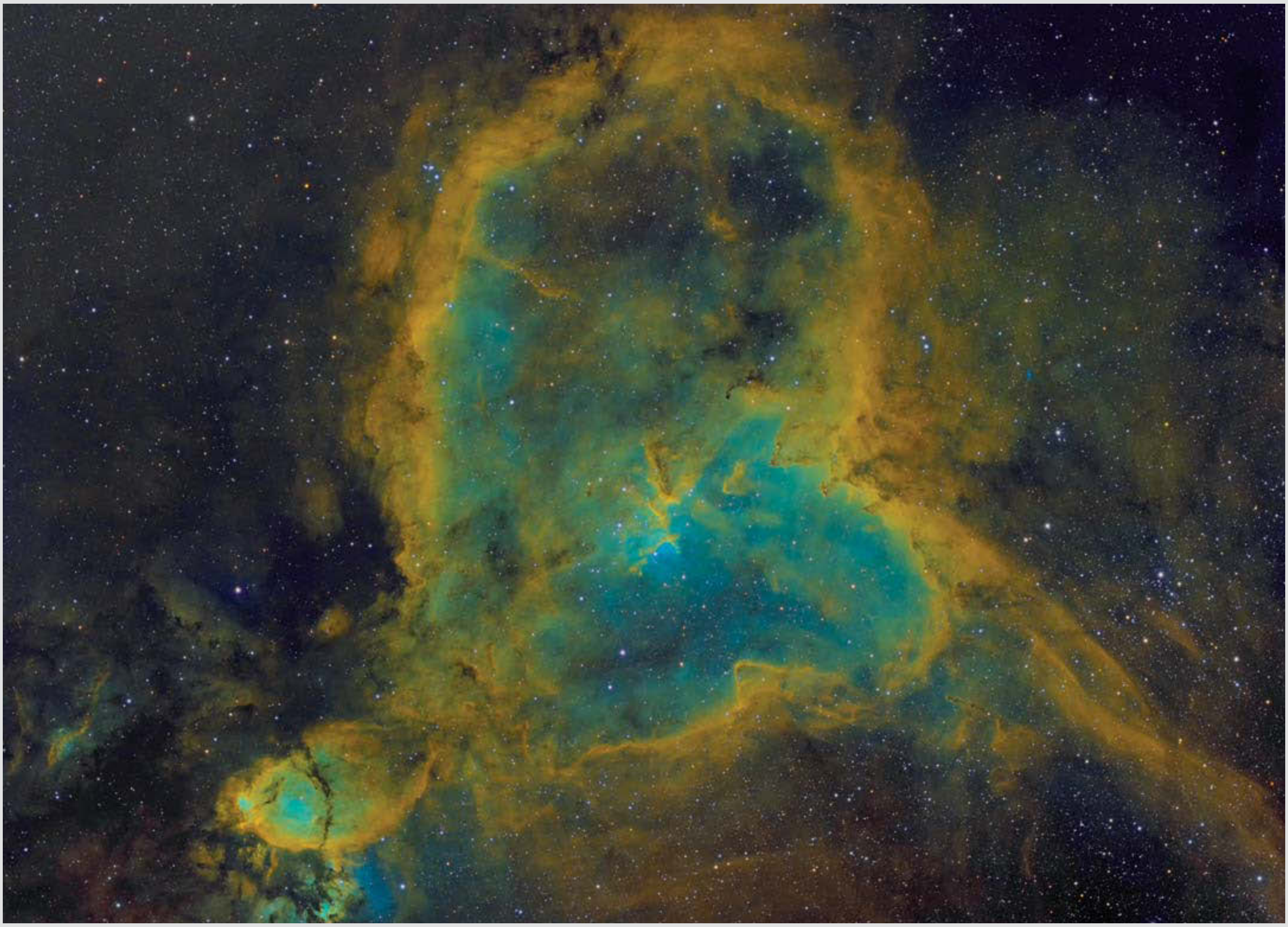


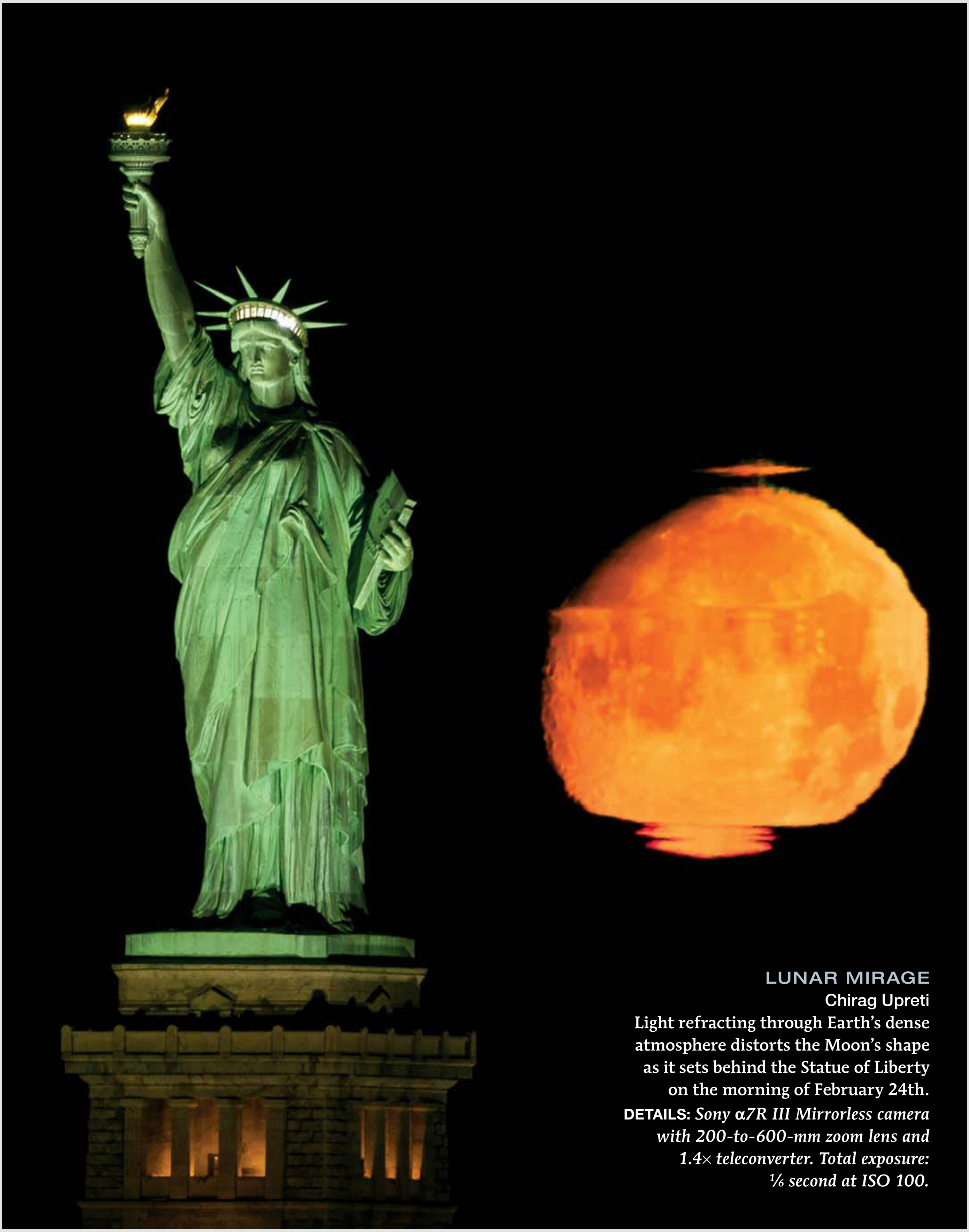
▽ THE HEART NEBULA

Fabian Rodriguez Frustaglia

IC 1805 is an emission nebula that adorns the Perseus arm of the Milky Way about 7,500 light-years away in Cassiopeia. The smaller nebula NGC 896 (lower left) resembles the head of a fish.

DETAILS: *Meade 115mm Series 6000 ED Triplet APO refractor with ZWO ASI1600MM camera. Four-panel mosaic totaling 24 hours of exposure through Astrodon narrowband filters.*





LUNAR MIRAGE

Chirag Upreti

Light refracting through Earth's dense atmosphere distorts the Moon's shape as it sets behind the Statue of Liberty on the morning of February 24th.

DETAILS: *Sony α7R III Mirrorless camera with 200-to-600-mm zoom lens and 1.4× teleconverter. Total exposure: ⅙ second at ISO 100.*

▷ EDGE-ON SPIRAL

Ian Gorenstein

Barred spiral galaxy NGC 7640 resides roughly 38 million light-years away in Andromeda. Its distorted shape implies recent interaction with another galaxy.

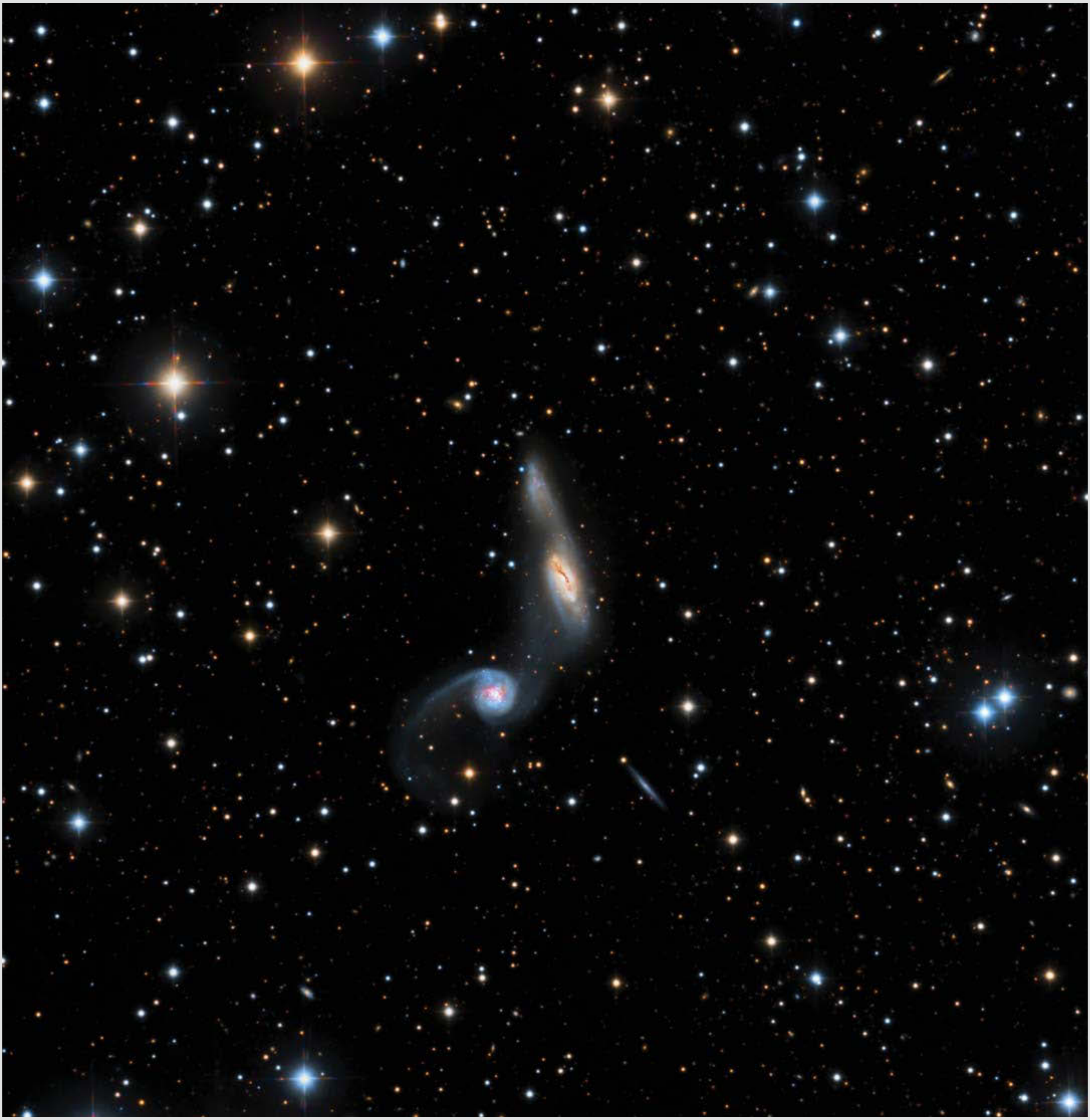
DETAILS: *Celestron EdgeHD 14-inch Schmidt-Cassegrain with Atik 460EX CCD camera. Total exposure: 12.1 hours.*

▽ GOBBLING INTERSTELLAR GHOSTS

Lydell D. Nunn

Emission nebula NGC 281 in Cassiopeia surrounds open cluster IC 1590 and contains several dark nebulae known as *Bok globules*. NGC 281 brings to mind the popular video-game character Pac-Man.

DETAILS: *Orion EON 115-mm ED triplet refractor with ZWO ASI1600MM CMOS camera. Total exposure: 8.6 hours through narrowband filters.*



△ BILLION-YEAR TANGO

Warren Keller and Michael Selby

Arp 245 in Hydra comprises the two interacting spiral galaxies NGC 2992 (center) and NGC 2993 (center left). The encounter is producing the tidal dwarf galaxy above NGC 2992, which is designated Arp 245N. Galaxy FGC 938 is seen to lower right of the interacting pair.

DETAILS: *Officina Stellare RiDK 500 and RiDK 700 Dall-Kirkham astrographs equipped with FLI ProLine PL16803 LDR cameras. Total exposure: 31.5 hours through LRGB filters.*

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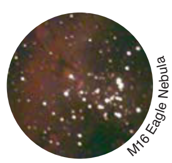

M16 Eagle Nebula

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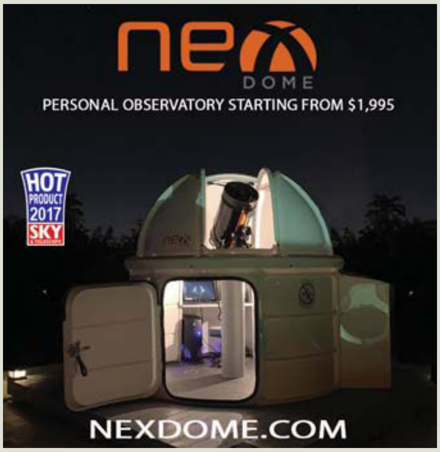
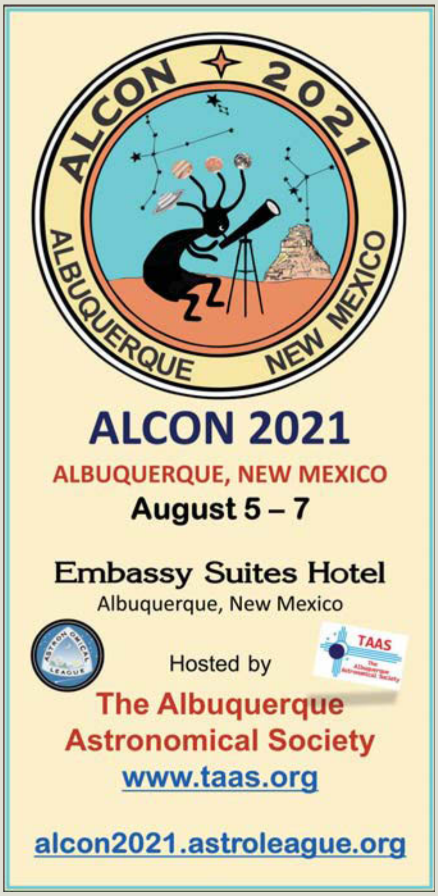


ORGANIZATIONS



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MIRADOR ASTRONOMY VILLAGE: https://miradorastrovillage.org. Contact David Oesper @ davedarksky@mac.com 608-930-2120.

SOUTHEAST ARIZONA: House and Observatory for sale under very dark skies. 22-inch Dobsonian with GOTO ArgoNavis available. Contact Tammy@HaymoreRealEstate.com, 520-210-1562 or George at 520-732-4841.

SOUTHWEST NEW MEXICO: Casitas de Gila Guesthouses. Dark skies, great accommodations; power, wifi, and pads available. casitasdegila.com/astronomy.html. 575-535-4455.

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Salvaging the Night

The author is caught off-guard — in the most pleasing way.

I LISTLESSLY ROLL the garbage can down the driveway, my eyes fixed low, aimlessly staring at the pavement below. I'm worn down from a long day at work, rattled from the commute, and, despite the joy my wife and two children bring me, uninspired for what lies ahead: another weeknight routine of fixing dinner, cleaning up, reviewing mail, and preparing for tomorrow.

I begin the walk back to the garage, my gaze lifting slightly, eyes tracing up the trunks of the giant oak trees that populate my backyard, until the leaves give way to the sky. Then I see them, just above the trees: Jupiter and Saturn, their glow starting to emerge from the fading twilight. I notice it's an especially clear sky tonight, with the Moon nowhere in sight.

I stop abruptly, realizing that these are ideal conditions. Charged with renewed energy, my childhood passion for planetary observation aroused, I instantly decide to set up my telescope and pay a visit to some old friends.

I'm excited now, inspired for what awaits. I bring my refractor outside to acclimatize while I set about completing a few of the chores that comprise my nightly routine. I do need to eat after all!

By the time I'm done, it's dark and I get to work, starting with radiant Jupiter. I'm delighted to find a bright, colorful disk intersected by prominent equatorial bands. Polar regions are readily apparent, too. I move through several eyepieces, trying different filters along the way in an attempt to discern the finest of detail and push the limits of seeing on this gorgeous night of steady air.

Somewhat content with my visit to Jupiter — one long look is never really enough — I slew over to Saturn with expectation for a fine showing, knowing the sky will support it. Anticipation gives way to awe as I marvel at the ringed planet. It contrasts sharply against the background black, a crisp yellow orb wrapped in a set of rings, not one but two, the distinct separation between them clearly evident. I think for a moment that I should get my CCD system but quickly dismiss the notion as counterproductive. I'm enjoying my time at the eyepiece, and that's sufficient for tonight.

I eventually surrender to growing fatigue and begin to tear down my telescope. With calculated, deliberate motions, I dismantle it, wiping away dew, returning each component to its rightful place so it's ready for the next time. I'm keenly aware that I enjoy this, the care and handling of my gear. I treat it not as a burden but rather as an opportunity to inspect things and inventory my eyepiece collection, reflecting on how it has grown over the years, in both quantity and quality, and how my observing skills have developed as I've learned to squeeze, squint, and avert every bit of performance out of my optics.

Somewhat content with my visit to Jupiter — one long look is never really enough — I slew over to Saturn with expectation for a fine showing.

I head straight to bed, physically exhausted but mentally stimulated. I can't sleep — my observing session has awakened youthful enthusiasm not unlike the memory of one's first love. As I lie in bed, musing, it occurs to me that I am fortunate to be so captivated by an activity that has been part of my life since childhood.

Engrossed in observing, I escaped. Forgetting the world for a while, I salvaged the night and transformed an otherwise unremarkable day into a fond memory. I am fortunate indeed.

◀ ▶ **OUT OF THIS WORLD** A view of "just" Jupiter and Saturn can be all that's needed for an indelible evening under the stars. This shot of Jupiter was taken on August 17, 2011, that of Saturn on February 23, 2006.

SEAN WALKER / *S&T* (2)

■ JOHN BESSE is an electrical engineer who lives in Millstone, NJ. He's been an avid observer since he received his first telescope as a Christmas gift in 1982.