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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

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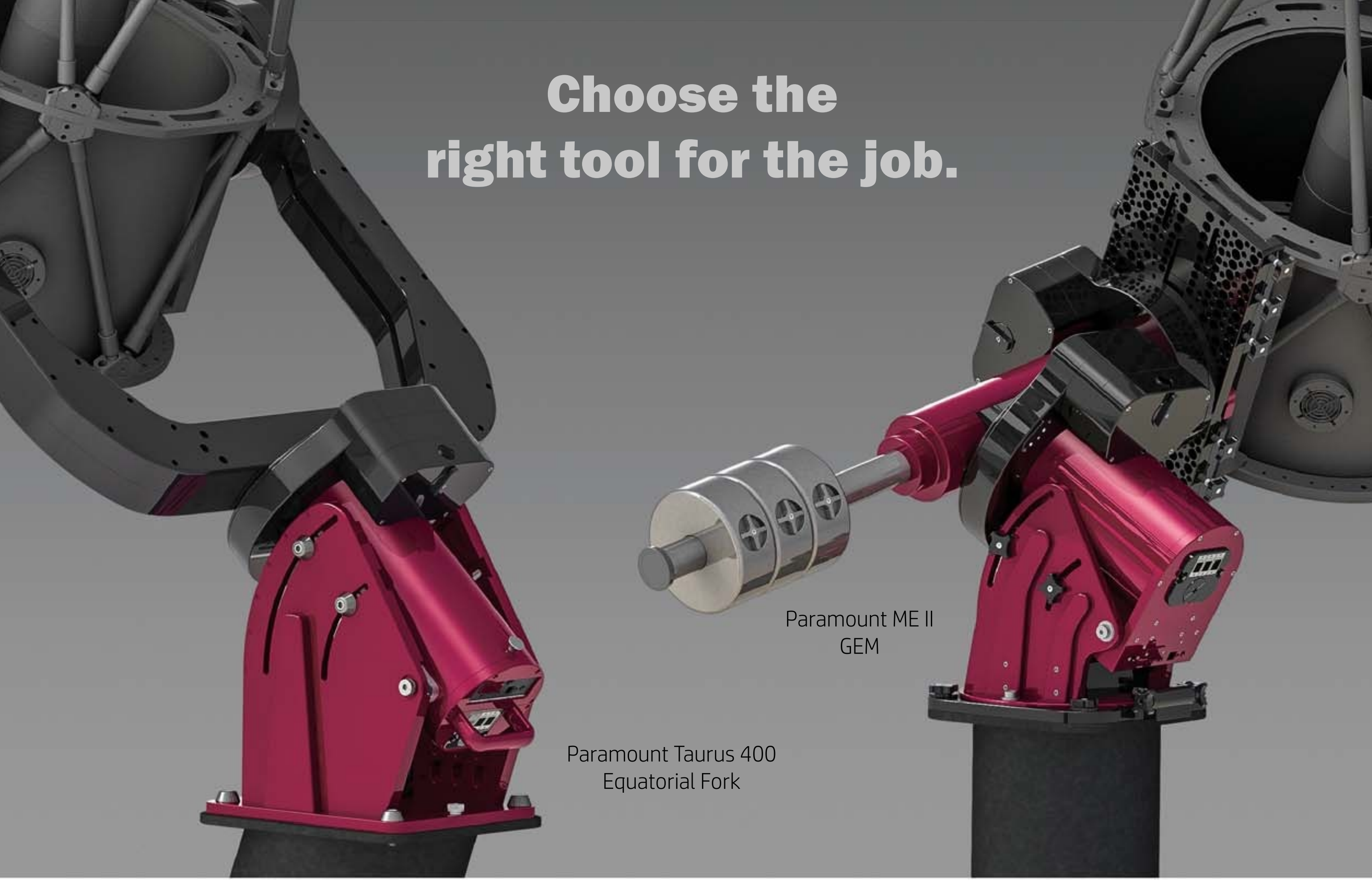

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September 2019 VOL. 138, NO. 3

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The first radio image of a black hole's silhouette

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Thank Our Lucky Stars

LAST FALL AT A PICNIC for current and former *Sky & Telescope* staff, I sidled over to Rick Fienberg, *S&T*'s Editor in Chief from 2001 to 2008. Being a science magazine, *S&T* had always felt like the odd one out amongst our parent company F+W Media's stable of craft and hobbyist publications. I asked Rick if he knew of any science-savvy organization that might be interested in exploring a potential purchase of *S&T*. He said he'd give it some thought.

A few days later, I received an email from Rick: "Further to what we discussed at the picnic, I have an idea I'd like to run past you."

He soon did so, and the rest will go down in *S&T*'s annals as the most important coming together since our founders, Charlie and Helen Spence Federer, merged *The Sky* and *The Telescope* into this magazine in 1941.

Rick is now Press Officer of the American Astronomical Society (**aas.org**), and sometime between his burger and his email he had a brainstorm: What about the AAS itself? Founded in 1899, the Society is the major organization for professional astronomers in North America. Yet recently, eager to better bridge the gap between professional and backyard astronomers, the AAS formed an Amateur Affiliate membership. It also hosts Education Affiliates who work in astronomy education and public outreach. By bringing *S&T* within its orbit, the Society could more thoroughly address its broader mission: to enhance and share humanity's scientific understanding of the universe.

Rick shared his idea with Kevin Marvel, AAS Executive Officer, who immediately grasped the inherent synergies and approached his Board of Trustees. The Board bought in, and Kevin reached out earlier this year to F+W's Ray Chelstowski, who since late 2016 has very effectively overseen the *S&T* business as General Manager. The timing proved propitious: On March 10th F+W filed for bankruptcy protection. Suffice it to say that the parties on both sides came to an agreement, and in mid-June the Society won the bid for *Sky & Telescope*. By the time you read this, the AAS will be our new owner.

What are the Society's designs for *S&T*? I think you'll be pleased to hear that it plans a light touch. As stated in our jointly issued press release of June 18th (**https://is.gd/AASpurchase**), "the Society anticipates making few if any changes to the editorial content or the way the magazine operates . . ." With the AAS's support, we'll continue to produce the magazine, website, products, and tours as we always have, with complete editorial independence.

As Kevin enthused in his online letter to AAS members about the new alliance (**https://is.gd/Marvelpost**), "Our future is so bright, we're going to have to wear shades!"

Peter
Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

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

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Post-Impressions of Jupiter

I just finished reading "JunoCam at Jupiter: Where Science Meets Art" (*S&T:* May 2019, p. 14), and I'm rather surprised no one mentioned the resemblance between some of the images and Vincent van Gogh's painting "The Starry Night." The image on the lower half of page 17 in particular looks like an interpretation of the painting. Is this coincidence, or were some of the image processors trying to imitate the effect?

Michael Farmer • Athens, Ohio

▲ Some of the images of Jupiter taken with JunoCam look surprisingly familiar.

Way Up North

I found your comments about observing Omega Centauri from northern latitudes (*S&T:* Apr. 2019, p. 22) very interesting, particularly observations from Point Pelee National Park. Our local astronomy club (RASC - Windsor Centre) has been attempting this observation for many years, with local member Dan Taylor credited with being the first to do so in 1988. We've had many successful attempts and have learned that the ideal conditions occur in March, when the air temperature and water temperature on Lake Erie are about the same and there is still ice on the lake. Of course, this means observing at 3:00 a.m. before and 2:00 a.m. after the start of Daylight Saving Time.

From our typical observing location on the West Beach of Point Pelee, the latitude is 41.93°N, and using a declination for Omega Cen of −47.5° you can see that it gets only about a half degree above the horizon. Of course, refraction gives us another half degree, so we clear the horizon by a full degree; however, atmospheric extinction causes about a 9-magnitude drop in brightness.

Steve Mastellotto
Tecumseh, Ontario

Tony Flanders replies: *I was aware of the initial observation, but I had no idea that attempting to re-observe it had become an annual event. That is very cool.*

The northernmost sighting that I'm aware of, from Cape Ann in Massachusetts, is a few tenths of a degree north of Point Pelee. It's no doubt significant that Cape Ann has many high bluffs overlooking the ocean. Even so, only the top two-thirds of the cluster was seen and photographed.

I wonder if this was, in fact, the northernmost sighting of Omega Cen, or if there are other contenders.

Solar System Shortcut?

The illustration accompanying the News Note about Voyager 2 entering interstellar space (*S&T:* Apr. 2019, p. 9) has me wondering: Wouldn't it have taken much, much longer for the Voyagers to enter interstellar space if they had been traveling in a different direction? The illustration appears to show them emerging from the solar system proper at the front of a bow shock. Was this just a lucky break?

Joel Marks
Milford, Connecticut

Monica Young replies: *You're right that the shape of the heliosphere is decidedly asymmetrical, and so the path taken by an interstellar-bound spacecraft matters. Pioneer 10, for example, is heading out of the solar system, but because it's heading into the "tail" of the heliosphere, it's going to be a lot longer before it reaches interstellar space. Voyagers 1 and 2 (and Pioneer 11) were on different trajectories, but all were going more or less toward the "head" of the heliosphere. Whether astronomers planned to send three of the four on a short course out of the solar system, I'm not sure. They would have known the rough shape of the solar system before the spacecraft launched, but they also had a lot of other factors to consider. For example, Voyager 1 was optimized for a Titan flyby and Voyager 2 was intended for a "grand tour" of the solar system, and their trajectories were planned accordingly.*

Circular Reasoning

In your recent article about gravitational lensing (*S&T:* May 2019, p. 28), the diagram on page 30 raises some very interesting questions. Once light from a distant star, galaxy, or quasar is bent, what happens to the light? Does it continue in its new direction indefinitely? If the light beam has really been curved, will it eventually end up in a circle? Maybe that idea is not so far-fetched. If I'm not mistaken, wasn't it Einstein that said if you could be on a rocket traveling close to the speed of light, you'll eventually end up in the same place you started?

Ralph Fusco
Edison, New Jersey

Camille Carlisle replies: *Once deflected, light would continue on its new path as long as it doesn't encounter anything else to change its trajectory. But light is only deflected a little bit by a gravitational lens, nowhere near what would be needed to make it travel in a circle. The only place I know of where light is bent into a complete circular path is just outside the horizon of a black hole. There, light can be temporarily trapped in a circular orbit, but it can eventually*

JUPITER: NASA / MSSS / GERALD EICHSTÄDT / SEÁN DORAN, THE STARRY NIGHT: MUSEUM OF MODERN ART / PUBLIC DOMAIN *escape. When it does, it will travel straight along the escape trajectory — barring any more gravitational detours, that is.*

Light a Standard Candle

"Lighting a Cosmic Fuse" by Shannon Hall (*S&T:* June 2019, p. 14) paints an interesting picture of an important issue in cosmology. The need for "standard candles" is further highlighted by Govert Schilling's article "Constant Controversy" in the same issue (p. 22). Hall's article concludes that astronomers now believe there are several mechanisms behind Type Ia supernovae (single- versus double-degenerate systems), and that they probably span a range of absolute luminosities. She goes on to explain how understanding these mechanisms can help in improving cosmological distance scales. Two observational studies are mentioned in this regard that seem to point to vastly different percentages for single-degenerate occurrences (25% versus less than 5%).

I wonder whether anyone has applied the results of stellar evolution models to predict what fraction of white dwarfs are paired with ordinary stars and what fraction with another white dwarf. This could lend another independent test to the distribution of single- versus double-degenerate supernovae that have been observed. On the other hand, if observational studies can sort the distribution out, couldn't this help validate the evolutionary models?

Dave Billesbach
Lincoln, Nebraska

Thank you for Govert Schilling's articles over the last several years and particularly his most recent article on the Hubble-constant controversy. His articles on black holes, gravitational waves, multi-messenger astronomy, and cosmology in general reflect scientific journalism at its best — lucid and informative. He, Monica Young, and Camille Carlisle constitute the best "troika" in astronomical journalism, especially on astrophysics and cosmology.

Nick Anderson
Arlington, Virginia

Star Power

I greatly enjoyed the three-part in-depth look at stars in the March, April, and May 2019 issues. I'm a long-time reader, and it's informative, well-written articles like those that make me value your magazine so highly.

Nick Britt
Lewis Center, Ohio

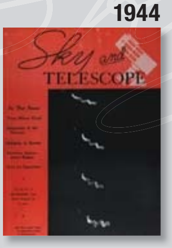
FOR THE RECORD

● In Sky at a Glance (*S&T:* June 2019, p. 41) on June 30th Aldebaran was 3° from the waning, not the waxing, lunar crescent.

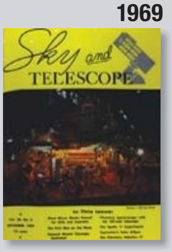
SUBMISSIONS: Write to *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, U.S.A. or email: letters@skyandtelescope.com. Please limit comments to 250 words; letters may be edited for brevity and clarity.

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

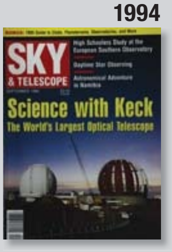
1944



1969



1994



◖ September 1944

Pleiades Probed "Dr. J. A. Pearce [at the Dominion Astrophysical Observatory has studied the spectra] and physical characteristics of the 12 brightest stars in the Pleiades. [He] collected some 214 observations of 10 of these stars made during the past 40 years, and combined these with 111 unpublished [radial] velocities of his own. From these he finds that the Pleiades appear to be receding from us at . . . five miles per second, a figure in good agreement with that predicted by observations of the apparent motions of these stars across the face of the sky. . . .

"The distance of the cluster, obtained from Dr. Pearce's work, is found to be about 240 light-years, in close agreement with the results from other methods."

*Notoriously hard to measure, the famed cluster's distance is now pegged at 446 light-years (*S&T:* Mar. 2019, p. 26).*

◖ September 1969

Apollo 11 "One of astronaut [Neil] Armstrong's tasks at Tranquillity Base was to carry an 18-inch-square aluminum block about 30 feet from the Eagle and leave it there. Emplanted in this block are 100 retro-reflectors 1½ inches in diameter. Each is a corner cut from a perfect cube of fused silica. . . .

"The purpose of this retro-reflector array is to allow a terrestrial telescope to send a laser light beam to the moon and observe its reflection. By using such a compact lunar 'bench mark,' a very great improvement in Earth-Moon distance measurements is possible [and] should ultimately reduce the uncertainty in measured distance to about six inches."

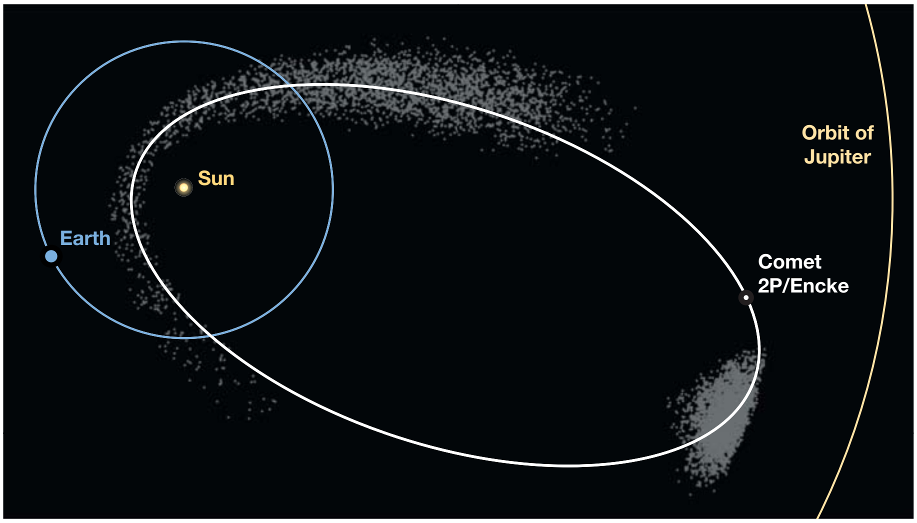
That retro-reflector is still being targeted to help pin down the Moon's orbit. Ranging uncertainty is now only a millimeter.

◖ September 1994

Keck Performs "The night I witnessed Keck in operation [Steven] Vogt and others measured the radial velocities of 19th- and 20th-magnitude stars in the nearby dwarf elliptical galaxy Leo II. Before Keck, it was a three-hour struggle to obtain a spectrum of one of these stars with the Palomar 5-meter. These astronomers . . . knock them off one every 10 minutes. . . .

"They were searching for the gravitational signature of dark matter. . . . Simply put, [large velocity variations mean] some unseen mass would be needed to keep the galaxy from flying apart —the luminous stars and gas can't do it alone. Their preliminary results suggest that the dispersion is about 7 or 8 km per second. Thus, as several earlier studies had suggested, dwarf ellipticals like Leo II contain lots of dark matter, just like large spiral galaxies."

Kevin Krisciunas, who is now at Texas A & M University, visited the first 10-meter Keck telescope on Mauna Kea two years after its dedication.



▲ This illustration shows Comet 2P/Encke sharing its orbit with asteroids, smaller fragments that create the annual Taurid meteors, and a concentration of objects known as the Taurid resonant swarm (TRS, lower right). The TRS approached Earth in June.

GREGG DINDERMAN / S&T; SOURCE: DAVID CLARK / UNIV. OF WESTERN ONTARIO

SOLAR SYSTEM

Astronomers Stalk the "Taurid Swarm"

IF THEORISTS ARE RIGHT, observers could spot potentially hazardous asteroids — part of the hypothesized *Taurid resonant swarm* (TRS) — as they cruise past Earth this summer.

In 1984 Victor Clube (then at Oxford University, UK) and Bill Napier (then at Royal Observatory, UK) proposed that Comet 2P/Encke, the Taurid meteors, and a number of near-Earth asteroids with similar orbits are actually fragments of a giant comet that broke apart some 20,000 years ago. If so, it's possible that huge chunks could still lurk unseen along and near Encke's orbit. In support of their theory, Clube and Napier pointed out that the Tunguska impact in 1908 involved a roughly 100-meter (300-foot) object with a Taurid-like orbit (*S&T:* Dec. 1978, p. 497).

Later work by dynamicist David J. Asher (then at the Anglo-Australian Observatory, Australia) showed that a concentrated bunch of these fragments should orbit in resonance with Jupiter, completing seven highly elongated loops around the Sun for every two by Jupiter. In 1975, seismometers left on the Moon by Apollo astronauts recorded a spike in tremors due to meteorite impacts just as the swarm would have neared Earth.

In June and July, the core of this hypothesized swarm makes its closest post-perihelion pass to Earth since 1975. Dynamicists aren't expecting Tunguska-like encounters, but the close passage does offer observers the chance to discover sizable near-Earth objects, with advance knowledge of where and when to look.

David Clark, Paul Wiegert, and Peter Brown (University of Western Ontario, Canada) simulated the swarm's arrival in the June *Monthly Notices of the Royal Astronomical Society: Letters*. In the study, the researchers identified two main observing windows when astronomers will have the best chance of discovering TRS objects more than roughly 100 meters across.

The first of these, between June 25th and July 11th, gives observers the opportunity to see relatively bright but fast-moving objects. Some will be around magnitude 21 or brighter, but they'll move rapidly across the sky, up to ½° per hour. They'll be moving through declinations of −40° to −60°, with the brightest objects the farthest south.

Within this window, from July 5th to 11th, there's a second opportunity to see slower but fainter objects. These individual objects would still be relatively close by but moving across the southern sky at less than 2¼° per day. The brightest bodies will be around magnitude 22 — a tall order for amateur-scale telescopes but easy pickings for professional instruments.

A final opportunity falls in the dark-sky window between full Moons, from July 21st to August 10th. During this time TRS objects will appear fainter by 3 or 4 magnitudes, but their sky motions will be slower still and the target area is not quite so far south.

The June–August encounter provides a unique opportunity to identify large bodies in the swarm, if they exist. Stay tuned for the results!

■ J. KELLY BEATTY

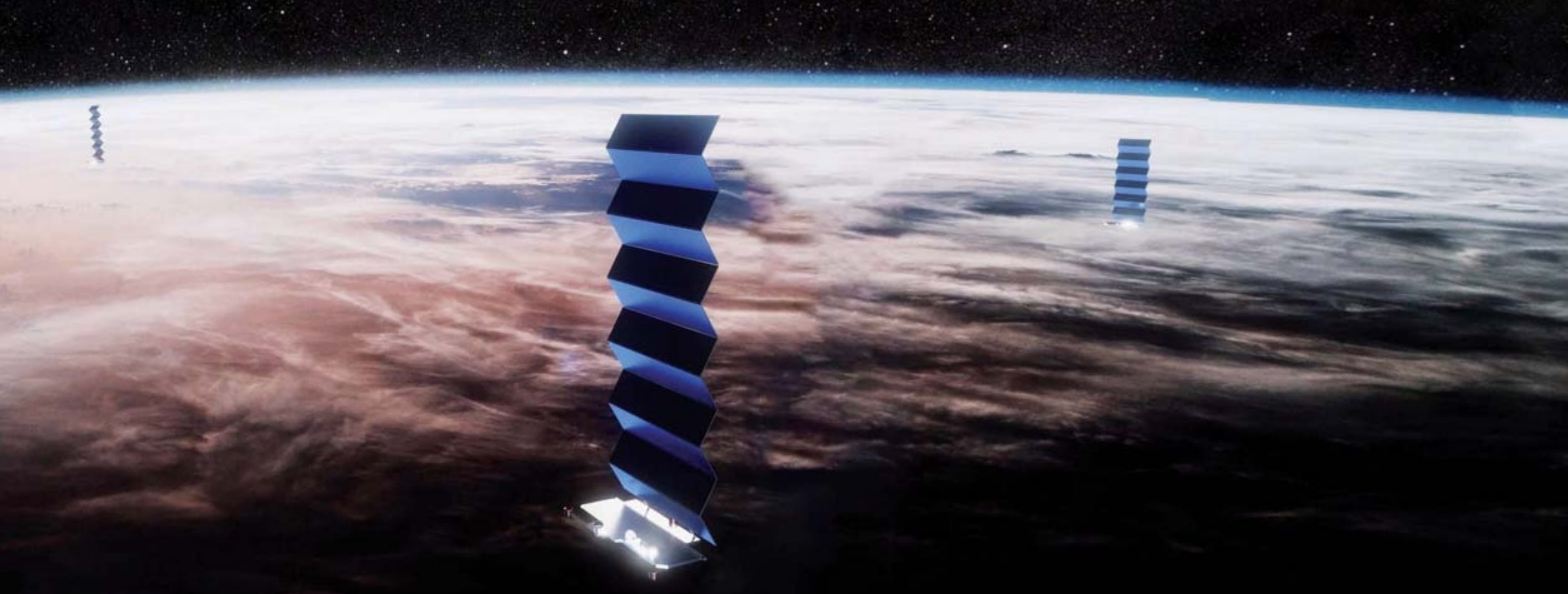
SOLAR SYSTEM

Jupiter's Great Red Spot Unfurls

JUPITER'S SOUTH EQUATORIAL BELT (SEB) has started peeling material from the Great Red Spot (GRS) in an event that has been visible in small telescopes.

The GRS currently sports a rich, orange-red color, made more distinct by the white "hollow" that often surrounds it. In May, a dark swirl began adding to the distinction: Large filaments of GRS material, some spanning more than 10,000 km (6,000 miles), started peeling away from the west end of the famous spot roughly once a week and dissipating in a churning bridge connecting the GRS to the SEB. JunoCam (aboard NASA's Juno spacecraft) and amateurs alike observed the phenomenon.

The "flakes" appeared to contain a substantial amount of GRS material, as they were seen most prominently at



SPACE

SpaceX Launches 60 Starlink Satellites

ON MAY 23RD SpaceX launched 60 satellites as part of its Starlink constellation, which aims to bring high-speed, broadband internet to locations across the planet. This is only the first volley of nearly 12,000 satellites planned for launch over the next decade.

Skywatchers and professional astronomers alike have expressed concerns about the detrimental effect on the night sky. In the satellites' initial orbit, they ranged in brightness from 1st to 3rd magnitude — easily visible to the unaided eye — and made a neat line about 7° long. The satellites are still climbing to an operational altitude of 550 km (340 miles), fading to magnitudes 3 to 6 as they go.

Six launches of 60 satellites will be needed to activate the system; after 24 launches, the constellation would provide global coverage. If all goes according to plan, SpaceX will launch satellite fusillades multiple times per year over about nine years. So the incredible sight that awaited skygazers in May could repeat two to six times in 2019 alone. To find satellite passes for your location, visit **Heavens-Above.com**.

The long-term plan for Starlink calls for nearly 12,000 satellites in multiple orbital planes, a number that includes 1,584 satellites at an altitude of 550 km and 7,518 at an even lower altitude of 340 km. Satellites in such low orbits could remain bright and visible after twilight, though it's still unclear how bright they'll be. A statement by the Large Synoptic Survey Telescope called the satellites' potential effects "a nuisance rather than a real problem." Meanwhile, the National Science Foundation and National Radio Astronomy Observatory have also issued statements, saying they are working with SpaceX to manage the use of particular radio bands. As other companies are planning to compete with SpaceX, additional negotiations may be needed.

■ BOB KING

▲ Ultimately, SpaceX wants to place nearly 12,000 Starlink satellites in orbit, a plan that includes 1,584 at an altitude of 550 km and 7,518 at an even lower altitude of 340 km.

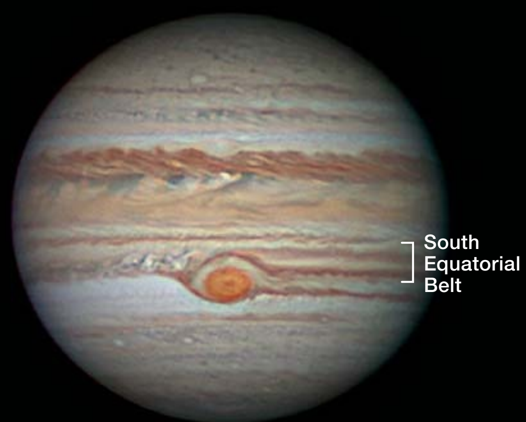
STARLINK SATELLITES: SPACEX; JUPITER: CLYDE FOSTER

near-infrared wavelengths, especially around 890 nanometers. Methane absorbs light at this wavelength, so methane-rich features such as belts and zones appear dark. However, strong winds clear out methane from the GRS, and the storm appears bright at this wavelength instead.

Visually, however, the GRS and its castoffs may be easier to see through a blue filter, where they appear darker than their surroundings.

Flakes from the GRS are common now but were only rarely seen before 2018. The May event also appears to have been more pronounced than those seen in the past. Observers are urged to monitor any continued changes in the GRS and SEB and share their observations with the British Astronomical Association (BAA) or the Association of Lunar and Planetary Observers (ALPO).

■ SEAN WALKER



▶ The swirl that connects the Great Red Spot to the South Equatorial Belt contains material drawn from the long-lived storm. North is up.

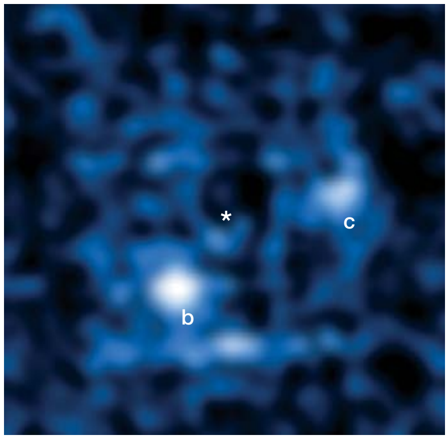
EXOPLANETS

Images Reveal Growing Newborn Planets

ASTRONOMERS HAVE CAPTURED the growth of infant planets forming around 5-million-year-old star PDS 70. Sebastiaan Haffert (Leiden University, The Netherlands) and his colleagues report the new observations June 3rd in *Nature Astronomy*.

Last year, another team directly imaged the massive planet PDS 70b orbiting within a gap in the protoplanetary disk surrounding the star (*S&T:* Nov. 2018, p. 9). Now, Haffert's team used a different instrument on the Very Large Telescope in Chile to detect hydrogen gas flowing onto the planet. What's more, they've discovered a similar gas flow onto another putative planet: PDS 70c.

"PDS 70b is certainly the most definitive case for a protoplanet," says Thayne Currie (Subaru Telescope), who was not involved in the study. "The PDS 70c object looks very encouraging. Hopefully, future studies will clearly show evidence for orbital motion."



▲ By canceling out most of the light from the central star, PDS 70 (whose location is marked by a white asterisk), astronomers revealed the signature of hydrogen gas flowing onto PDS 70b and another possible planet, PDS 70c.

Both protoplanets have mass estimates many times Jupiter's, and spectral measurements show that these gas giants are both still growing. But at current rates, it would take them 50 million to 100 million years to add a Jupiter's worth of mass. Given that protoplanetary disks only stick around for about 10 million years, these planets have probably experienced growth spurts in the past.

Based on the current positions of PDS 70b and c, they seem to be in or near a 2:1 resonance, in which PDS 70c completes a single orbit for every two orbits by PDS 70b. This arrangement is similar to the 3:2 orbital resonance that Jupiter and Saturn were thought to have had billions of years ago. If future observations confirm the resonant orbits around PDS 70, the system may provide a glimpse into the dynamics that shaped the early solar system.

■ MONICA YOUNG

SOLAR SYSTEM

Was ʻOumuamua a Fragment from a Disintegrated Comet?

▲ One artist's impression shows ʻOumuamua as a cigar-shaped object.

1I/2017 U1 ʻOUMUAMUA, the interstellar mystery object that briefly visited the inner solar system in 2018, experienced a mysterious "non-gravitational acceleration" away from the Sun on its way back out. New calculations by Zdenek Sekanina (Jet Propulsion Laboratory) rule out comet-like behavior as the cause. Instead, Sekanina suggests radiation pressure could have pushed the object — if its density were ultra-low.

While observations had already limited comet-like activity from ʻOumuamua, Darryl Seligman and Greg Laughlin (both at Yale) suggested in a recent study that a small jet of sublimating water ice might have escaped detection and could have explained the object's acceleration (*S&T:* July 2019, p. 11).

However, in a paper posted on the astronomy preprint arXiv in May, Sekanina objects to the explanation of outgassing altogether. He puts forth multiple arguments, but the nail in the coffin is his calculation that water ice — even if present — couldn't have sublimated quickly enough to spur ʻOumuamua on its way.

Seligman accepts Sekanina's assertion, agreeing that ʻOumuamua wouldn't have received enough energy from the Sun to power the jet.

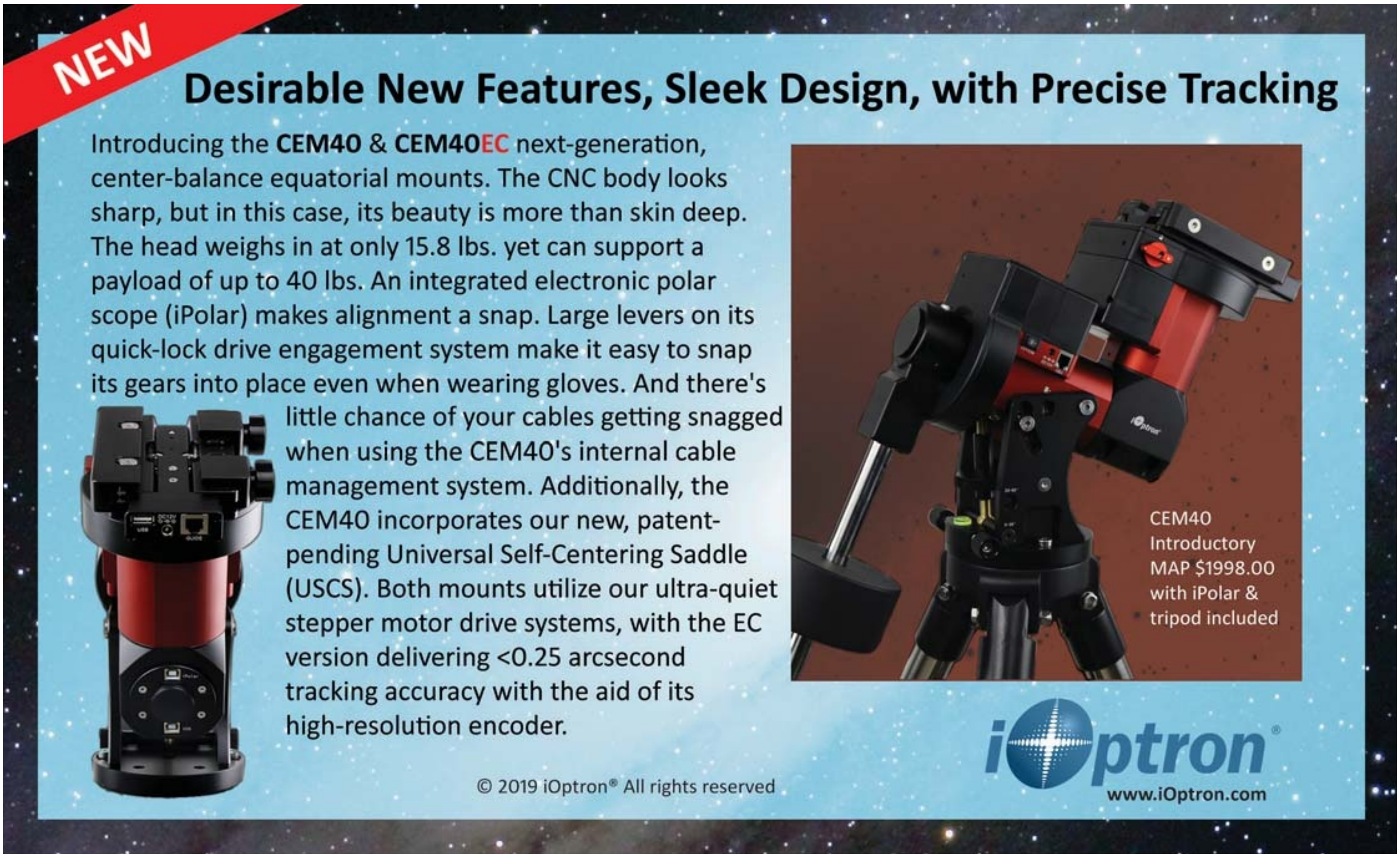
Without comet-like activity, the only force that remains under consideration is solar radiation pressure. But for the Sun's photons to push ʻOumuamua hard enough to explain its acceleration, Sekanina calculates, the object itself would have had to have a density less than about 0.001 gram per cubic centimeter — making it effectively as light as air. This scenario is possible, Sekanina writes, if ʻOumuamua were a surviving fragment from a comet that disintegrated while passing near the Sun.

Seligman adds that he and Laughlin are also exploring alternative scenarios, including the possibility that ʻOumuamua was a porous pile of icy dust known as a *fractal aggregate*.

"Either way," Seligman notes, "the ramifications for planet formation are extremely interesting."

■ MONICA YOUNG

NEWBORN PLANETS: ESO / S. HAFFERT (LEIDEN OBSERVATORY); ʻOUMUAMUA: ESO / M. KORNMESSER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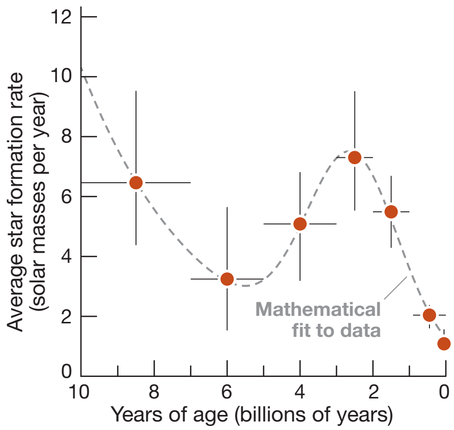
GALAXY

The Milky Way Used to Burst with Stars

NEW RESEARCH SHOWS that just a couple billion years ago, our quiet galaxy was birthing stars at a rate up to 10 times higher than it is today.

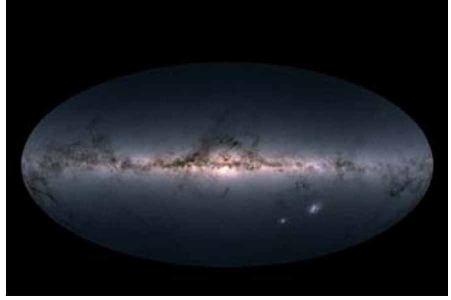
Roger Mor (University of Barcelona, Spain) and colleagues used data from the European Space Agency's Gaia satellite, along with sophisticated computer algorithms, to delve into the Milky Way's past. Their results appear in April's *Astronomy & Astrophysics*.



▲ This plot shows how many Suns' worth of stars formed per year through the last 10 billion years of our galaxy's history.

First, the researchers selected brightness and color information for 2.9 million stars listed in Gaia's second data release (*S&T:* Aug. 2018, p. 9). Then they fed this information into a simulation, which reconstructed our galaxy's star-formation history.

The results suggest that our galaxy was churning out stars 10 billion years ago. Other studies have already suggested that around this time the Milky Way had swallowed a Small Magellanic Cloud–size galaxy, dubbed Gaia-Enceladus. That merger might have stimulated a rush of star formation before eventually quashing it — the star-formation rate steadily declined for the next 5 billion years.



▲ This representation shows Gaia's measurements of 1.7 billion stars in the Milky Way and neighboring galaxies.

Then, our galaxy experienced a second stellar baby boom, most likely due to another collision with a gas-rich satellite galaxy. This time, the proliferation of new stars lasted some 4 billion years, peaking about 2 billion years after it started. The galaxy churned out enough stars during this period to populate half of its thin disk. The rate of star formation has been diminishing ever since, down to today's rate of a Sun's worth of stars per year.

If the Milky Way really did engulf a companion galaxy a couple billion years ago, one thing's for sure: Our night sky wouldn't be the same without it.

■ MONICA YOUNG

IN BRIEF

NASA's Artemis Gets Budget Boost

The White House has requested an extra $1.6 billion toward NASA's accelerated return of astronauts to the Moon, a program dubbed Artemis for the Greek lunar goddess. NASA had already been planning to return to the Moon by 2028, but the new initiative aims to put boots on the lunar surface by 2024. The additional funds put NASA's FY2020 budget request at $22.6 billion — about a 5% increase over FY2019. The increase would come from a surplus in the Pell Grant program for low-income college students. However, estimates of funds necessary to achieve a 2024 landing range from $25 billion to $40 billion. NASA is already moving ahead with some Artemis contracts, including $45.5 million for 11 companies participating in the Next Space Technologies for Exploration Partnerships. The companies' six-month contracts will go toward the development of elements involved in transferring to lunar orbit, landing on the Moon's surface, and refueling.

■ DAVID DICKINSON

Find more details about the budget at https://is.gd/ArtemisBudget.

Exocomets Detected Transiting Beta Pictoris

Astronomers have discovered three exocomets transiting the nearby star Beta Pictoris. At only 23 million years old, Beta Pic is in the "young adult" phase of starhood, still surrounded by a debris disk of dust and gas. Using the Transiting Exoplanet Survey Satellite (TESS), Sebastian Zieba (University of Innsbruck, Austria) and colleagues have tracked the star's brightness over 105 days, revealing three distinct dips that indicate the passage of exocomets. The dips are asymmetric, not periodic, and the longest one lasts about two days. "What we are seeing is not the comet nucleus itself, but the material blown off the comet and trailing behind it," explains coauthor Konstanze Zwintz (also at the University of Innsbruck). That material dims the star's light. However, the dips in the light curve do not distinguish between big, fluffy, close-in exocomets and small, dense ones farther from the star. To better characterize these exocomets, the team suggests taking spectra at the same time as future transits. The results appeared in May's *Astronomy & Astrophysics*.

■ MONICA YOUNG

Amateur Filmed Solar Eclipse in 1900

On May 28, 1900, amateur astronomer and filmmaker John Nevil Maskelyne captured the first-ever movie of a total solar eclipse from the small town of Wadesboro, North Carolina. Seven seconds into the reconstructed film, released by the Royal Astronomical Society and British Film Institute, a tiny bead of sunlight escapes through a lunar valley and creates a diamond ring shape around the Sun. The rest of the movie shows a faintly oblate solar corona that's brighter near the equator and dimmer near the poles. Maskelyne compensated for the change in brightness at totality by adjusting the exposure and camera aperture for each image. After the eclipse, Maskelyne brought his film back to England. But it disappeared into the Royal Astronomical Society's archives until librarian and archivist Sian Prosser and her colleagues discovered it a few years ago. Bryony Dixon, the curator of silent film at the British Film Institute, and her colleagues restored and digitized the film.

■ MONICA BOBRA

View the film at https://is.gd/oldeclipse.

Sea Change on Venus

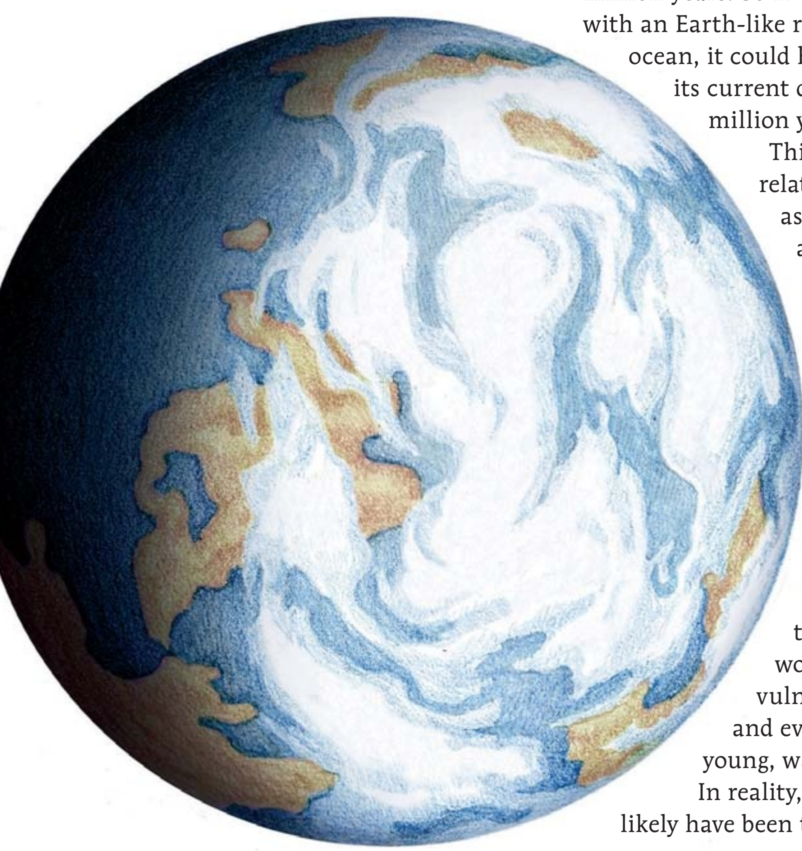
Tidal drag from a putative ocean might have helped cool our sister planet for billions of years.

VENUS AND EARTH are a strange pair for two planets so similar in size and apparent composition. Our planet's rapid spin sets the 24-hour day-night rhythm of light and life on Earth, gives us our cyclonic weather patterns, and shapes ocean currents. It's a paradise next to Venus, which a runaway greenhouse desiccated and broiled long ago.

Venus rotates backward, compared to Earth and most other solar system planets, and so slowly that its yearly orbit outpaces its daily spin. You can't see the stars on Venus, but if the sky was ever clear, their rising and setting wouldn't be diurnal but annual.

You might expect the planet's sunward side to be much hotter than its nightside, but Venus also possesses continuous planet-wide clouds of sulfuric acid and an atmosphere 92 times as thick as Earth's. This redistributes heat so effectively that no temperature differences exist from day to night or from equator to pole. At ground level, it's all a sweltering 460°C (860°F).

As hard as it is to imagine today, observations suggest that Venus might once have had water oceans. What effect might global seas have had on the planet's unusual rotation rate? Oceanographer Mattias Green (Bangor University, UK), collaborating with planetary scientists Michael Way (NASA Goddard) and Rory Barnes (University of Washington), tackled this question in a recent study. They found that ocean tides could have caused drag forces on the planet, reining in its rotation by as much as 72 Earth days every million years. So if Venus started out with an Earth-like rotation rate and an ocean, it could have decelerated to its current day in less than 50 million years.



LEAH TISCIONE / *S&T*

This would seem to relate to climate history as well, but how? In an illustration of just how complex and counterintuitive planetary science can be, several initial news stories about the team's result got it backwards.

As the rotation slowed, these stories implied, the planet's oceans would have been more vulnerable to heating and evaporation by the young, warming Sun.

In reality, the effect would likely have been the opposite. When some colleagues and I, led by Way, modeled the ancient atmosphere of Venus with a general circulation model of the kind we use to model climate changes on Earth, we learned — to our surprise — that a slowly rotating Venus is more effective at holding onto an ocean than a rapidly rotating one.

> On a slowly spinning oceanic Venus, the clouds organize themselves so that the dayside is always cloudy and the nightside is always clear. This is perfect for keeping the planet cool.

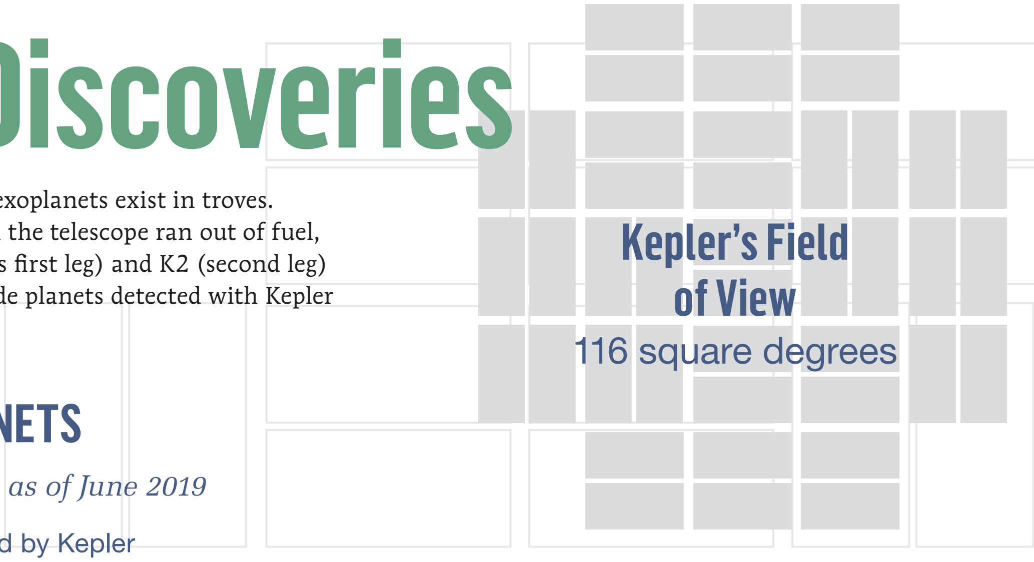
This results from cloud behavior. On a slowly spinning oceanic Venus, we discovered that the clouds organize themselves so that the dayside is always cloudy and the nightside is always clear. This is perfect for keeping the planet cool, because clouds reflect sunlight but clear night skies allow for maximum cooling. So if Venus had a habitable ocean that put the brakes on its rotation speed, it might have helped keep the planet cool for up to 2 billion years.

Clearly, "habitable zone" is not a simple question of distance from a star. Through more missions and more modeling, we'll need to understand the complexity of oceans, tides, and atmospheric motions to get a handle on just where a biosphere could thrive — on a primordial Venus or elsewhere.

■ Contributing Editor **DAVID GRINSPOON** is the author of *Venus Revealed: A New Look Below the Clouds of Our Mysterious Twin Planet*.

Kepler's Discoveries

NASA's Kepler space telescope found that exoplanets exist in troves. Although the mission ended in 2018 when the telescope ran out of fuel, discoveries from both Kepler (the mission's first leg) and K2 (second leg) are still pouring in. The tallies don't include planets detected with Kepler but discovered with other facilities.



2,694 TOTAL PLANETS CONFIRMED *as of June 2019*

2,333 confirmed planets discovered by Kepler
361 confirmed planets discovered by K2

2,586 HOT Planets

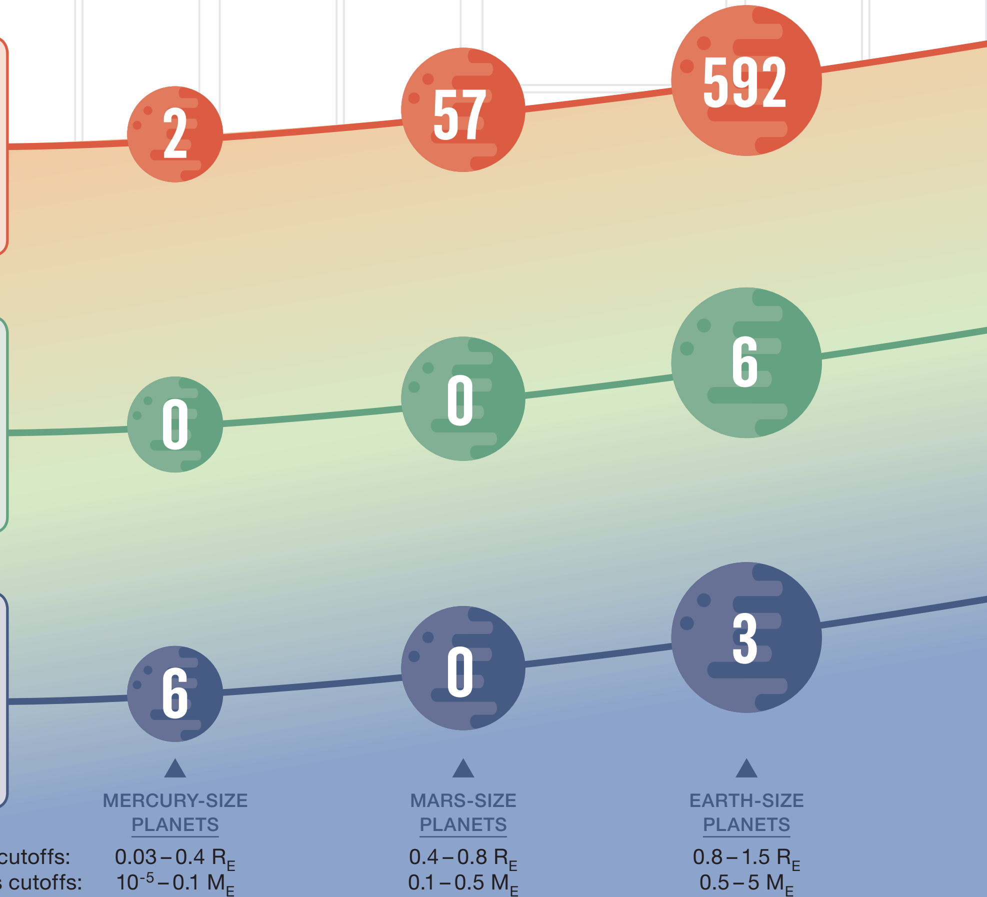
2,229 discovered by Kepler
357 discovered by K2
Too close for liquid surface H_2O

73 WARM Planets

69 discovered by Kepler
4 discovered by K2
Right place for liquid surface H_2O

35 COLD Planets

35 discovered by Kepler
0 discovered by K2
Too far for liquid surface H_2O



Planet sizes not to scale

Astrophysical Targets

Kepler has proved to be a game-changer for astrophysics as well. Its data have enabled astronomers to peer deep within stars, track supernovae, and image planets, moons, and asteroids in our own backyard.

4 SOLAR SYSTEM PLANETS
0 *(Kepler)*, **4** *(K2)*

21 COMETS
0 *(Kepler)*, **21** *(K2)*

67 SUPERNOVAE
6 *(Kepler)*, **61** *(K2)*

81 OBJECTS BEYOND NEPTUNE
0 *(Kepler)*, **81** *(K2)*

75,162,687 Kepler light curves

1,206 potentially rocky planets

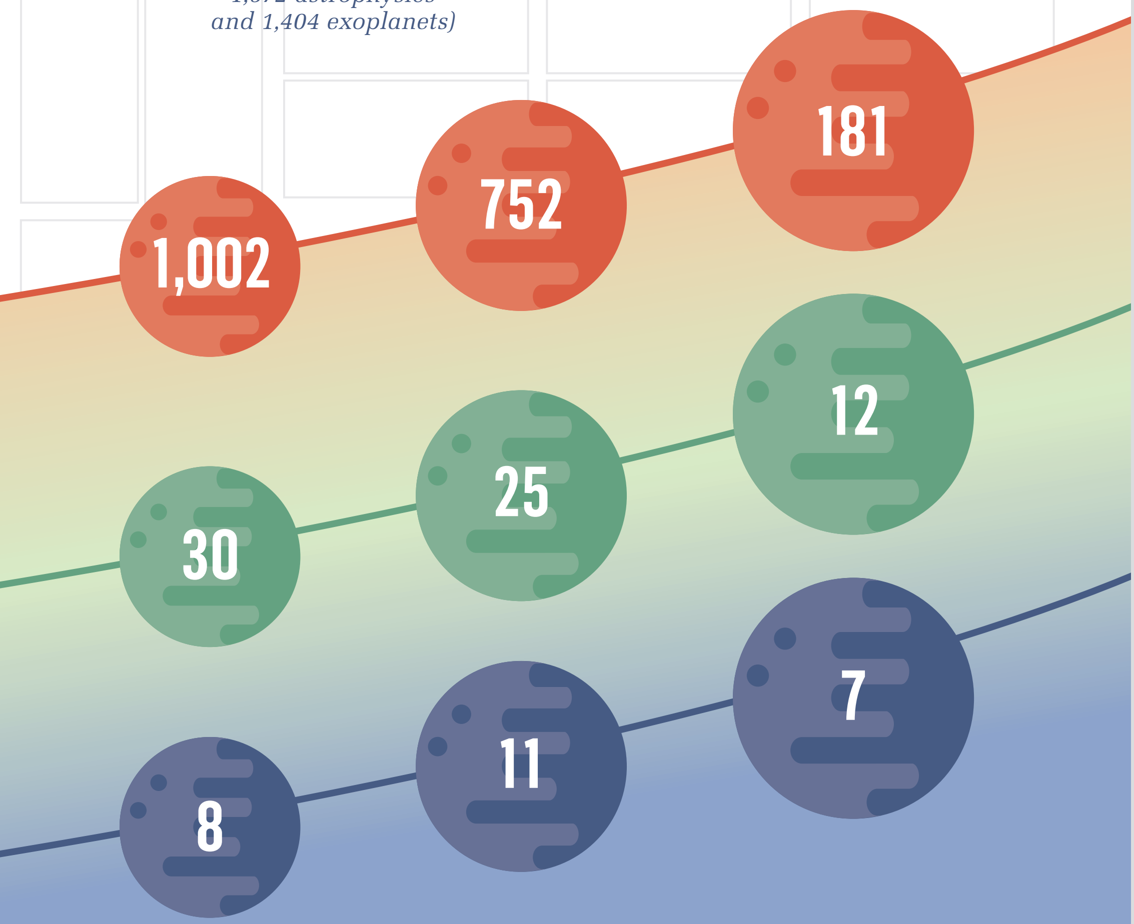
2 missions complete

12 kilograms of fuel used

2,976 papers published before 2019 *(breakdown by 1,572 astrophysics and 1,404 exoplanets)*

9.6 years in space *(8.4 years of full science operations)*

150 million kilometers away



SUPER-EARTHS & MINI-NEPTUNES
1.5 – 2.5 R_E
5 – 10 M_E

NEPTUNE-SIZE PLANETS
2.5 – 6.0 R_E
10 – 50 M_E

JUPITER-SIZE PLANETS
6 R_E and up
50 M_E and up

268 ASTEROIDS **0** *(Kepler)*, **268** *(K2)*

644 PLANETS THAT ORBIT SUN-SIZE STARS **604** *(Kepler)*, **40** *(K2)*

78,748 GALAXIES **400** *(Kepler)*, **78,348** *(K2)*

530,506 STARS **200,038** *(Kepler)*, **330,468** *(K2)*

Is Anyone There?

Kepler and K2 found **31 potentially habitable planets**

M — **11** around *M* dwarf stars

K — **14** around *K* stars

G — **5** around *G* stars

F — **1** around *F* stars

SOURCE: PLANETARY HABITABILITY LABORATORY, UNIVERSITY OF PUERTO RICO, ARECIBO

The (-est)

A few of the exoplanet records set by Kepler/K2

Closest worlds detected:
Kepler-444 b, c, d, e, and f
116.5 light-years

Farthest world detected:
Kepler-40b
8,800 light-years

Shortest year: K2-317b
0.18 Earth day

Longest year: KIC 3558849b
1,322 Earth days

PLANETS: ISTOCK / GETTY IMAGES PLUS; STAR TYPES: PANUWAT SRIJANTAWONG / THE NOUN PROJECT (4); SUPERNOVAE: ANDRÉ LUIZ GOLLO / THE NOUN PROJECT; SOLAR MASS STAR PLANETS: FLATART / THE NOUN PROJECT; GALAXY: LUIZ CARVALHO / THE NOUN PROJECT; ASTEROID: FLATART / THE NOUN PROJECT; COMET: RALF SCHMITZER / THE NOUN PROJECT; SOLAR SYSTEM PLANETS: EUCALYP / THE NOUN PROJECT

The Face of a Black Hole

A worldwide team of scientists has detected the shadow created by an event horizon. Here's how they did it.

▲ **MEET M87*** The gravity of the supermassive black hole in the elliptical galaxy M87 creates a dark shadow feature surrounded by a ring of light. The image is purposely blurred to show only the structure the team is confident of.

EVENT HORIZON TELESCOPE COLLABORATION

Scientists have unmasked mystery incarnate. On April 10th, representatives of the Event Horizon Telescope collaboration unveiled a reconstructed image of the gargantuan black hole that squats in the heart of the giant elliptical galaxy M87. The black hole is an invisible behemoth, so large that light would take 1½ days to cross it.

And it's beautiful.

"We have seen what we thought was unseeable," said EHT director Sheperd Doeleman (Center for Astrophysics, Harvard & Smithsonian) during a National Science Foundation press conference in Washington, D.C. "We have seen and taken a picture of a black hole. Here it is."

An outcome of Einstein's equations of gravity, black holes have suffered a century of disbelief, debate, and then wonder as scientists grappled with their existence. It was astronomical observations of blazing beacons in distant galaxies, as well as of invisible partners to stars closer to home, that ultimately turned the tide in black holes' favor in the late 20th century. They are now thought to exist at a wide range of masses, from the corpses of individual stars to colossi that serve as key players in galaxies' evolution. We've even detected ripples in spacetime created by objects that behave just as colliding black holes should (*S&T:* Sept. 2017, p. 24).

But until the EHT, no one had ever seen one. "Science fiction has become science fact," says theorist Avery Broderick (Perimeter Institute and University of Waterloo, Canada).

The Shadow Knows

Technically speaking, the EHT's radio images don't show the black hole but rather the silhouette of its defining characteristic — the *event horizon*, the point of no return. As gas swirls around a black hole and dives deeper into the pit the black hole creates in spacetime, it heats up, emitting light across the electromagnetic spectrum, from X-rays to radio. Very close to the event horizon, these photons can be diverted or even temporarily trapped by gravity, looping around and around the black hole in what's called a *photon ring*, explains EHT astronomer Feryal Özel (University of Arizona). But if the light continues inward, it will plunge past the event horizon and never reach us. These effects combine to create what's called the black hole's *shadow*: a dark circle surrounded by a bright halo. The halo's inner edge is the photon ring.

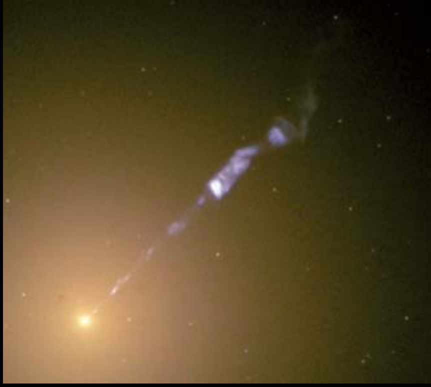
Einstein's description of gravity, the general theory of relativity (GR), predicts what this shadow should look like: a nearly perfect circle approximately five times wider than the black hole's horizon. The size and shape depend primarily on the way the black hole bends light around itself, not the behavior of the gas, radiation, or magnetic fields nearby.

However, the shadow only exists because of that nearby matter. The bright ring outlining the darkness is made of *synchrotron radiation*, radio photons spat out by electrons corkscrewing along magnetic field lines. (Magnetic fields thread the giant tutu of gas that encircles the black hole.) The closer observers look to the black hole, the hotter the radiation. To peer as close to the black hole as possible, where gas temperatures reach some 100 billion degrees, astronomers need to observe at short radio wavelengths of about 1 millimeter.

But they also need large targets. The black holes that form binaries with stars are only as wide as cities; to detect shadows, astronomers must observe supermassive black holes, which squash millions to billions of Suns' worth of mass into a region the size of a planetary system. The black holes also have to be bright at the right wavelengths, and not all are.

Scientists thus settled on two optimal targets: Sagittarius A*, which sits in the center of the Milky Way, and M87*, which lies about 55 million light-years away in the constellation Virgo (*S&T:* Feb. 2012, p. 20). Each of these black holes should have a shadow roughly 50 microarcseconds across, or the apparent size of an orange at the distance of the Moon. They're also very different black holes: Sgr A* is a quiet beast, constantly flickering as it snacks on gas, whereas M87* rages, spewing a plasma jet toward us that stretches thousands of light-years into space. Even so, M87* is a steadier source, varying on daylong time scales instead of minutes as Sgr A* does.

But how do you take a picture of something the size of an orange on the Moon?

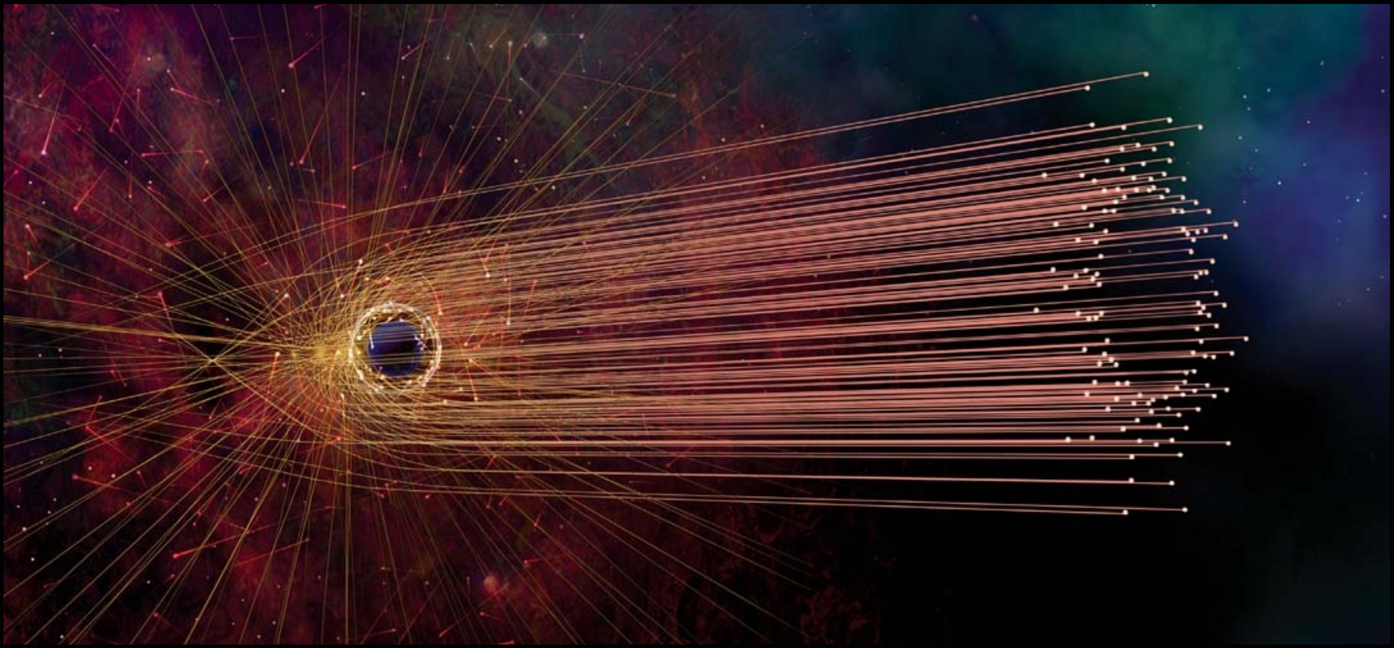


▲ **HOME GALAXY** The elliptical galaxy M87 contains roughly 10 times more stars than the Milky Way and dominates over the Virgo Cluster's some 2,000 galaxies. A powerful jet streams from its central black hole, stretching across several thousand light-years.

Making the Invisible Visible

Working at a wavelength of 1.3 mm, astronomers need a telescope approximately 10,000 km in diameter to resolve the shadows of these black holes. That's roughly the size of Earth itself. No agency will fund that.

▼ **MAKING THE SHADOW** Photons traveling close to a black hole have their paths bent by gravity. Some will plunge in, but others are redirected or even caught in circular orbits just outside the event horizon. These orbiting photons then escape and travel toward the observer (right), tracing out a slightly magnified picture of a light ring around a dark center.

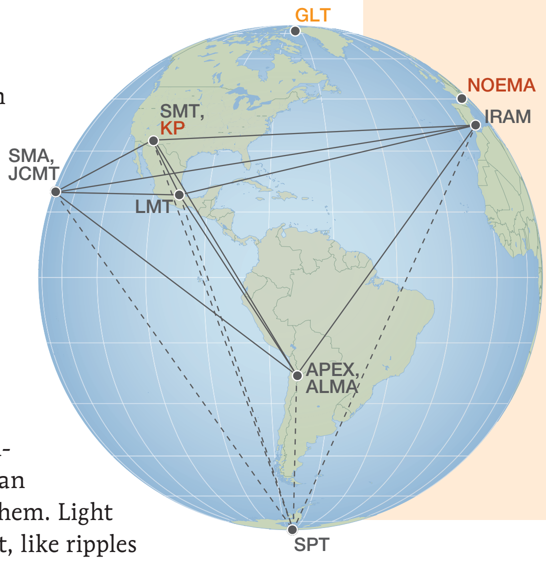


M87*: NASA / HUBBLE HERITAGE TEAM (STSCI / AURA); SHADOW: NICOLLE R. FULLER / NSF

Instead, the EHT's worldwide team of researchers, comprising 200 people working in 20 countries and regions, constructed the black hole's image using a technique called *very long baseline interferometry* (VLBI). VLBI combines the data from multiple radio telescopes scattered across the globe into a single image.

The basic principle of interferometry is this: Take two telescopes, separated by some distance, and observe an object simultaneously with both of them. Light comes from the object as a wavefront, like ripples in a pond, explains imaging team leader Michael Johnson (Center for Astrophysics, Harvard & Smithsonian). The two telescopes will catch a slightly different part of each ripple. Account for that delay, then carefully add the data together, and you can measure the object's structure with the resolution you'd have from a telescope that is the size of the distance between the two dishes.

But when observing something with structure on a variety of scales, things get complicated — it's like having a flock of ducks cavorting in the pond, their waves interacting and changing the pattern in complex ways. In order to reconstruct the image, you need a detailed understanding of how the radio waves are augmenting or canceling one another out as they travel to the dishes. The solution is a bunch of telescopes with different separations, which enable you to mix and match the pairs and detect structures of various sizes and orientations.



OBSERVATORIES

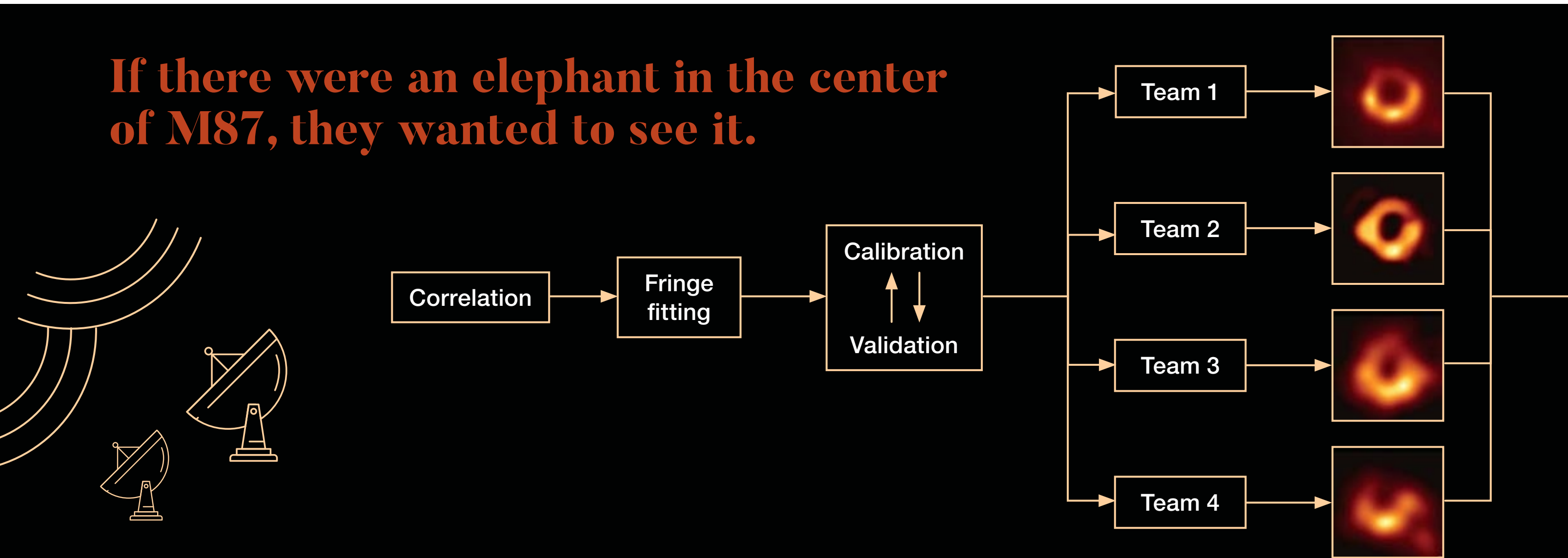
Atacama Large Millimeter/submillimeter Array (ALMA)
Atacama Pathfinder Experiment (APEX)
IRAM 30-meter Telescope (IRAM)
James Clerk Maxwell Telescope (JCMT)
Large Millimeter Telescope (LMT)
Submillimeter Array (SMA)
Submillimeter Telescope (SMT)
South Pole Telescope (SPT)
Greenland Telescope (GLT)
Kitt Peak 12-meter Telescope (KP)
NOEMA Observatory (NOEMA)

▲ **A GLOBAL TELESCOPE** Eight stations participated in the 2017 EHT observing campaign. Seven of them (connected by solid lines) observed M87*; dotted lines mark sites that observed the calibration source, the quasar 3C 279. In 2018 the Greenland Telescope joined the array, and two more stations (red) will sync up in 2020.

The approach is thus akin to the old joke about a bunch of blindfolded scientists studying different parts of an elephant. With VLBI, each blindfolded scientist represents the separation, or *baseline*, between two telescopes. But instead of sampling different body parts, each baseline observes a different scale of the elephant: One says it's 10 feet high, another says there's a foot-long ear, still another explores the fine texture of the elephant's skin. As Earth turns, different baselines see the target, detecting different scales of the elephant. The scientists then piece these bits of information together into a coherent image.

MAP: LEAH TISCIONE / *S&T*, SOURCE NSF AND THE EHT COLLABORATION / *ASTROPHYSICAL JOURNAL LETTERS* 875:L1 (2019); WORKFLOW: TERRI DUBÉ / *S&T*, SOURCES: EHT COLLABORATION / *ASTROPHYSICAL JOURNAL LETTERS* 875:L4 AND L5 (2019), ZINA DERETSKY / NSF

If there were an elephant in the center of M87, they wanted to see it.



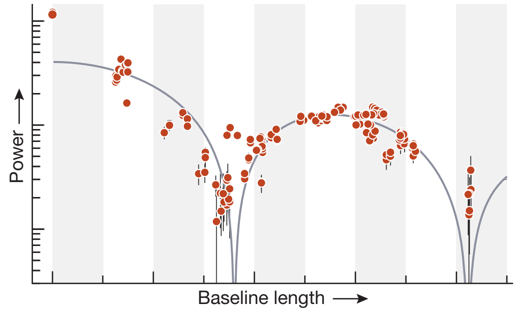
Telescopes scattered across Earth simultaneously record emission from near the black hole.

Correlators combine the raw data, sifting out signals from noise.

Team members align all the signals to within picoseconds.

Data are converted to radio brightness measurements.

Blind imaging stage: Teams use independent algorithm approaches to create images.



▲ **THE MOMENT THEY SUSPECTED** Maciek Wielgus (left) runs to director Shep Doeleman to show him an initial plot of the VLBI data. The data's bouncing pattern indicated the array had detected ring-like structure — even before the team reconstructed an image.

REACTION PHOTOS: HSIN-YU CHEN. GRAPH: EHT COLLABORATION / *ASTROPHYSICAL JOURNAL LETTERS* 875:L3 (2019)

Although the images of M87* are derived from only four days of observations, EHT scientists spent years testing and installing equipment, working in the thin air of the remote Chilean desert, braving the cold of Antarctica. They built computer algorithms and developed simulations of what they might see. They installed atomic clocks so precise that they'll lose only 1 second in 10 million years. They did dry runs, agonizing over go/no-go weather conditions at eight telescopes at six geographic sites scattered from Hawai'i to Spain and Arizona to the South Pole. "In VLBI, you really only get one shot," says Dan Marrone (University of Arizona), who has flown repeatedly to the South Pole to retrofit the telescope there. "Everything has to be working exactly right."

Then, in April 2017, they went for it.

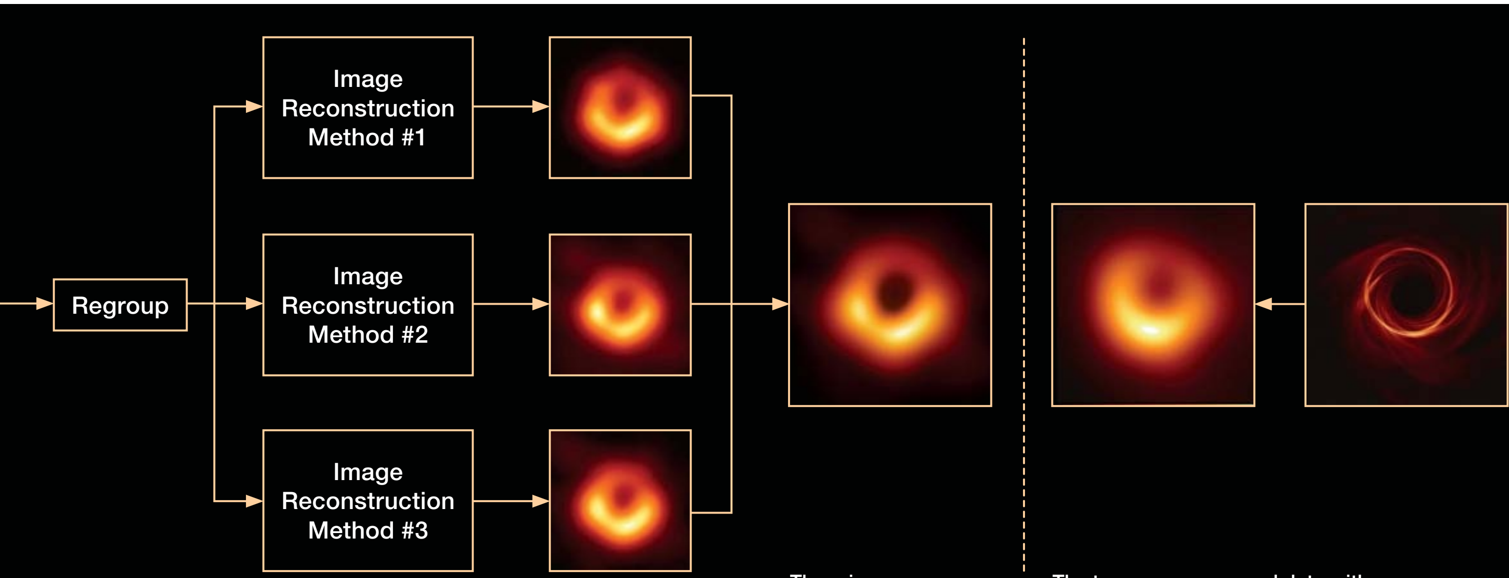
As Earth turned, each telescope set its sights on M87* and the other targets, stockpiling data. By the end of the observing run, they'd filled a half ton of hard drives with 5 petabytes of data — equivalent to 5,000 years of MP3 files or, Marrone quips, "the entire selfie collection over a lifetime for 40,000 people."

The team then flew these hard drives to Massachusetts and Germany, where the stations' observations were fed into supercomputers and aligned by their time stamps to within trillionths of a second. "They have to be exactly right," says Johnson. "If they're even a tiny bit off, you see *nothing*."

Once the researchers had calibrated their data, a subset of them (mostly young astronomers and computer scientists just starting their careers) split into four teams spread around the world. "We told them, 'Don't talk to each other or anyone else,'" says Marrone. "'Choose whichever imaging algorithms you think are best, and make images of these data.'"

"We went into a room, there were six or seven of us there," says Johnson, "and we actually had the first picture 30 minutes later."

The challenge isn't making one image, he explains, but understanding its subtleties. The teams had to know all the potential images their algorithms might create and where the codes might lead them astray. Nor did they limit their codes to reproducing shadows: To steal a comparison from com-

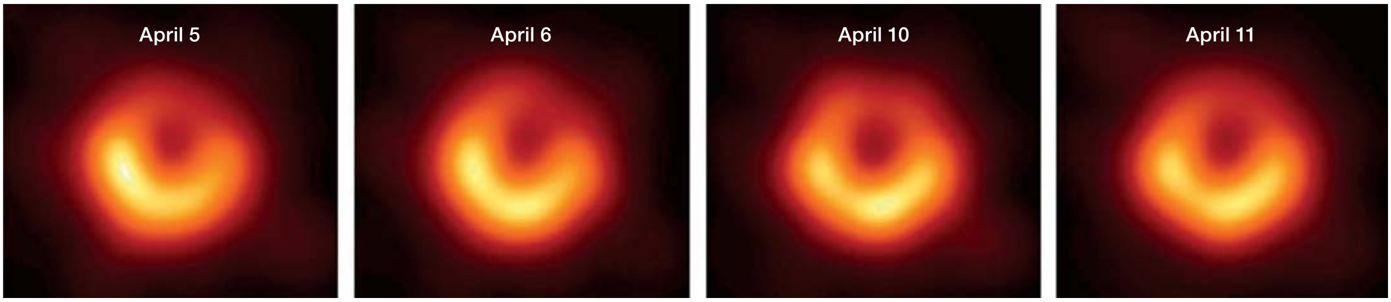


Teams use different software packages to attack data systematically, producing three independent results.

Three images are averaged to create a final consensus image.

The team compares real data with simulated shadows, blurred to the same resolution, to deduce where the photon ring is in the fuzzy image.

> “It might look like we’re just taking a picture of a sleeping giant or something, but this system is alive like the surface of the Sun.” –**MICHAEL JOHNSON**



▲ **IT’S ALIVE** Images of the shadow from four days of the observing run reveal small changes, indicating that the black hole’s environment is evolving from day to day. Each image is the average of the three reconstruction methods’ results for that day.

puter scientist Katie Bouman (now Caltech), if there were an elephant in the center of M87, they wanted to see it.

After testing the countless alternatives, they all met and unveiled their four images — and all looked remarkably alike: four dark circles surrounded by ringlike structures.

Then they started over. The team members reorganized themselves, using what they’d learned to systematically attack each day’s data three different ways. Each method produced a slightly different image, but once again, the images were strikingly consistent with one another.

Combining these images into a single one took a long, long time, Johnson says. The researchers wrestled with how to convey what was sure versus what might be the byproduct of a single algorithm’s favorite bits. They finally decided to take the three images from a single day, blur them to match the instruments’ resolution, and then average the blurred results into a single image. By doing so, they only showed the structure that appears using all analysis methods. “We stand behind basically every element” of this conservative image, Johnson says.

And what an image it is. The width of the silhouette is about 40 microarcseconds — the size of a hydrogen atom seen at arm’s length. “This is the first time that I saw this image,” said NSF Director and astrophysicist France Córdova during the press conference, “and it did bring tears to my eyes.”

Around the Rabbit Hole

The team’s primary focus thus far was creating the image. But they have ascertained some of the underlying physics, too. Based on the size of the shadow, the researchers calculated the black hole contains 6.5 billion solar masses, a figure close to the larger of two contested values.

The black hole is spinning clockwise from our perspective; the bright crescent to the south is the boosted beam of gas moving toward us, while the dimmer north is where gas recedes from us. The data do not, however, reveal how quickly the black hole spins, because the shadow’s shape and size are independent of the spin except for the most extreme rotations. The observations also don’t yet connect the black hole with its jet, because the jet is on the wrong scale and too faint to be resolved with the current data.

Nevertheless, the image boosts astrophysicists’ confidence in their theories about what happens near an accreting black hole. “I have to admit I was a little stunned that it matched so closely the predictions we had made,” says Broderick.

“Just the fact that our [simulations] came so close to images like the one we ended up getting for M87* already tells us that we’re on the right track for understanding accretion physics,” says Özel. “We could have been completely off.”

But there’s little detail yet about how that accretion physics works. Although many immediately hailed the shadow image as a verification of Einstein’s theory of gravity, astrophysicists aren’t content with that. “It’s not like I’m sad we confirmed GR again,” says X-ray astronomer Daryl Haggard (McGill University, Canada). But what she cares about is the magnetically tangled gas wreathing the black hole and how the black hole eats it. “These are supposed to be the most efficient engines in the universe,” she says. And yet when astronomers look closely, they see stuff flowing *out* — winds off the accretion disks, powerful jets. Of all the matter trying to make it across the event horizon, it’s unclear how much successfully dives in. “That’s

▶ **THEY’RE MULTIPLYING** *Left:* EHT members (plus the author, back row) gathered in January 2010 to strategize. *Right:* A November 2018 photo from a workshop in the Netherlands shows how much the collaboration has grown — and only includes half the team.

VARIATION: EHT COLLABORATION / *ASTROPHYSICAL JOURNAL LETTERS* 875:L4 (2019); 2010 PHOTO: EHT COLLABORATION; 2018 PHOTO: DICK VAN AALST / RADBOUD UNIVERSITY super fascinating," she says. "They had to get mass somehow, they're supermassive! So what gives?"

Initial answers may already lie in the EHT's data. Soon, the researchers will start putting together maps of how the magnetic fields move near the event horizon, information encoded in the light's polarization. Theorists think magnetic turbulence helps slow the gas around black holes, making accretion possible. Magnetic fields also enable black holes like M87* to power their light-saber-esque jets by sapping energy from the objects' spins.

"We think of black holes as an endpoint of matter — you fall in, you can't get out," Johnson says. "A black hole's spin is not sacred in that way." Magnetic fields in the accreting gas pile up near the event horizon, and as the black hole spins, it whirls the field lines around, which drag on the black hole and slow it down. This stolen energy then powers the fling-out of charged particles as gigantic jets. "It might look like we're just taking a picture of a sleeping giant or something, but this system is alive like the surface of the Sun," he says.

What many onlookers await, however, are the results for our own galaxy's central black hole, Sgr A*. The team is still analyzing those observations. Because it's about a thousandth the mass of M87*, Sgr A* is smaller, and gas whips around its circumference a thousand times faster. That means we see much faster changes in its light, making teasing apart the shadow signature more complex. "We knew it was a more turbulent child," says Özel. "We have to apply special care."

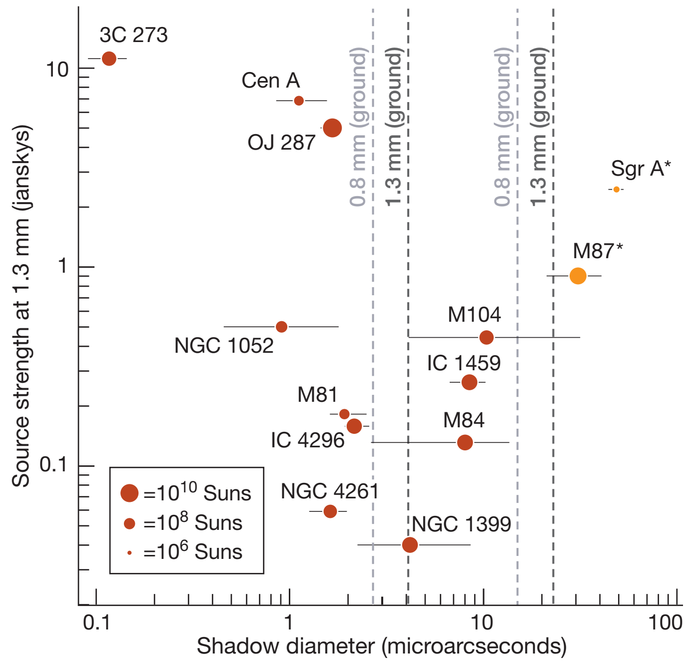
That includes devising new algorithms, says Bouman, whom fellow EHT members credit with bringing key insights from the computing community to their imaging methods. Although the team won't have to start completely from scratch, the current algorithms will likely have to be modified to handle Sgr A*'s variability, she explains.

Next year, the EHT will integrate stations in France and Arizona, and it has already added a dish in Greenland. Researchers are also pushing to a slightly shorter wavelength than the 1.3 mm currently used, which will boost their resolution considerably.

But M87* and Sgr A* are the only two black holes whose shadows are large enough for us to detect with ground-based networks. To expand to a larger number of black holes, they'll have to put radio telescopes in space. Adding geosynchronous orbits would lengthen baselines by more than six times Earth's radius, enabling the EHT to see black hole shadows roughly one-tenth as wide as M87*'s.

This utterly serious push to space VLBI is remarkable progress for a collaboration that, back when I first met them nearly 10 years ago, was once a huddle of astronomers working on what they affectionately referred to as "Shep's Event Horizon Telescope." Over the years, the team has grown, complexified, and faced a stream of setbacks and frustrations. "I didn't realize how hard it would be when we started out," Doeleman admitted to me the afternoon of the announcement, thinking back on the journey. But quitting wasn't an option. "You know, there are just some projects that you have to keep pushing on, no matter what."

That they've seen a black hole's shadow — not yet another blob, not something that violates gravity, but a heart of darkness nestled in the glow of gas hurtling into oblivion — is a humbling testament to the years of everyone's hard work. Or, as Doeleman puts it: "Sometimes you have to kiss a lot of frogs before you get the prince."



▲ **SHADOW TARGETS** With current facilities, the EHT collaboration can resolve the silhouettes of two black holes: Sgr A* and M87*'s. Moving to a shorter wavelength will increase resolution (moving left on the chart). By adding one or more satellites in either medium-Earth orbits (10,000 to 20,000 km altitude) or geosynchronous orbits (35,786 km), researchers could bag three, maybe four more shadows.

DOMINIC PESCE

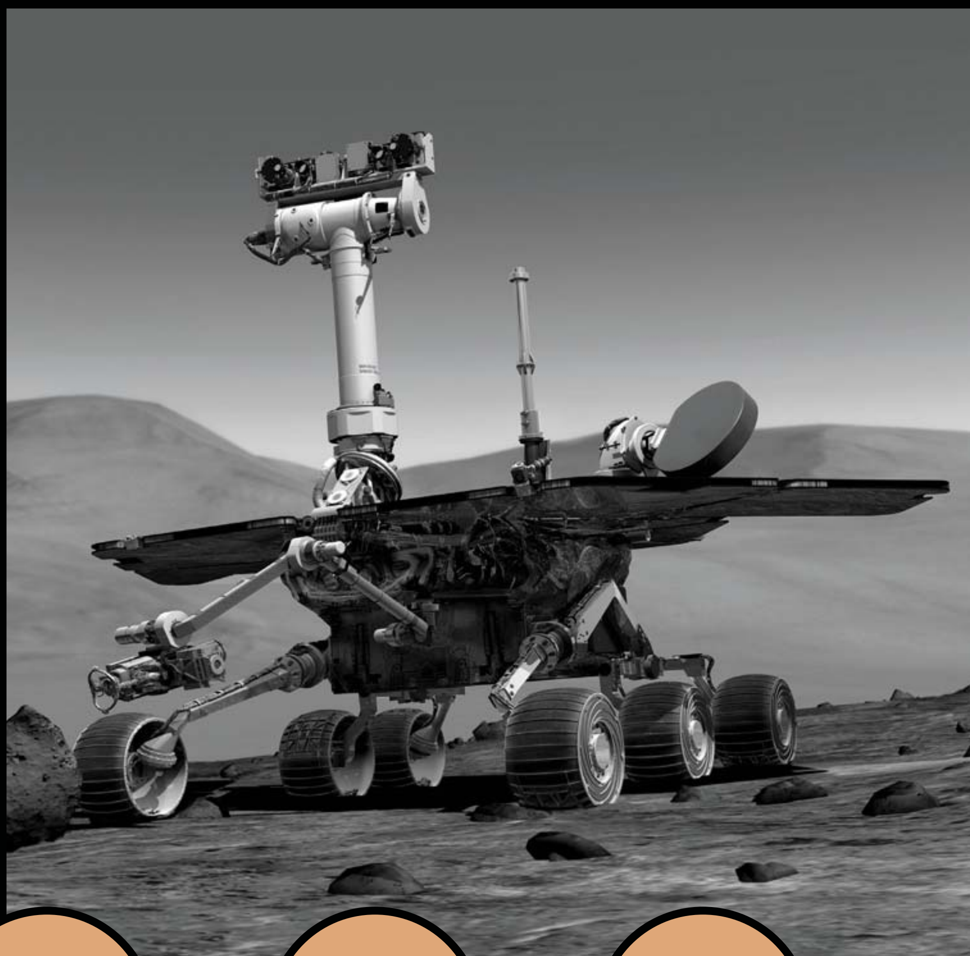
■ Science Editor **CAMILLE M. CARLISLE** has buzzed around the EHT team's ears since she was a wee master's student. This article is based on her reporting for *S&T*'s website.

Watch videos explaining how VLBI and image reconstruction work: https://is.gd/vlbiprimer.

 by Shannon Hall

Opportunity's End

The Martian rover's spectacular and heartbreaking saga helped rewrite textbook knowledge of the Red Planet.



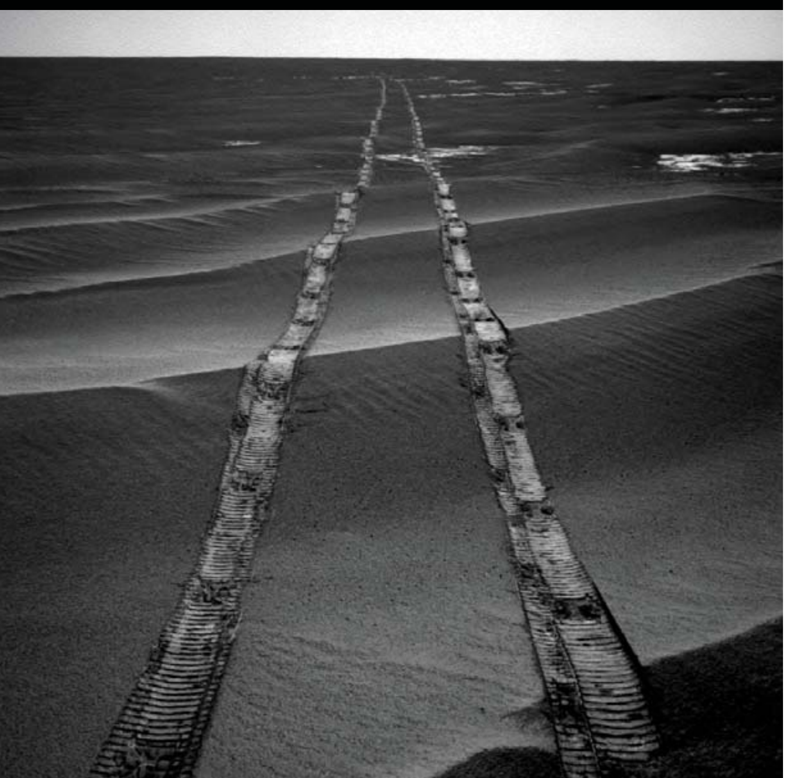
14+ years lifespan

217,594 raw images

45 kilometers traveled

32 degrees (steepest slope)

> “Opportunity had gotten through a lot of tough scrapes before, so we learned never to bet against the vehicle.”
>
> —ABIGAIL FRAEMAN



◀▲ **THE ROAD TRAVELED** Opportunity looks back on its own tracks on two days in 2010: May 8th *(far left)* and August 4th *(above)*. An artist’s concept sits between.

The Martian winds were picking up — kicking dust, sand, and debris off the ground in a storm that would soon envelope the entire globe.

For weeks, amateur astronomers on Earth would swing their telescopes toward the Red Planet only to find its familiar surface features hidden under a thick veil of dust. The many satellites that orbit Mars would similarly image a hazy globe. And a beloved rover on the surface would fail to see the Sun, as daytime temperatures plummeted and the winds pummeled against it. Opportunity was in the heart of the storm.

On June 10, 2018, when the storm was well underway, NASA scientists asked the rover to take two photos of the Sun. But the images revealed nothing more than the faintest pinprick of light surrounded by a blackened sky. “By the time the dust storm was at its strongest, it was as dark for Opportunity at noon as it would be on a moonless night here on Earth,” says Tanya Harrison (Arizona State University). “I’m not sure we can even fathom a storm that severe on Earth — that just could completely black out the Sun.”

Little did scientists know at the time, those two photos would be Opportunity’s last. After the rover transmitted the images to Earth, it hunkered down for the dust storm. Scientists on Earth waited, hopeful that once the storm cleared the rover would pop back to life. But the intrepid explorer never stirred. In February 2019, NASA declared the mission complete.

“It’s almost like the death of a loved one,” says project manager John Callas (Jet Propulsion Laboratory). “You’re used to seeing that individual every single day and interacting with that individual. You have meals with them. You live your day with them. Suddenly, they’re gone.”

The Long Goodbye

Unaware of the coming tragic ending, the mood last September was hopeful — optimistic even — with many scientists expecting that the rover would pull through. “Opportunity had gotten through a lot of tough scrapes before, so we learned never to bet against the vehicle,” says deputy project scientist Abigail Fraeman (JPL). “Anything is possible.”

In the best-case scenario, the rover would simply wake up and phone home. “We were hoping that all we really had to do was wait and listen, and we were listening every day,” Callas says. More likely, however, was a scenario in which heavy dust had settled onto Opportunity’s solar panels, blocking the Sun and preventing the rover’s batteries from recharging. Here, too, scientists had hope: They expected that a heavy wind would clear away any settled dust, allowing the rover to rouse from its deep slumber.

But when the silence stretched into January, the team started to worry, convinced that there was another issue. It was possible that the rover’s internal clock had stopped keeping track of time. This would be a serious problem, because Opportunity wouldn’t know when to go into deep sleep at night and would instead just burn through the battery. Or perhaps one of the radio antennas was broken and the rover couldn’t send signals home, even if awake. So the team

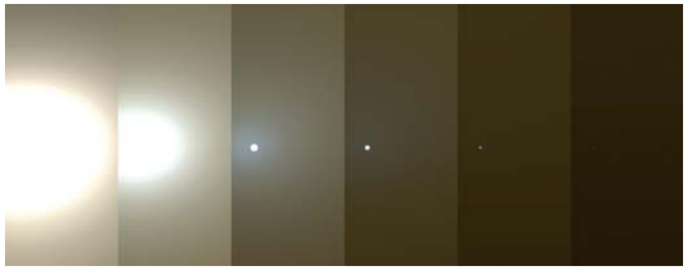
TRACKS: NASA / JPL-CALTECH (2); OPPORTUNITY: NASA / JPL / CORNELL UNIV.; STATS: SOURCE: NASA / JPL-CALTECH started to exercise more extreme measures, sending Opportunity commands to restart its clock or communicate with the orbiters overhead by using different antennas.

Nothing worked. To make matters worse, February signaled the end of the winds and the beginning of colder, darker days, even near the equator. If Opportunity didn't stir before the seasons turned, the rover definitely wouldn't after.

So on the night of February 12th, scientists and engineers gathered at JPL where Thomas Zurbuchen, the associate administrator of NASA's Science Mission Directorate, announced that they would send the last commands to Opportunity that night. If there was still no response, he would declare the end of the mission.

Over the next two hours, the team sent four commands streaming toward the Red Planet. And for the most part, the spirit was jubilant: People hugged colleagues they didn't see often, they shared stories about the rovers, and they talked about how the rover had impacted their lives.

Mike Seibert, a former mission manager who left JPL in 2017, for example, got married on the anniversary of Spirit's launch day. Fraeman won a contest sponsored by the Planetary Society when she was in high school and scored a trip to JPL for the night Opportunity landed — a moment that encouraged her to become a planetary scientist. And Doug Ellison (JPL) was a multimedia producer for a medical company when he began stitching together mosaics from Spirit and Opportunity's publicly available images in his free time



▲ **THE SUN GOES DARK** This series of simulated images shows what Opportunity would have seen as the rising dust storm blotted out a mid-afternoon sky. Each frame corresponds to a measure of atmospheric opacity, called *tau*, of 1, 3, 5, 7, 9, and 11. The rover survived a 2007 storm with a tau somewhere above 5.5 (similar to the third panel from left), but the 2018 storm neared 11 (far right).

— a hobby that ultimately landed him a job directing Opportunity to take images of the Red Planet.

With a trip to the bar before the event and a never-ending number of stories to be told, the evening was akin to an Irish wake. But when the last command was sent, the room grew deadly silent as everyone waited 27 agonizing minutes (13.5 for the signal to reach Mars and 13.5 for a signal to return).

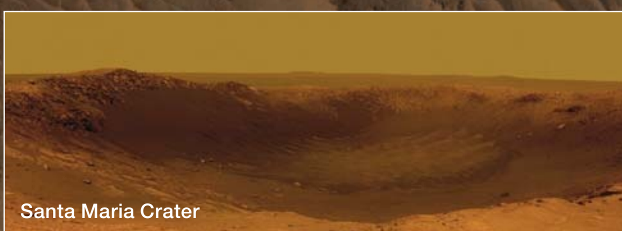
The countdown hit zero with no news.

"We knew with that final command, that this is it — this is over," Harrison says. "And then a lot of people just kind of lost it. I stood in the corner crying, hugging Keri Bean (JPL) for a long time."

DARKENING SKY: NASA / JPL-CALTECH / TAMU

THE TREK

Over the course of more than 14 years, Opportunity traveled some 45 km, visiting several craters, finding evidence of water-deposited bedrock, and seeing dust devils, among other sights.



Santa Maria Crater

Eagle Crater

Endurance Crater

Victoria Crater

In that moment, the team was forced to accept the inevitable. They were forced to say goodbye.

More than Machine

For those who see space-faring robots as gadgets of scientific discovery and nothing more, it may sound strange that so many considered the rover something analogous to a friend. Even the most calculated scientists tend to anthropomorphize Opportunity — better known as "Oppy" — and her twin, Spirit. And it's easy to see why from merely a design standpoint: They were each about five feet tall and outfitted with a robotic arm and a neck topped with two eye-like science cameras, all eerily sentient-looking.

But Callas notes that not only did the rovers appear human, they had human-like qualities. "They were intrepid, they were dutiful, they were accomplished," he says. "Sometimes they were recalcitrant. Sometimes they were funny. They were loyal. How could you not fall in love with them?"

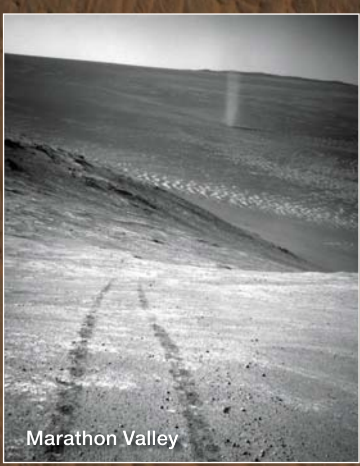
And fall in love many of us did. Not only did the final command leave the rover team wistful, but it also inspired an outpouring of affection from much of the world. Opportunity trended on Twitter for days as scientists and non-scientists alike shared stories of the rover's impact on them. Even former President Barack Obama posted a photo of the rover's tracks to Instagram and congratulated the team.

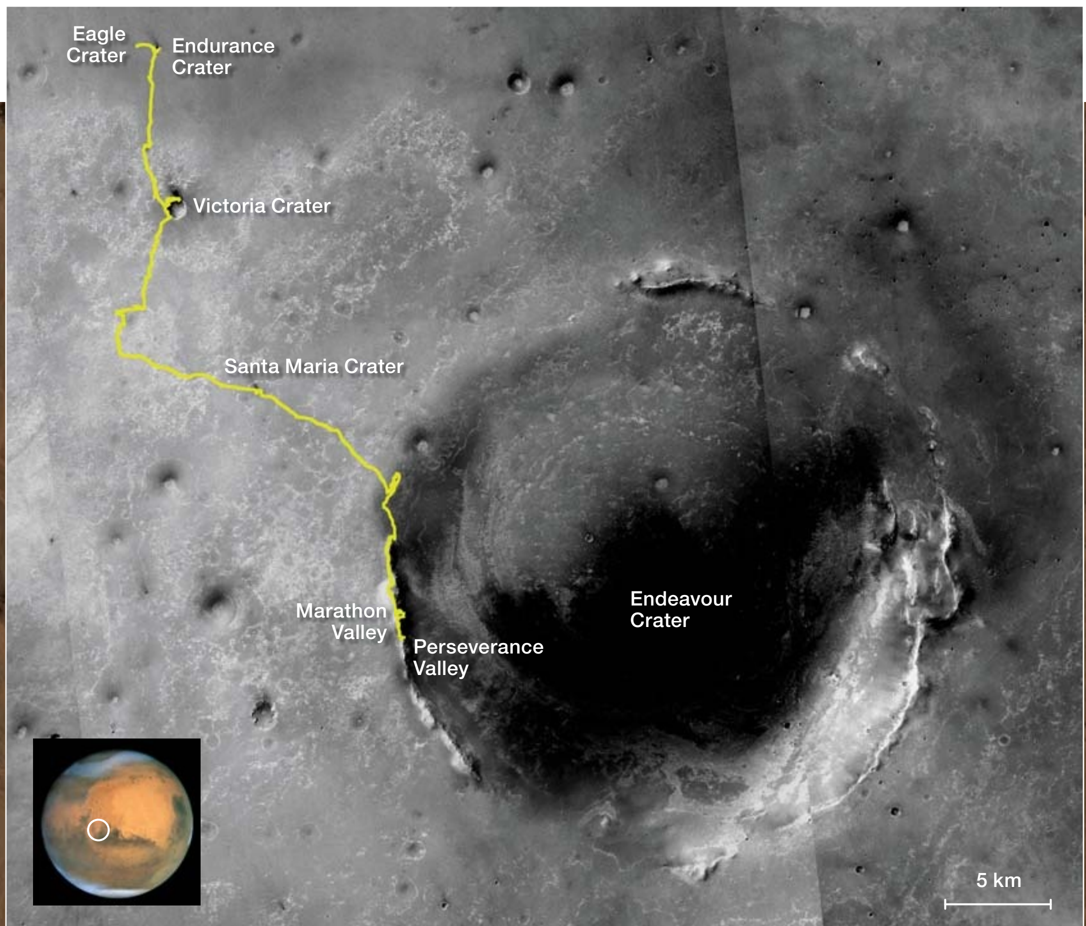
"Sometimes they were recalcitrant. Sometimes they were funny. They were loyal. How could you not fall in love with them?" —JOHN CALLAS

But for many, it was the days after the final command that were harder. For more than a decade, the day-to-day lives of these scientists had revolved around Opportunity. Every morning they would check the status of the vehicle, plan rover operations, and prepare the commands. "You really do start to feel a connection to something that's more than just a machine when you spend 15 years of your life making sure Opportunity is healthy, making sure her power is okay, making sure all the commands you're sending are good," Fraeman says.

Now, the team's daily activities have shifted. "We come into work now and it's like, 'What do we do?'" Callas says. "It's dramatic change."

Seibert, who had a head start on mourning because he left in 2017, points out that the new daily routine likely won't include the adrenaline rush that often came with working on the rovers. "You don't have that little dopamine hit you get when every image comes down and shows whatever you





THE TREK: MAP: NASA / JPL-CALTECH / MSSS; GLOBE: NASA / CORNELL / SSI / STSCI / AURA; INSETS: EAGLE, ENDURANCE, AND VICTORIA: NASA / JPL-CALTECH / CORNELL (3), SANTA MARIA: NASA / JPL-CALTECH / CORNELL / ASU, MARATHON VALLEY: NASA / JPL-CALTECH; BACKGROUND MARS TERRAIN TEXTURE: NASA / JPL-CALTECH / UNIV. OF ARIZONA planned the previous day was successful and you see a new piece of Mars," he says.

Already, many team members are planning their next move. Some have been lucky enough to find jobs on other Martian projects, like Curiosity, the Insight lander, and the upcoming Mars 2020 rover. But now they have to bid farewell to the team, too. "Opportunity is metal, glass, and silicon," Seibert says. "But the team that became a family to operate it — that's what everyone is going to miss."

Legacy Left Behind

But while mourning Opportunity, the team is also celebrating her achievements.

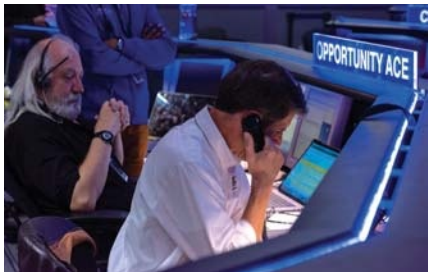
Opportunity and Spirit bounced onto Mars in January 2004, but their life expectancies were dramatically short. Engineers estimated that the rovers only had three months before so much dust accumulated on their solar panels that they both failed from lack of power.

Mars, however, intervened: Gusts of wind repeatedly wiped the solar panels clean and boosted power levels back up. That allowed Spirit to last for 6 years and Opportunity to last for more than 14. Their unexpectedly lengthy lifetimes allowed them to transform our vision of Mars.

Before the rovers tumbled onto the Red Planet, scientists had only seen signs from orbit that Mars had hosted liquid water in the past. But Opportunity's first image revealed layered bedrock, which the team determined was probably sediments laid down by water.

Then, Opportunity stumbled upon tiny spherical grains, fancifully called blueberries, embedded within the sandstone. On Earth, similar orbs form when minerals dissolved in acidic groundwater solidify again in a different form. It was further evidence that Mars was once warm and wet.

"Then came the magnificent benefit of the extended mission," Callas says. "As we drove this rover kilometers away from where we landed, we continued to see this evidence of liquid water. We're not just talking about a puddle or a pond, but we're talking about at least kilometer-scale bodies of water on the surface."



◀ **FAREWELL** Top: Mars Exploration Rovers project manager John Callas makes the call ending the Deep Space Network's last listen for Opportunity, February 12, 2019. Bottom: Former mission manager Cindy Oda shares her experience working on the rover that same evening.

All in all, Opportunity drove more than a marathon on Mars — a distance that allowed the team to not only image extensive features carved by long-gone lakes but to actually drive back in time. Eagle Crater, where Opportunity landed, dates back to the Hesperian Period, 3.7 to about 3 billion years ago. In 2011 however, Opportunity reached Endeavour Crater, which formed in the Noachian Period, 4.1 to 3.7 billion years ago. It's the oldest period yet studied on Mars.

Here Opportunity found signs of another ancient wet environment, but with water less acidic and more favorable to life. That find, coupled with Spirit's discovery of hydrothermal vents, paints a tantalizing early portrait of Mars. After all, where there is both energy and water on Earth — such as within the geysers of Yellowstone or the hydrothermal vents of the ocean deep — there is life. Throw in the organic compounds that Curiosity later found on Mars, and the Red Planet seems to have once had everything organisms would need.

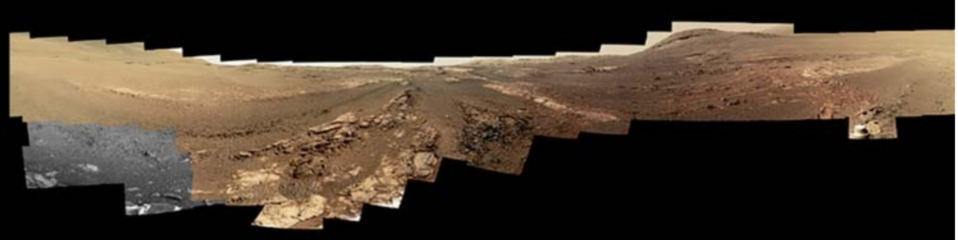
"You have the energy, you have the liquid water, you have the neutral pH, you have the warm temperatures, you have the thick atmosphere," Callas says. "Boy, you don't have to go much further than that to say, 'This is physically habitable to support life as we know it.'"

Thanks to their extended forays, both rovers rewrote every textbook on Mars — and that is surely cause for celebration.

Opportunity Lost

"I always thought there were only two honorable ways for a mission like this to end," says Steve Squyres (Cornell University), the principal investigator and godfather of the mission.

▶ **THE LAST HURRAH** This last 360° panorama of Perseverance Valley combines 354 images taken from May 13 through June 10, 2018. That same day, a global dust storm cut off the rover's communications with Earth. The valley sits on the inner slope of Endeavour Crater's rim, which rises in the distance. Had the rover survived, it could have followed the valley down to the crater floor.



PHONE CALL AND SHARING: NASA / JPL-CALTECH (2); LAST PANORAMA: NASA / JPL-CALTECH / CORNELL / ASU

“I always thought there were only two honorable ways for a mission like this to end. One is that we simply wear the vehicle out . . . and the other is that Mars just reaches out and kills it.” —STEVE SQUYRES

“One is that we simply wear the vehicle out, and that’s what happened with Spirit, and the other is that Mars just reaches out and kills it. And that’s what happened with Opportunity. To have a mission end after 14.5 years of science, being taken out by one of the worst dust storms to hit Mars in decades, you can walk away from that with your head held high.”

But no matter when a mission finally ends, some tantalizing discovery remains just beyond reach. Indeed, Opportunity was halfway down Perseverance Valley — a feature that looked like it had been carved by water — when the dust storm hit. And scientists were anxious to drive to the bottom, where sediments would have gathered, to further study the crater and verify that it was indeed sculpted by water and not by wind.

“It would have been the first opportunity we had had to look at a feature like this on the ground,” Fraeman says. Although scientists have spotted a number of similar gullies from orbit, they were excited to dive into one (literally) on the ground. If the hypothesis is true, then Fraeman suspects the groundwork would have helped the team better understand the history of water within the region, and perhaps across the entire Red Planet.

It also would have painted quite a vivid picture of the Red Planet’s wet past. Callas suspects that, if it really were carved by water, this valley might once have looked like the magnificent cascading waterfalls in Hawai‘i. And while scientists might never answer this exact question, it points toward yet another legacy of the mission.

“We have made Mars familiar to the public,” Callas says. “They get an idea of what it’s like to be on the surface of Mars. It’s no longer this strange, distant, mysterious world.”

Although Opportunity played a large role in this legacy, it’s not hers alone. The rover is preceded in death by Spirit, and it is survived by Curiosity and the Insight lander. All in all, there are eight spacecraft from the world’s space agencies currently on or orbiting Mars, with a handful set to launch next year.

And that leaves scientists like Callas hopeful. He was 10 years old when Neil Armstrong walked on the Moon. “I was inspired by the Apollo program because I thought that there were no limits to what we can do,” he says. “These rovers are continuing that inspirational legacy. It’s the Apollo program of our day.”

■ Award-winning freelance science journalist **SHANNON HALL** still tears up when watching the video of Opportunity’s successful landing.

Read the team’s favorite stories from the mission: jpl.nasa.gov/opportunity-memories.

A Shortlist of Rover Discoveries

Both Spirit and Opportunity penned a new story of Mars — one that is overflowing with water and the necessary conditions to support life as we know it. Here are some of their most significant discoveries.

Acidic Waters When Opportunity first landed in Eagle Crater, the rover spotted layered bedrock probably made from ancient sediments laid down by water. She also discovered the mineral hematite, which often forms in acidic water.

Blueberries At the start of her mission, Opportunity discovered tiny spherical grains embedded within the sandstone. Those so-called blueberries are thought to have formed in liquid water.

▲ **BLUEBERRIES** The rover found these tiny mineral spherules in April 2004. They’re hematite-rich, and their shape suggests they formed in an ancient, watery environment.

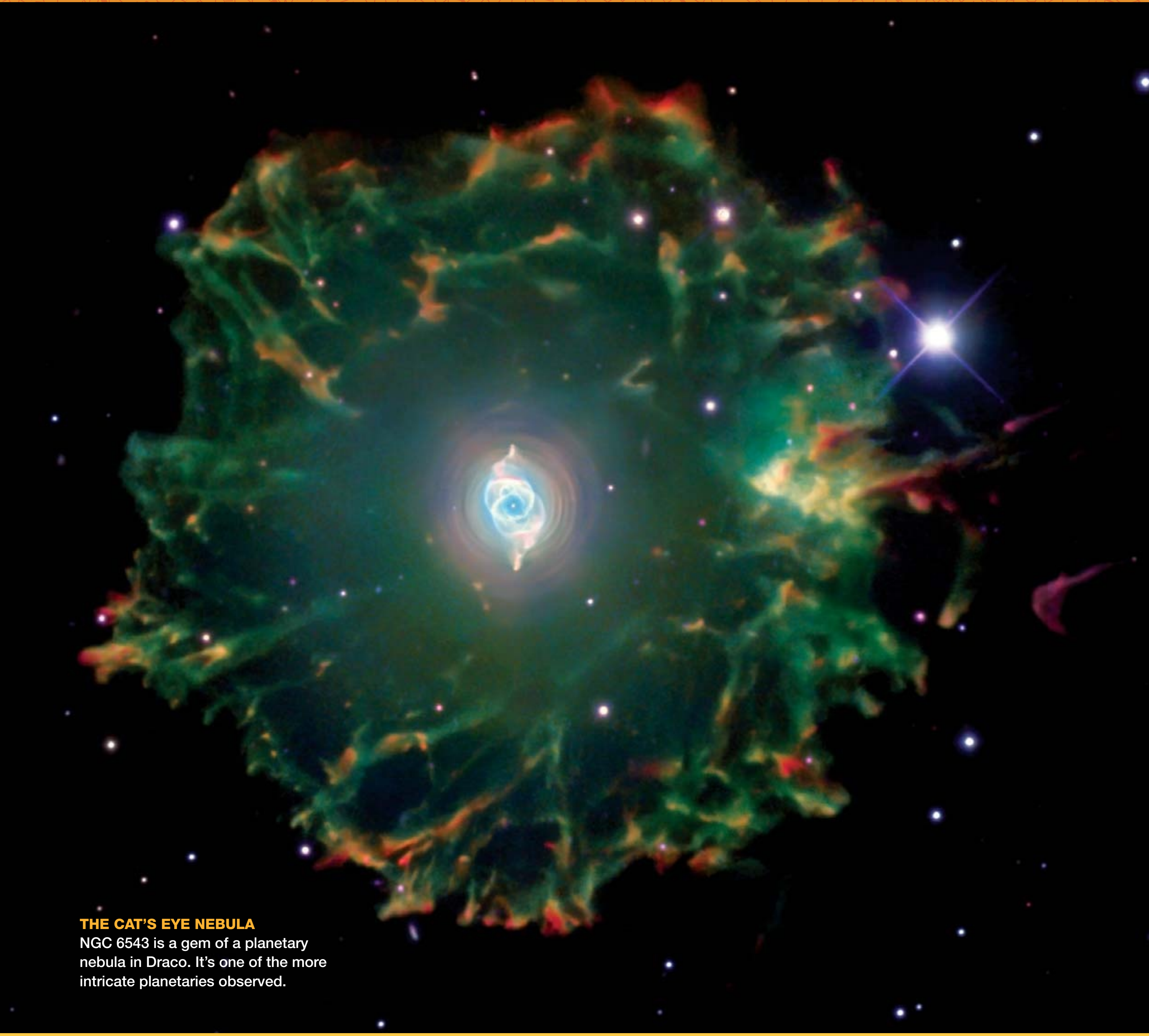
Hot Springs In 2007, Spirit accidentally churned up silica-rich soil, which typically forms within hot springs like those found in Yellowstone National Park on Earth. Scientists think that our planet’s early life might have developed in similar environments.

Neutral Waters In 2010, Spirit found rocks 10 times richer in magnesium and iron carbonates than any other Martian rocks studied before. Such rocks can only form in an environment with neutral water.

Flowing Waters In 2011, Opportunity found bright-colored veins of gypsum in the rocks near the rim of Endeavour Crater. Because the mineral likely formed when water flowed through underground fractures in the rocks, it was the first sign of flowing water.

BLUEBERRIES: NASA / JPL-CALTECH / CORNELL / USGS; WATER DROP ICON: MAHABBAH / THE NOUN PROJECT; BLUEBERRIES ICON: JULISSA URENA / THE NOUN PROJECT; FLAME ICON: PROSYMBOLS / THE NOUN PROJECT

Favorite Septe



THE CAT'S EYE NEBULA
NGC 6543 is a gem of a planetary nebula in Draco. It's one of the more intricate planetaries observed.

mber Sights

Join the author on a saunter through September skies and admire some of his favorite planetary nebulae.

Ages ago as a novice observer, I accidentally stumbled upon a bright nebulous object while scanning through the Summer Triangle with my first telescope. The serendipitous "discovery" was so thrilling that I credit it for my current obsession with visual astronomy. That first observation of the Dumbbell Nebula (M27) also sparked my interest in planetary nebulae.

Planetary nebulae are the remnants of highly evolved low- to intermediate-mass stars. An ionized cloud of glowing gas — the ejected outer layers of the progenitor star — surrounds a hot compact object, the exposed core of that parent star. Planetary nebulae exhibit a wide range of structures that include disks, rings, bipolar and multipolar shapes, and even bright starlike points. They're some of the most colorful and intricate objects in the sky and remain my favorite telescopic targets. The September sky contains enough fascinating examples that this tour of planetary nebulae just might make you a fan as well.

Fascinating certainly applies to the Cat's Eye Nebula, or **NGC 6543**, in Draco, and it's the perfect place to start our tour. A remarkable Hubble image of this object reveals a complex structure of overlapping bubbles and shells that indicate a history of repeated mass ejections.

NGC 6543 is also of historical significance. In 1864, William Huggins, then a little-known amateur astronomer from London, established the gaseous nature of planetary nebulae based on his spectroscopic examination of the Cat's Eye (see *S&T:* Aug. 2018, p. 58). It continues to be a source of discovery and has been studied extensively at multiple wavelengths.

The origin of the Cat's Eye moniker is uncertain, but its bright yellow central star embedded in a greenish nebula does indeed evoke that image. The nebula itself is irregularly bright, which is evidence of its multiple shells. A detached knot to the west gets its own designation, IC 4677. This wisp of nebulosity is quite challenging to detect, but it gives a sense of the true extent of the outer halo of the Cat's Eye, which is many times larger than the rather small central region that's easily visible.

We could fill our tour with interesting planetary nebulae without ever leaving the constellation of Cygnus. The Swan is home to some of the season's best planetaries. **NGC 7048** is an exceptional example and a great object with which to demonstrate the benefit of narrowband nebula filters. It appears as a disk without a filter, but the application of the O III filter will show it as a nice annular ring.

I would be hard pressed to choose a favorite Cygnus planetary, but **NGC 7008** is definitely a contender. The view of this intricate dual-lobed object is enhanced by a pair of stars to the south-southeast. Two knotlike orbs make a kidney-bean shape with the northernmost lobe being considerably brighter. In large aperture at high magnifications, this object is nothing short of magnificent! Filters aren't necessary to enjoy this planetary, but they'll change the apparent brightness distribution and reveal some additional structure.

I really enjoy sharing **NGC 6826** at outreach events. Several planetary nebulae elicit a visual effect that's quite fun: They seem to *blink* when the observer alternately employs direct and averted vision to see the object. NGC 6826 does this so well that it has earned its nickname as the Blinking

Filters for Planetary Nebulae

Planetary nebulae produce their peak emission in a narrow range of wavelengths that are visually enhanced by the application of filters that preferentially pass those wavelengths. Most effective are the filters that are optimized to pass light at the wavelengths emitted by doubly ionized oxygen (O III) at 500.7 and 495.9 nanometers. Wider bandpass filters that span the range between 484 and 506 nm (Ultra-High Contrast, or UHC, filters) are also very effective. The benefit gained from using a filter is somewhat aperture-dependent: They block a good deal of light and might darken the view too much in smaller apertures.

CAT'S EYE NEBULA: MAKIS PALAIOLOGOU / STEFAN BINNEWIES / JOSEF PÖPSEL; LEAF TEXTURE: ZOZODESIGN / ISTOCK / GETTY IMAGES PLUS

Planetary. A disklike halo surrounds a bright central star. Concentrating intensely on the star with direct vison causes the nebula to seemingly disappear. Averted vision makes the nebulous disk easily visible, so shifting one's gaze back and forth makes the object appear to blink. After having fun with that phenomenon, be sure to notice the subtle *fliers* (fast low-ionization emission regions) that manifest as two opposing brighter knots to the east and west in the otherwise uniformly bright nebula.

Two curious planetaries flank the expansive North America Nebula (NGC 7000). **NGC 7026**'s disk is linearly bifurcated roughly along the east-west axis. Two brighter layers sandwich a dark inner layer, giving rise to its nickname: the Cheeseburger Nebula. The greenish **NGC 7027** is known as the Green Rectangle. It has a very bright knot toward its central region that must surround the central star, which is itself too faint to detect in amateur scopes.

Campbell's Hydrogen Star is a lesser-known object in southern Cygnus about 3 degrees northeast of Albireo. It's bright enough to be easily visible as a star in an 8-inch scope, but rather difficult to detect as an extended nebulous object. The relatively bright 11th-magnitude central star overwhelms the tiny disk. A hydrogen-beta filter may aid in its detection, but only in larger-aperture scopes. These filters have a very narrow bandpass (just 9–12 nm wide) around the hydrogen emission line at 486 nm. When conditions allow, Campbell's may show a reddish hue when the filter is removed.

For many observers, the Dumbbell Nebula is the only deep-sky object they visit in the small constellation of Vulpecula. But several other fine objects exist there, including **NGC 6842.** This planetary is a rather ghostly disk that's nearly invisible without the aid of a narrowband filter. I find it necessary to fix its position and extent in the filtered view before it's detectable without a filter as a round ethereal disk.

It's just a short hop to Sagitta where we find **NGC 6879**. Like a great many planetary nebulae, NGC 6879 appears stellar. In most backyard telescopes, it can be distinguished from ordinary stars only by employing a narrowband filter. The filter dims NGC 6879 less than neighboring stars, exposing the object's true nature as a planetary. Rapidly switching between the filtered and unfiltered view makes detection easier. You do this either by employing a filter wheel or slide bar, or by developing your handheld blinking technique. Hold a filter between thumb and forefinger and quickly move the filter into and out of the light path by passing it between eye and eyepiece. It's harder than it sounds and requires a bit of practice, but it's a valuable skill to develop. Tiny objects like NGC 6879 possess

▼ **NGC 7048** This ghostly ring floating in Cygnus offers a good example of how applying an O III filter will greatly enhance the view.

STEFAN HEUTZ / STEFAN BINNEWIES / JOSEF PÖPSEL the advantage of having relatively high surface brightness, making them detectable in less than pristine skies.

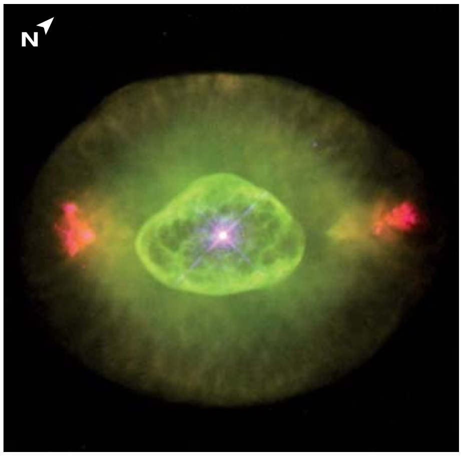
IC 4997, also in Sagitta, is another example of a tiny planetary nebula that's detectable even in urban skies. It forms a pair with a brighter star (10th-magnitude HD 355464) and can be confirmed as a planetary by employing a filter. In a dark sky and with large apertures, the nebula appears as a tiny blue-green disk.

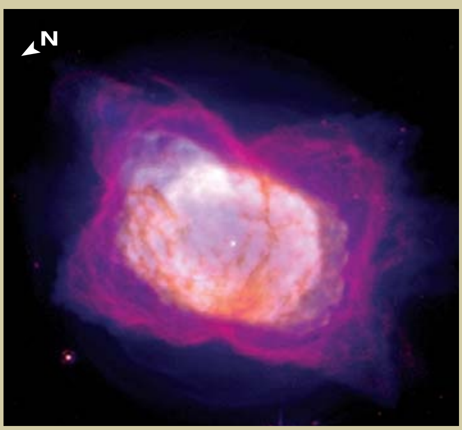
Delphinus, the Dolphin, is home to the Blue Flash Nebula, **NGC 6905**. It makes for a particularly pleasing view in that it sits in a pretty star field and within a triangle of 10th-, 11th-, and 12th-magnitude stars. Nicknames always add interest and popularity to celestial objects. The evocative moniker Blue Flash is attributed to amateur astronomer John H. Mallas, who described the little planetary as "glimmering and flashing between the triangle [of stars]". It seems to have multiple personalities — it sometimes appears blue, but as often it appears nebular grey. It's a round disk but can appear vaguely annular when a UHC filter is used.

Aquila is filled with interesting planetary nebulae that we toured in "Aquila's Gems" in the August 2018 issue (page 34). We'll revisit just one here that definitely deserves another look. **NGC 6781** is visible with as little as 6 inches of aperture and is a remarkably intricate object when viewed with larger scopes. It's vaguely annular with a noticeably darker center. The 17th-magnitude central star is too faint for detection in backyard telescopes. An O III filter will bring out some additional structure, but the unfiltered view is my favorite. Its northern edge seems to fade into a delicate extension. In contrast, the rest of the boundary is more sharply defined. Sometimes the object gives an excellent impersonation of the Owl Nebula (M97) when the inner portion resolves into two dark voids.

The term *planetary nebula* itself comes down to us from Sir William Herschel's description of **NGC 7009** in Aquarius. It was probably the first nebula he discovered and one of several objects that he described as *planetary* due to their round shape and ability to respond to magnification in much the same way as the planets. Eventually the term came to label the whole class.

William Parsons, the third Earl of Rosse, bestowed on NGC 7009 its nickname, the Saturn Nebula. Two extensions, properly termed *ansae*, give the object an appearance reminiscent of the planet. The central star is sometimes hidden in the bright blue-green disk, but in the right conditions it's more easily seen. The ansae require moderate aperture or good seeing for reliable detection. Large instruments and high power reveal quite an intricate inner structure of looping rings that stand out from the disk. In the





▶ **THE BLINKING PLANETARY** *Top:* This Hubble Space Telescope image of NGC 6826 reveals several phenomena associated with dying stars: The outer green bubble is thought to be gas that used to make up about half the star's mass, while the hot remnant star produces a fast wind that produces shocks — seen as the brighter rim — as it rams into the previously expelled material.

▶ **NGC 7026** *Middle:* This planetary is nicknamed the Cheeseburger Nebula. In the Hubble image starlight is colored in green, glowing nitrogen gas in red, and oxygen in blue. In fact, the oxygen appears greenish in reality, but the color in the image has been shifted so as to increase the contrast.

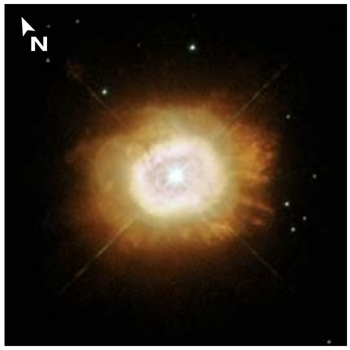
▶ **NGC 7027** *Bottom:* Hubble Space Telescope images of this planetary nebula in Cygnus clearly reveal the central white dwarf, in addition to the complexities of the mass-loss processes. In this false-color image, infrared (purple and yellow) and visible (blue) data are combined.

NGC 6826: BRUCE BALICK / JASON ALEXANDER / ARSEN HAJIAN / YERVANT TERZIAN / MARIO PERINOTTO / PATRIZIO PATRIARCHI / NASA / ESA; NGC 7026: ESA / HUBBLE / NASA / LINDA MORGAN-O'CONNOR; NGC 7027: WILLIAM B. LATTER / SIRTF SCIENCE CENTER / CALTECH / NASA / ESA; LEAF TEXTURE: ZOZODESIGN / ISTOCK / GETTY IMAGES PLUS

The term **planetary nebula** *itself comes down to us from Sir William Herschel's description of NGC 7009 in Aquarius. Eventually the term came to label the whole class.*

very best of conditions, brighter knots highlight the ends of the handlelike extensions.

Another popular jewel in Aquarius is the magnificent Helix Nebula, **NGC 7293**. At about 700 light-years distant, it's one of the nearest planetary nebulae to Earth. It's so large that it can actually be difficult to view in a telescope. It shows in binoculars and is rather lovely in rich-field telescope wide-angle views, so use low power to enjoy it. A filter improves the contrast and makes this huge object more apparent. The giant ring is mostly round, irregularly bright, and mottled.



◀ **CAMPBELL'S HYDROGEN STAR** This fascinating star, HD 184738, snapped with the Hubble Space Telescope, is in fact a rare Wolf-Rayet star (see *S&T:* Aug. 2019, p. 28). The image shows the star at the center of a small planetary nebula, surrounded by a larger nebula composed of glowing gases, primarily hydrogen and nitrogen.

High-resolution images of the Helix reveal a large number of bright knots around its circumference, the origin of which aren't yet fully understood. A rather remarkable Hubble image of NGC 7293, featured in 2003 as an Astronomy Picture of the Day and captioned "The Eye of God," captured the public imagination and was widely circulated. The view in a backyard telescope may be considerably less dramatic, but it definitely qualifies as a celestial showpiece nonetheless.

My planetarium software reports that there are no fewer than 543 planetary nebulae in Sagittarius! September finds most of them well past their best availability. Still well-placed, however, is one of the best planetary nebulae in the Archer. **NGC 6818**, known as the Little Gem, is nestled between two 13.5-magnitude stars that flank its east and west sides. The object itself is a blue disk that's darker toward the center, giving the impression of annularity. Occasionally, the center devolves into

ETHEREAL SHELL The author can't resist NGC 6781 in Aquila, which ranks among his favorites.

CAMPBELL'S HYDROGEN STAR: ESA / HUBBLE / NASA / JEAN-CHRISTOPHE LAMBRY; NGC 6781: JOSEF PÖPSEL / BEATE BEHLE

It's astounding to think that life wouldn't be possible without the elements that planetary nebulae distribute throughout the interstellar medium.

two or three dark patches. Noted planetary nebula observer Kent Wallace describes the inner dark patches as making an S shape. The nickname Little Gem, also coined by Mallas, rightly belongs to this object although some references apply the name to NGC 6445. According to Wallace, this was originally due to an error in the *Sky Catalogue 2000.0* that was repeated often enough to have permeated through the amateur community.

Planetary nebulae are important laboratories for the study of stellar evolution, which only enhances their interest. It's astounding to think that life wouldn't be possible without the elements that planetary nebulae distribute throughout the interstellar medium. And it may be that in observing planetaries, we're witnessing the end state of our Sun. It's currently not entirely clear whether or not our Sun will ever become a visible planetary nebula. Recent research suggests that binary interactions may be required to produce the sort of bright complex objects like those on our tour. In any case, the demise of our Sun will be similar, even if less spectacular. These beautiful and mysterious objects not only foretell our future, but are an essential component of the process that led to our very existence.

■ Contributing Editor **TED FORTE** enjoys observing planetary nebulae from his home observatory in southeastern Arizona. He is the coordinator of the Astronomical League's Planetary Nebula Program.

▲ **LITTLE GEM** This Hubble image of NGC 6818 clearly shows how mass loss from dying stars is an uneven process. Head over to Sagittarius to take a peek at this jewel of a planetary nebula.

ESA / HUBBLE / NASA / JUDY SCHMIDT

FURTHER READING: See the August 2018 issue of *Sky & Telescope* for two articles on planetary nebulae: Ted Forte's "Aquila's Gems" and Howard Banich's "The Riddle of the Nebulae."

Favorite Planetary Nebulae

Object	Nickname	Constellation	Mag(v)	Size	Central Star Mag(v)	RA	Dec.
NGC 6543	Cat's Eye Nebula	Draco	8.1	20″	11.1	$17^h 58.6^m$	+66° 38′
NGC 7048		Cygnus	12.1	61″	19.1	$21^h 14.3^m$	+46° 17′
NGC 7008		Cygnus	10.7	86″	13.2	$21^h 00.6^m$	+54° 33′
NGC 6826	Blinking Planetary	Cygnus	8.8	36″	10.4	$19^h 44.8^m$	+50° 32′
NGC 7026	Cheeseburger Nebula	Cygnus	10.9	45″	14.2	$21^h 06.3^m$	+47° 51′
NGC 7027	Green Rectangle	Cygnus	8.5	55″	16.2	$21^h 07.0^m$	+42° 14′
Campbell's Hydrogen Star		Cygnus	9.6	7″	11.3	$19^h 34.8^m$	+30° 31′
NGC 6842		Vulpecula	13.1	57″	15.9	$19^h 55.0^m$	+29° 17′
NGC 6879		Sagitta	12.5	9″	14.8	$20^h 10.4^m$	+16° 55′
IC 4997		Sagitta	10.5	3″	14.4	$20^h 20.1^m$	+16° 44′
NGC 6905	Blue Flash Nebula	Delphinus	11.1	72″	15.7	$20^h 22.4^m$	+20° 06′
NGC 6781		Aquila	11.4	114″	16.7	$19^h 18.5^m$	+06° 32′
NGC 7009	Saturn Nebula	Aquarius	8.0	35″	11.5	$21^h 04.2^m$	–11° 22′
NGC 7293	Helix Nebula	Aquarius	7.3	1054″	13.5	$22^h 29.6^m$	–20° 50′
NGC 6818	Little Gem	Sagittarius	9.3	46″	16.9	$19^h 44.0^m$	–14° 09′

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.

Imaging on the High Seas

Take advantage of dark skies on your next luxury cruise.

▲ **SKY FROM THE SEA** Capturing twilight phenomena, such as the Belt of Venus (above the shadow of Earth hugging the horizon) and anticrepuscular rays pointing towards the rising Moon — both seen above — is easy out to sea where you can view the true horizon.

Taking an ocean cruise is a popular vacation activity that's growing by leaps and bounds. In 2019 alone, roughly 30 million passengers are expected to embark on luxury cruise ships worldwide. One thing many of these cruises have in common is venturing far into the open sea, where light pollution is minimal or even non-existent — well, except from the ship itself. On the open ocean you can see much of the night sky better than at most rural locations, and you can even capture it in wide-field images.

You may be asking yourself, "Wait, how can you take astrophotos from a moving ship? Won't they be blurry? Aren't cruise ships all lit up?" All valid questions. An online search on the subject produces a paucity of information, with blog posts asking "Can it be done?" and responses often stating "You can't because cruise ships are too brightly lit" or expressing frustration from those who have tried to image the night sky at sea.

With some effort, it can be done! Eclipses, conjunctions, aurorae, and the zodiacal light are some of the many astrophotographic possibilities from these giant pleasure boats, some of which offer astronomically themed tours. Two ships, Cunard's Queen Mary 2 and Viking Cruises' Viking Orion, even have onboard planetariums. The Orion is also the first cruise ship to have a dedicated astronomer on staff, while Princess Cruises conducts regular stargazing sessions. So astronomy is not only welcomed, it is, in many cases, encouraged.

Cruise Gear

Successful astro-images from a moving ship require a good camera setup and some knowledge of your "floating observatory." While most any camera can take astropics, your best bet is to use a DSLR or mirrorless camera (*S&T:* Apr. 2019, p. 60). These cameras typically operate at high ISO speeds with acceptable noise levels and accept a wide variety of high-quality lenses.

I use a Nikon D810a full-frame DSLR (reviewed in *S&T:* Feb. 2016, p. 56). It's designed specifically for astrophotography, with an extended spectral sensitivity to better record hydrogen-alpha nebulosity. However, you don't need a special

UNLESS OTHERWISE NOTED, ALL PHOTOS BY THE AUTHOR; WATER BACKGROUND: DAVID MARANO PHOTOGRAPHY / MOMENT / GETTY IMAGES camera to record the night sky. Other models take perfectly pleasing astro-images, and if you desire more pinkish hydrogen-alpha nebulosity in your images, several vendors offer affordable services to modify your camera.

Regardless of your camera body, it's the glass (the lens) that makes the shot. The stars in night-sky photographs are points of light that excel at revealing the flaws of an inferior lens, by being distorted into elongated blurs or other strange shapes. Try to buy quality lenses for your camera — you and your astrophotos will be glad you did. And since you'll be shooting at sea where a mist of salty spray might land on your lens and damage its coatings, pick up a skylight or other neutral lens filter to protect its exposed element.

The focal length of the lenses you use depends on what astronomical object you want to photograph. Wide-angle lenses in the 18-to-50-mm range, combined with a full-frame camera (or 14-to-35-mm range on an APS-format or "cropped-frame" camera), will capture excellent vistas that include several constellations, the Milky Way, or dazzling aurorae in one shot paired with the glittering sea below. Longer focal lengths are better suited to capturing bright subjects, particularly solar eclipses (with a proper solar filter during the partial phases) or lunar eclipses.

You'll want to use as fast a lens as you can get, such as f/2.8 or better, in order to take the shortest exposures to minimize smearing due to the movement of the ship. Be aware that lens prices get pretty steep on high-quality, fast-focal-ratio lenses, though you can often find good prices on the used market.

The Moon and planets are very small in wide-angle photos, and you really need a long telephoto lens — at least 300 mm — to start to resolve craters. But high-resolution images of the Moon and planets are better left to your time on land. After all, you can capture them from virtually any place on Earth, whereas dark skies often require travelling great distances for many of us.

▲ **VENUS RISING** This 8-second exposure recorded through a 35-mm f/1.4 lens captures the rising central bulge of the Milky Way with bright Venus reflecting in the waters of a Chilean fjord.

Still, the planets will reveal their respective brightnesses and colors in wide-angle shots, which can be very beautiful when combined with the Moon or a few constellations over the open sea. A nifty trick is to photograph the Moon or planets when they are rising or setting above the sea and capture their reflected light on the water. If you're lucky enough to have the Milky Way in the frame — well, it doesn't get much better than that!

Imagers on a limited budget may prefer a multi-purpose lens to serve both daylight and night photography needs. I recommend a good 28-to-300-mm zoom lens. These lenses combine a moderately wide field to get those Milky Way shots, with enough magnification to pull in details on the

▼ **OCEAN OBSERVATORY** *Left:* The open ocean is perhaps an unlikely destination for photographing the night sky, but cruise ships can get you to clear, wide-open skies in a way you may not have considered before. *Right:* It's often best to avoid shooting from the main deck, where lights from the recreational facilities overwhelm everything but the Sun and Moon.

CRUISE SHIP: SEAN WALKER / S&T

Moon or the solar corona during a total solar eclipse. This lens is also excellent for framing conjunctions of the Moon and planets, or just the Moon paired with a distant ship near the horizon.

As for other lenses, close-up solar eclipse photos require more focal length than 300-mm, so you may want to look into purchasing a catadioptic mirror lenses, such as a 500-mm f/8. While large, fixed-focal-length lenses are great for land-based imaging, I don't recommend them on a cruise because they take up a lot of the limited space in your camera bag.

When bringing your photography gear on board, avoid checking it with your luggage, as damage can often occur in transit. Your camera and lenses should fit in an airline carryon bag, or better yet, a padded camera backpack that never leaves your sight.

Much of the night sky can be seen better on the open ocean than at most rural land-based locations.

▲ **LIGHT SHIELDING** A good lens hood can block the pervasive lights on board, enabling you to record Milky Way scenes as if you were in a dark location. The author took this photo centered on the Southern Cross and the Carina Nebula off the coast of Chile using a 14-mm f/2.8 lens and a 13-second exposure at ISO 5000.

▲ **STEADY SHOT** Calm seas offer opportunities for close-ups of interesting areas of the sky. The author captured this image of the Coal Sack *(top left)* and the Tarantula Nebula, NGC 2070 *(right)* using a 3-second exposure through a 50-mm f/1.4 lens with the camera set to ISO 5000.

Additional equipment you'll need are a shutter release cable and a light but sturdy tripod. A simple cable release is all that is required for the task at hand, as your longest exposure will be only several seconds at most. You can set the camera to "continuous fire" mode with the exposure length set to 5 seconds, and then simply lock down the shutter button and snap away.

As for a tripod, I prefer a carbon-fiber model with a 3-way locking head. This helps steady the camera for focusing and shooting. You may be tempted to purchase a tripod that can wrap its legs around a post or rail, but in my experience these models aren't reliable for holding a heavy camera and lens steady for several seconds. Not only that, but there are no padded surfaces on the outside decks of cruise ships, so a failure of these grasping legs could be catastrophic for your equipment.

Focusing is accomplished the same way as in most DSLR astrophotography. I use the camera's "Live View" to zoom into a bright star and tweak focus until the star is as small as I can make it on the screen. This can be challenging as the star bobs in and out of the frame, but with a little patience focus can be achieved quickly. A good tip is to focus your camera on a star before embarking on your cruise and mark the exact position on the lens. You'll still have to tweak the focus on the ship, but you'll be starting off very close right away.

Know Your Ship

Once you're aboard your chosen vessel, familiarize yourself with any potential observing spots during the day. Find where the highest deck is, as well as access to the main deck, the bow, and the stern. At night you should explore the ship again to see where to avoid the worst lights and hopefully find some dark or shadowed areas. This is particularly important in reference to the direction your ship is sailing when it comes to deciding what you want to shoot.

Of course, the ship at sea will be in motion and well-lit

WAVE TEXTURE: LESIKVIT / ISTOCK / GETTY IMAGES PLUS most of the time. Even so, there are ways to minimize the ship's rocking as well as its omnipresent lights. I often use ISO speeds of up to 6400 and short exposures of less than 10 seconds to "freeze" the ship's motion as much as I can. Another way to minimize the rocking of the ship is to shoot from a lower deck. The rocking motion is more pronounced the higher up you are, especially at the fore or aft positions. The closer you are to the center of the ship near the water level, the smaller these motions are.

Cruise ships are lit up for the safety of the passengers and crew and to make them visible to other ships and avoid collisions. While this can be very frustrating, there are some spots on a cruise ship that can work well for night-sky imaging. Most ships will turn off some lights on the stern late at night, often where there is a bar or dining area that has closed for the evening. If you're on a very large vessel where the promenade deck goes completely around the ship including in front of the bridge, you're in luck. This should be the darkest place on the ship to allow the bridge officers to see unhindered into the distance. There will be no lights on the bow apart from the masthead navigation lights and mast lighting will be high up behind you. Elsewhere on the ship there are lights, so be sure to use a lens hood and place your camera and tripod very close to the deck railing. There will be light around you but the view out to sea that your lens sees will be very dark. If you get a little lens flare in your exposure, some ship's light is entering the lens. In these instances, position your body to act as a light shield for your camera.

The ship's course determines where your astro-object will be in the sky in relation to the various areas of the ship. Your object may be forward, astern (behind), port (left), or starboard (right). The ship may change course, which will change your sky orientation. It can also be particularly confusing if you are in a new hemisphere for the first time — familiar sights such as Orion and even the Moon appear upside-down compared to the view you're familiar with. The entire sky will even appear to rotate in the opposite direction in relation to the horizon than what you're used to.

Getting your bearings in the sky is much easier with a planetarium app that can show you the sky for your particular location. In your stateroom, the ship's Navigation or Bridge TV channel may tell you the ship's latitude, longitude, weather forecast, sunrise, sunset, course, speed, and an overview of the area where the ship is transiting — all useful information for planning what to shoot. Input your location in the app, being mindful of the correct time zone, and you are in business.

When taking your images, try to take lots of exposures of the same target. Many may be filled with trailed stars, but some will inevitably be captured when the ship is briefly paused between its steady up-and-down motions. Take the time to assess your results before moving on to your next composition, and adjust your technique based on the results. It takes practice, but the results can be quite pleasing, particularly when you consider you are on a moving ship. So fair winds and following seas, shipmate!

▲ **SKY EFFECTS** Daytime atmospheric phenomena, such as this bright sundog seen over Ireland Island in Bermuda, are common sights from the upper decks.

▲ **CRAZY STARS** Most exposures lasting more than a second or two will show zig-zagging star trails, like this photo of the zodiacal light. Be sure to take several exposures of each target to ensure at least one acceptable result.

SUNSET: SEAN WALKER / S&T

■ **GREG REDFERN** is the author of *Cruise Ship Astronomy and Astrophotography*, available at **https://is.gd/astrocruise**.

▼ CLASSICAL CASS

Agena Astro carries a full line of Guan Sheng Classical Cassegrain optical tube assemblies. Available in 6-inch ($499), 8-inch ($899 shown below), and truss-tube 10-inch ($2,795) apertures, each with an f/12 focal ratio, these scopes mate a parabolic primary mirror with a convex hyperbolic secondary to produce a well-corrected field free from spherical aberration. Each tube assembly includes a dual-speed 2-inch Crayford focuser with 1¼-inch non-marring eyepiece adapter, a Vixen-style dovetail rail, a finder bracket shoe, and a dust cap.

Agena AstroProducts
16313 Arthur St., Cerritos, CA 90703
agenaastro.com

▲ PREMIUM ASTROGRAPH

Stellarvue announces the SVX130T-WR35-IS Imaging System ($7,995). This 5.1-inch air-spaced f/7 triplet refractor combines Stellarvue's premium apochromatic optics with Moonlite Telescope's NiteCrawler WR35 remote focusing system. The 3½-inch NightCrawler WR-35 worm-driven rotating focuser can accommodate the heaviest cameras and filter wheels available today without sagging. Its dual-axis motors enable users to both focus and rotate the imaging train remotely, and an internal temperature sensor monitors and corrects focus position during changing temperatures. The system comes with both 1¼- and 2-inch adapters as well as an integrated dovetail shoe for mounting an optional finder scope. Each purchase includes a lens cap, two heavy-duty CNC-machined tube rings, and a C130L padded carry case.

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

▶ 6-INCH OBSERVING PACKAGE

Meade offers its 6-inch Advanced Coma-Free (ACF) telescope paired with its versatile LX85 Go To mount. The LX85 Series 6-inch ACF Telescope with UHTC coatings ($1,399) features a 152-mm f/10 ACF optical tube that presents well-corrected views of deep-sky objects and detailed views of the planets in a compact catadioptric tube just 16½ inches long. The tube weighs a mere 9.14 lb and rides atop the new LX85 Go To German equatorial mount. The mount is equipped with an AudioStar hand controller that comes with an internal database of more than 30,000 objects accessible at the touch of a button. The LX85 runs on 12 volts DC and includes an ST-4 autoguider port. The 6-inch OTA attaches via a Vixen-style dovetail and comes with an 8×50 viewfinder, 9.7-mm and 26-mm 1¼-inch-format eyepieces, and a 90° mirror star diagonal.

Meade
27 Hubble Dr., Irvine, CA 92618
800-626-3233; meade.com

5 EVENING: The first-quarter Moon and Jupiter hang in the south-southwest above the Scorpion's heart, Antares, after sunset. Watch as they sink toward the horizon and set before midnight.

6 DUSK: The Moon, Jupiter, and Saturn grace the sky above the tail of Scorpius. Watch as the Moon follows Jupiter to the horizon, setting near midnight.

6 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:05 p.m. PDT.

7 DUSK: Golden Saturn glows upper right of the waxing gibbous Moon, hanging above the Teapot of Sagittarius.

8 DUSK: Find the fattening gibbous Moon and slew some 7° to the right or lower right to spot Saturn — Moon and planet hover above and left of the Teapot's handle.

9 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:54 p.m. EDT.

20 DAWN: If you're up before sunrise, look high in the southern sky toward Taurus to see the waning gibbous Moon in the Hyades, not far right of Aldebaran.

23 MORNING: The Moon is in Gemini and forms a triangle with Castor and Pollux.

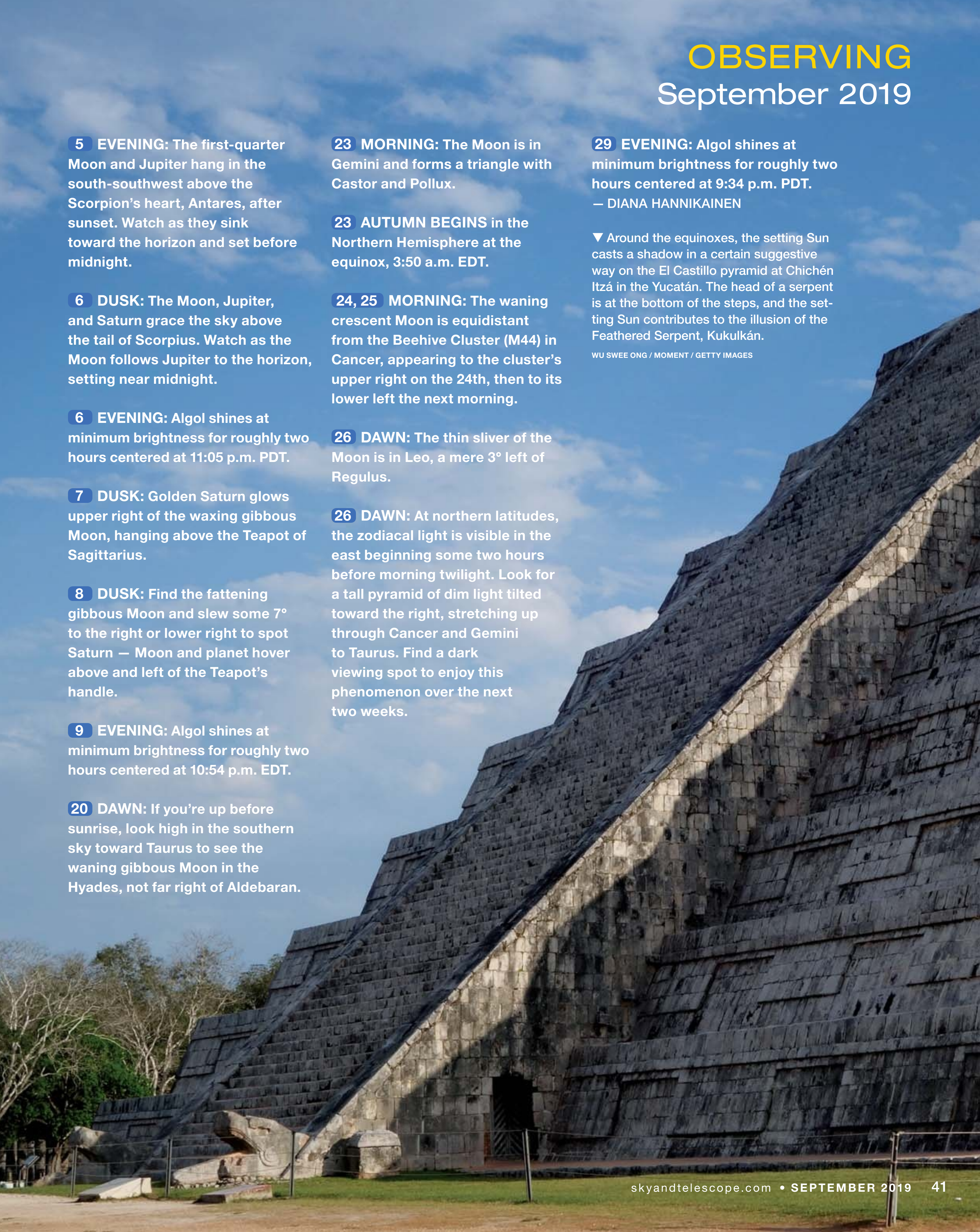
23 AUTUMN BEGINS in the Northern Hemisphere at the equinox, 3:50 a.m. EDT.

24, 25 MORNING: The waning crescent Moon is equidistant from the Beehive Cluster (M44) in Cancer, appearing to the cluster's upper right on the 24th, then to its lower left the next morning.

26 DAWN: The thin sliver of the Moon is in Leo, a mere 3° left of Regulus.

26 DAWN: At northern latitudes, the zodiacal light is visible in the east beginning some two hours before morning twilight. Look for a tall pyramid of dim light tilted toward the right, stretching up through Cancer and Gemini to Taurus. Find a dark viewing spot to enjoy this phenomenon over the next two weeks.

29 EVENING: Algol shines at minimum brightness for roughly two hours centered at 9:34 p.m. PDT.
— DIANA HANNIKAINEN



▼ Around the equinoxes, the setting Sun casts a shadow in a certain suggestive way on the El Castillo pyramid at Chichén Itzá in the Yucatán. The head of a serpent is at the bottom of the steps, and the setting Sun contributes to the illusion of the Feathered Serpent, Kukulkán.

WU SWEE ONG / MOMENT / GETTY IMAGES

SEPTEMBER 2019 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart

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

NASA / LRO

MOON PHASES

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

FIRST QUARTER

September 6
03:10 UT

FULL MOON

September 14
04:33 UT

LAST QUARTER

September 22
02:41 UT

NEW MOON

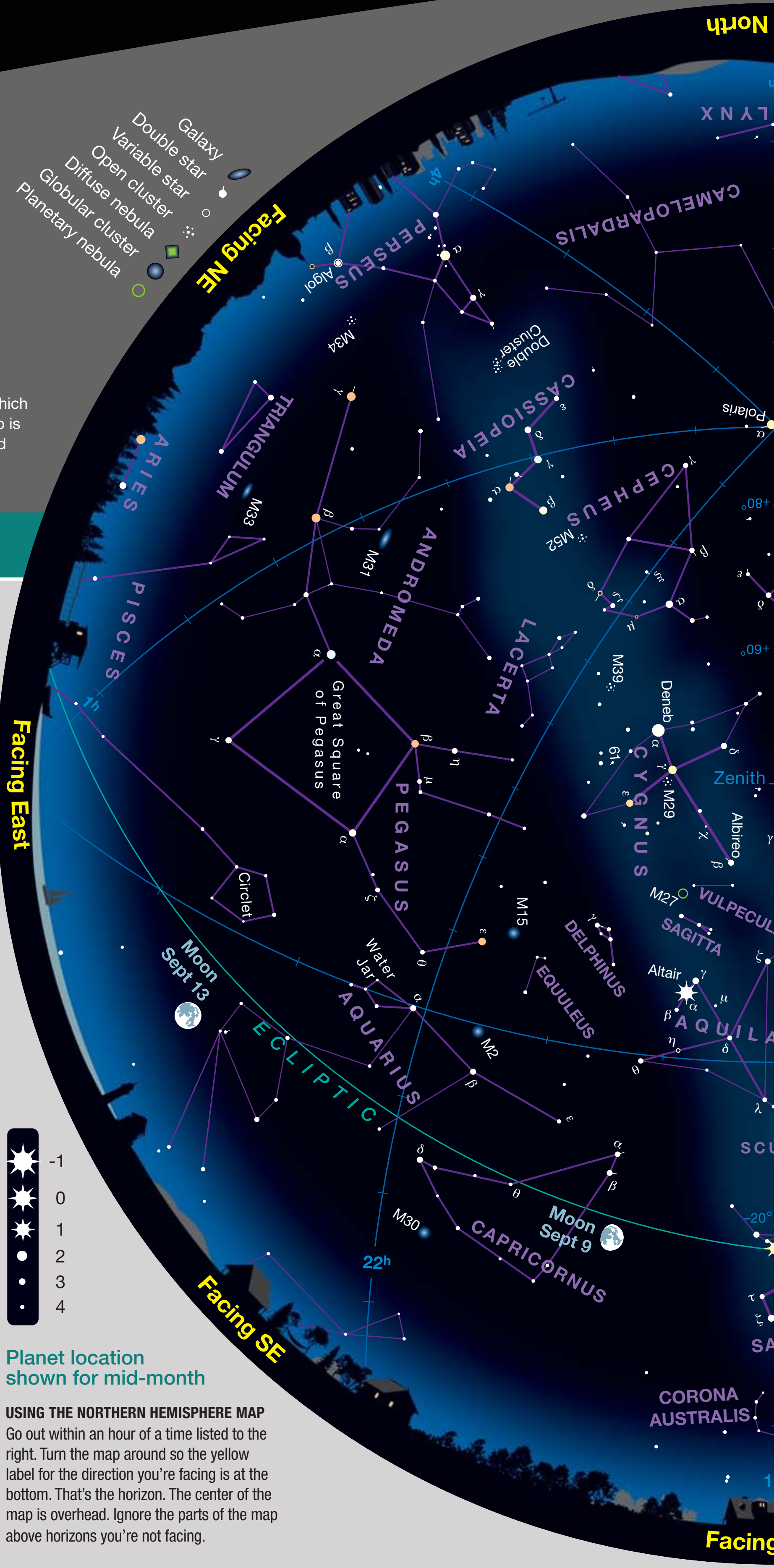
September 28
18:26 UT

DISTANCES

Apogee	September 13, 14ʰ UT
406,377 km	Diameter 29′ 24″
Perigee	September 28, 02ʰ UT
357,803 km	Diameter 33′ 24″

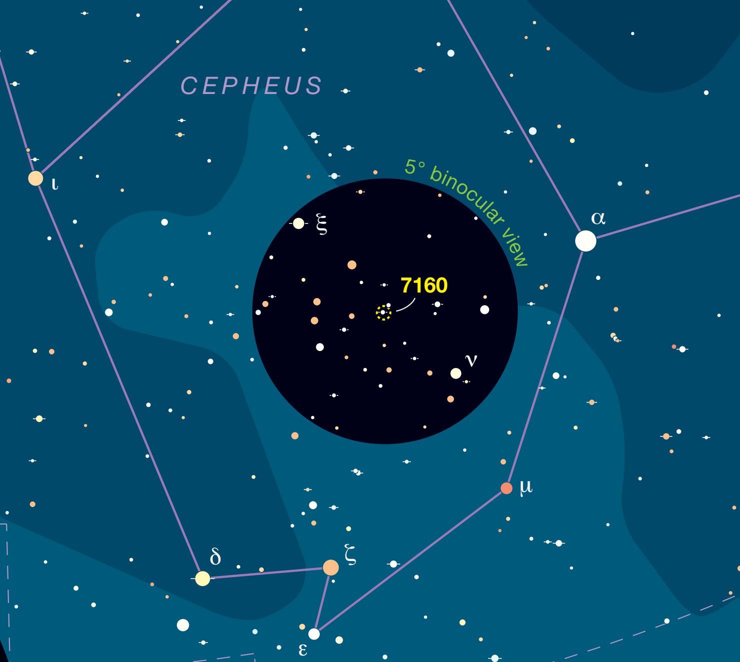
FAVORABLE LIBRATIONS

- Hecataeus B Crater — September 7
- Hubble Crater — September 10
- Baade Crater — September 26
- Hausen Crater — September 27



Planet location shown for mid-month

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



Binocular Highlight by Mathew Wedel

New Kid on the Block

We expect kings to be adorned with jewels, and the constellation Cepheus, named for the mythical king of Ethiopia, doesn't disappoint. One glittering gem at the heart of the constellation is the open cluster **NGC 7160**. I first observed this cluster more than a decade ago, writing in my notebook, "small, compact, surprisingly bright, with stars packed so close together that they are difficult to resolve despite their brightness."

It's fun for me to revisit those notes, because I unknowingly had stumbled upon an astrophysical truth: NGC 7160 is *really* small as open clusters go. It's only 7 arcminutes in diameter as seen from Earth, corresponding to a physical diameter of just 5 light-years. For comparison, the average diameter of the open clusters that I've discussed in previous columns is about 20 light-years, and NGC 1893 in Auriga, the Charioteer, is a whopping 80 light-years across.

NGC 7160 isn't just small, it's also quite young, between 10 and 20 million years old. That's a lot of time in human terms — the lineages that led to humans and the other great apes hadn't even separated from their common ancestor when NGC 7160 formed — but it's just a tick of the clock in cosmic terms, around 1⁄1000 of the age of the universe. NGC 7160 is part of the Cepheus OB 2 Association, a vast cloud of young stars that stretches between Alpha (α) and Delta (δ) Cephei, and most of the cluster's brighter members are hot young *B*-type stars. There are no more *O*-type stars in NGC 7160 — those blow themselves up long before their 15-millionth birthdays — and the *B*-types won't last forever. So go have a look at NGC 7160 to see one of the galaxy's newer additions.

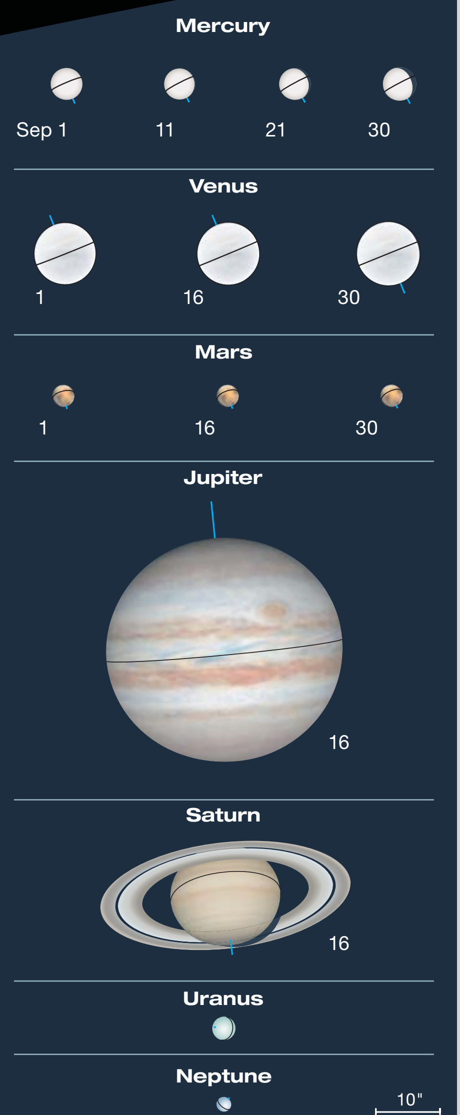
■ When he's not stargazing, **MATT WEDEL** works on dinosaur bones ten times the age of NGC 7160.

WHEN TO USE THE MAP

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

*Daylight-saving time

Planetary Almanac



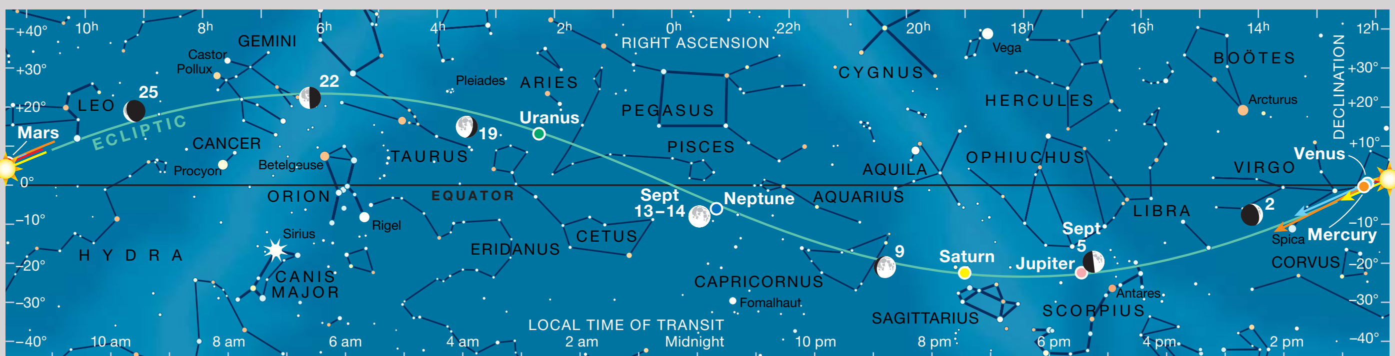
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY Mercury: hidden in the Sun's glow all month • **Venus:** visible at dusk after the 18th • **Mars:** hidden in the Sun's glow all month • **Jupiter:** visible at dusk, sets mid-evening • **Saturn:** visible at dusk, sets after midnight

September Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$10^h\ 38.7^m$	+8° 34′	—	–26.8	31′ 41″	—	1.009
	30	$12^h\ 23.1^m$	–2° 30′	—	–26.8	31′ 56″	—	1.002
Mercury	1	$10^h\ 30.1^m$	+11° 19′	3° Mo	–1.8	5.0″	99%	1.347
	11	$11^h\ 39.6^m$	+3° 35′	6° Ev	–1.2	4.8″	98%	1.387
	21	$12^h\ 40.7^m$	–4° 08′	14° Ev	–0.5	5.0″	93%	1.356
	30	$13^h\ 30.9^m$	–10° 27′	19° Ev	–0.2	5.2″	86%	1.287
Venus	1	$10^h\ 59.1^m$	+8° 02′	5° Ev	–3.9	9.7″	100%	1.719
	11	$11^h\ 44.9^m$	+3° 07′	8° Ev	–3.9	9.8″	99%	1.706
	21	$12^h\ 30.2^m$	–1° 59′	10° Ev	–3.9	9.9″	98%	1.687
	30	$13^h\ 11.2^m$	–6° 32′	13° Ev	–3.9	10.0″	98%	1.666
Mars	1	$10^h\ 42.2^m$	+9° 23′	1° Ev	+1.7	3.5″	100%	2.675
	16	$11^h\ 17.8^m$	+5° 40′	5° Mo	+1.8	3.5″	100%	2.664
	30	$11^h\ 50.7^m$	+2° 05′	9° Mo	+1.8	3.5″	100%	2.641
Jupiter	1	$16^h\ 54.5^m$	–22° 14′	97° Ev	–2.2	39.0″	99%	5.055
	30	$17^h\ 07.0^m$	–22° 37′	72° Ev	–2.0	35.9″	99%	5.492
Saturn	1	$19^h\ 00.2^m$	–22° 29′	126° Ev	+0.3	17.6″	100%	9.421
	30	$18^h\ 59.6^m$	–22° 33′	97° Ev	+0.5	16.9″	100%	9.863
Uranus	16	$2^h\ 14.9^m$	+12° 59′	137° Mo	+5.7	3.7″	100%	19.088
Neptune	16	$23^h\ 13.4^m$	–6° 09′	174° Ev	+7.8	2.4″	100%	28.934

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. is 149,597,871 kilometers, or 92,955,807 international miles.) For other dates, see skyandtelescope.com/almanac.

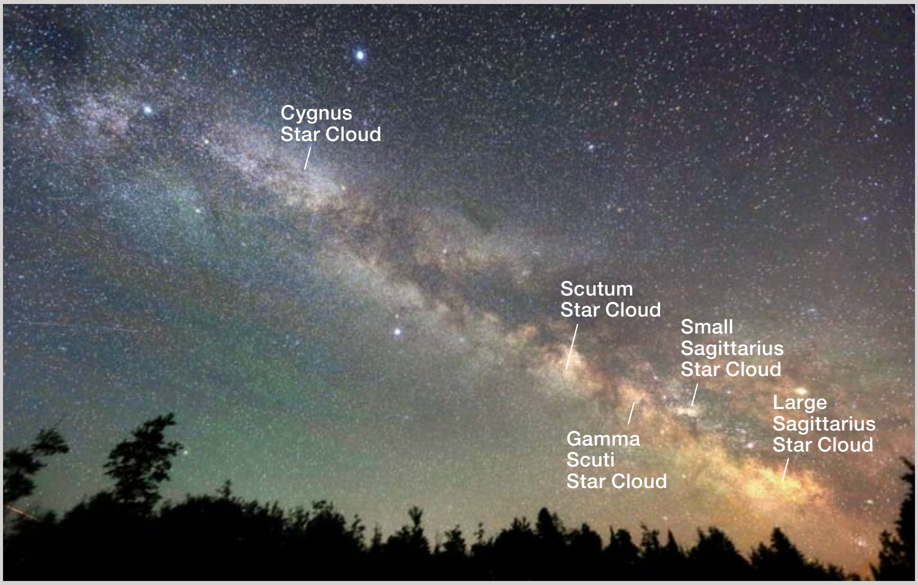


The Sun and planets are positioned for mid-September; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side). "Local time of transit" tells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

Musings on Eternity

The arch of the Milky Way provides the setting for thoughts on the passage of time.

I saw Eternity the other night,
Like a great Ring of pure and endless light,
All calm, as it was bright;
And round beneath it, Time in hours, days, years,
Driv'n by the spheres
Like a vast shadow mov'd; in which the world
And all her train were hurl'd.
—Henry Vaughan, *The World*



BOB KING

The lines of the poem above are the most famous penned by the 17th-century Welsh metaphysical poet Henry Vaughan. The topic of those lines — and of my column this month and next — is as much about eternity as it is for our thoughts when we stare at the majesty of the Milky Way band after nightfall at summer's end. But the topic is also time and the productions of time — for time and eternity are inextricably linked.

A ring of pure and endless light. Vaughan's line about the ring of pure and endless light brings to mind the Milky Way band in our sky. Our solar system lies within the equatorial disk of the flattened spiral galaxy that is the Milky Way. So we see a relatively narrow, heavens-encircling band of glow that's the combined radiance of millions of distant stars in the equatorial disk. They're stars that are too faint from being far away — a few thousand light-years — for us to see them individually with the naked eye.

Actually, the *entire* ring of the Milky Way band is only above the horizon when it is low along that horizon — and thus too dimmed by thick air and haze low in the sky to see properly. In late summer we see only about half the ring. But what a half! It arches high across the evening sky, displaying prominently the brightest of Milky Way star clouds ever visible from mid-northern latitudes.

As viewed from those latitudes, the cloud overhead is the Cygnus Star Cloud (enwreathing the neck and body of Cygnus, the Swan). About halfway to the southern horizon is the badge of beauty known as the Scutum Star Cloud. Next is the bright spot of the little-known Gamma Scuti Star Cloud (also called the "Seventh Glow"). Last and lowest but not least are the Large Sagittarius Star Cloud and the Small Sagittarius Star Cloud (the latter is also known as M24) — puffs of glowing "steam" hanging, respectively, above the spout and above the lid of the Teapot.

Steppingstones to eternity. Not even the stars, not even the star clouds, not even our mighty Milky Way Galaxy is eternal. However, when we compare the age of these things to the span of a human lifetime or human history we find our sights and thoughts take us stunningly far down the (endless) road to eternity.

Much of the Earth's crust is less than a billion years old (the average age of the oceans' floors is some 200 million years). Remarkably, some of our brightest stars are similarly "young." The Sun and planets are less than 5 billion years old. What's the oldest bright star in our sky? It could be the one low in the west right after September nightfalls — Arcturus, whose original galaxy may have collided with ours as much as 8 billion years ago. The Milky Way Galaxy itself, whose greater structure we begin to glimpse in the glowing band these evenings, is perhaps more than 13 billion years old — as are some of its globular star clusters, so well represented in the September evening sky.

Next month: Eternity — Part 2! All jests aside, next month here we'll explore the rural area "on the edge of forever" and the interface of now and eternity. We'll also discuss just why it is that "Eternity is in love with the productions of time."

■ **FRED SCHAAF** welcomes your letters and comments at **fschaaf@aol.com**.

To find out what's visible in the sky from your location, go to skypub.com/almanac.

The Month of the Harvest Moon

The smaller planets are largely missing from September's skies, but the two gas giants are joined by the two ice giants — and the full Moon heralds the harvest.

Much of the night is starved of bright planets this month. Mercury and Mars continue to be hidden from view in the solar glare. Venus does gleam back into sight in late September but early in dusk, very low in the Sun's afterglow. Jupiter burns in the southwest as evening twilight fades, while Saturn shines in the south — but even Saturn is setting around midnight at month's end.

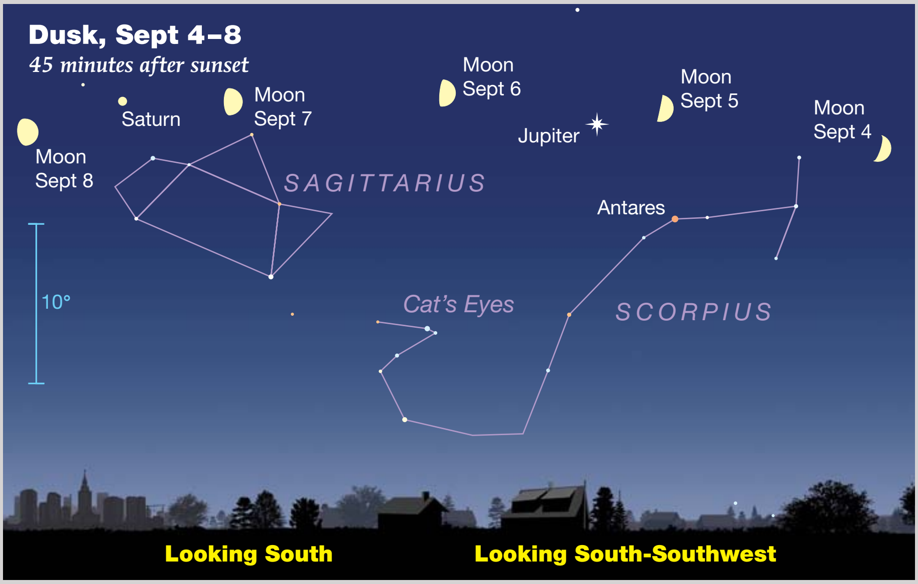
DUSK

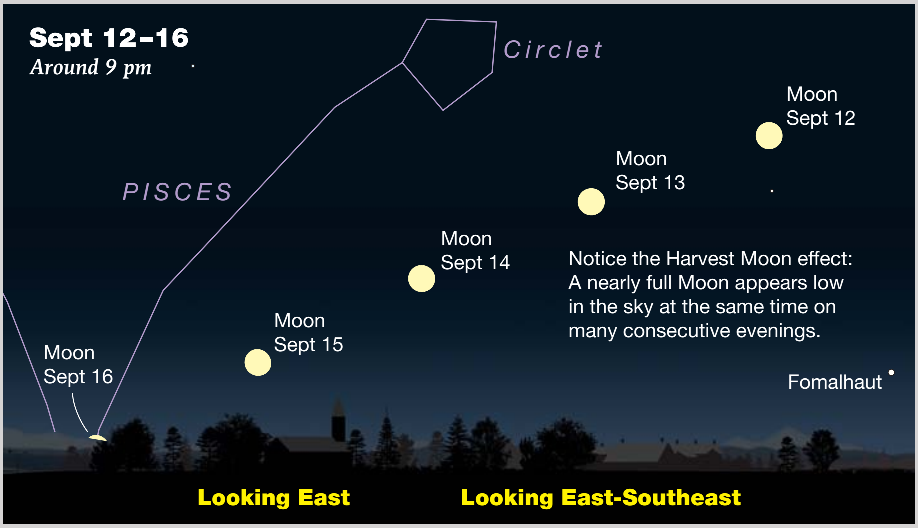
Venus went through superior conjunction on August 14th but in the second half of September comes back into view after sunset for observers at mid-northern latitudes. After two months of being out of sight at these latitudes, Venus is still difficult to catch due to the shallow angle of the zodiac with respect to the sunset horizon at this time of year. Venus sets only about 30 minutes after the Sun at month's end. On a clear day in the latter part of September, however, the brilliance of this –3.9-magnitude planet stands out briefly down near the western horizon, even in bright twilight.

Mercury is at superior conjunction with the Sun on the night of September 3–4. Only with optical aid at more southerly latitudes will observers be able to catch fainter Spica a little more than 1° southwest of Mercury on the American evening of September 28th.

DUSK THROUGH EVENING

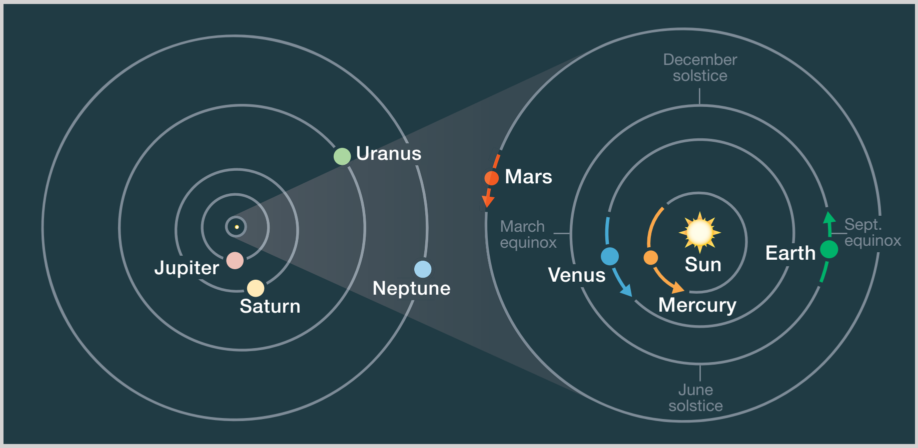
Jupiter and **Saturn** have been the great planetary attractions of summer nights. Now, as summer ends, they're setting earlier. Jupiter begins September just past the meridian in the south as it comes into view early in evening twilight. Its magnitude dims from –2.2 to –2.0 this month, but of course that's plenty bright enough for it to stand out brilliantly in southwestern Ophiuchus as it continues to move slowly away from Antares. Jupiter's angular diameter decreases from 39″ to 36″ in September. It reaches eastern quadrature (90° east of the Sun) on September 8th, so this is a good month to see eclipses of the Galilean moons (see page 51). By the end of the month the planet sets not long after





10 p.m. daylight-saving time.

Saturn follows about two hours behind Jupiter. It culminates in the south for our best telescopic views of it not long after 9 p.m. as September opens, but only a little more than half an hour after sunset as the month closes. Saturn fades from magnitude +0.3 to +0.5 this month. It halts its retrograde motion and resumes direct motion (eastward relative to the stars) on September 18th, so we see it dawdle near the handle of the Teapot of Sagittarius all month. The apparent equatorial diameter of Saturn decreases to less than 17″ late this month, but the gorgeous rings remain nicely tilted at 25.1°.



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

NIGHT

Neptune comes to opposition on September 10th and is therefore visible all night long. It's at its highest — for best telescopic observations — in the middle of the night. Neptune is the most distant of the major planets, so even when closest to Earth in this month of opposition, its magnitude-7.8 light takes 4 hours (indeed almost exactly 4 hours) to reach us.

Uranus doesn't climb to its highest until about 3:30 a.m. daylight-saving time in mid-September. But the magnitude-5.7 world will arrive at opposition — and therefore more convenient visibility — late next month. You can access a chart for finding Neptune in Aquarius and Uranus in Aries by going to **https://is.gd/urnep**.

DAWN

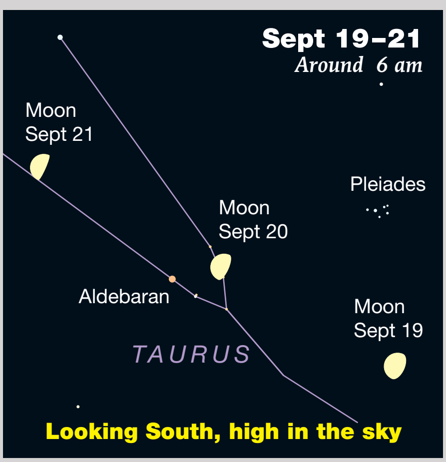
Mars is at conjunction with the Sun on September 2nd, a day and a half before Mercury. Since Mars's orbital speed isn't much less than Earth's, the Red Planet usually moves rather swiftly eastward relative to the background stars, and therefore it takes many weeks to emerge from morning twilight after its conjunction. Mars won't return to visibility until about the third week of October.

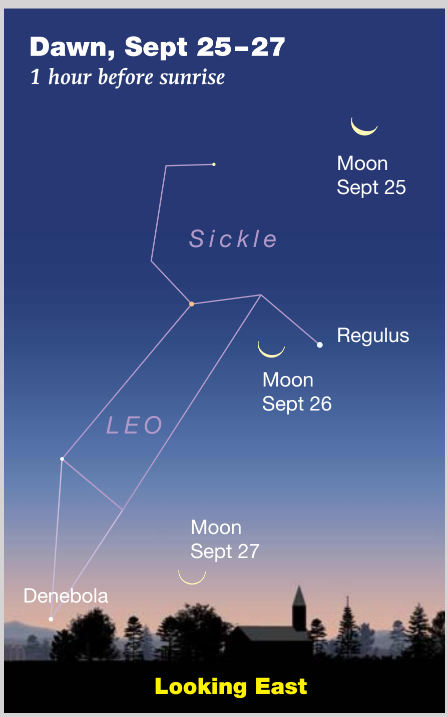
SUN AND MOON

The Sun arrives at the September equinox at 3:50 a.m. EDT on September 23rd. This event inaugurates the start of autumn in the Northern Hemisphere and spring in the Southern Hemisphere.

The Moon reaches its first-quarter phase on the American evening of September 5th. That's also the evening it forms a beautiful triangle with Antares 7° or less below it and Jupiter much closer to its left (the gap between the Moon and Jupiter shrinks all evening as they sink towards their setting). The waxing gibbous Moon is 5–6° right of Saturn at nightfall on September 7th, and a similar distance left or lower left of the planet on September 8th. The distant full Moon (it's at apogee) on the night of September 13–14 is the Harvest Moon. The waning gibbous Moon is in the Hyades and near Aldebaran high in the south at dawn on September 20th. A very thin waning lunar crescent is just a few degrees left of Regulus at dawn on September 26th.

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

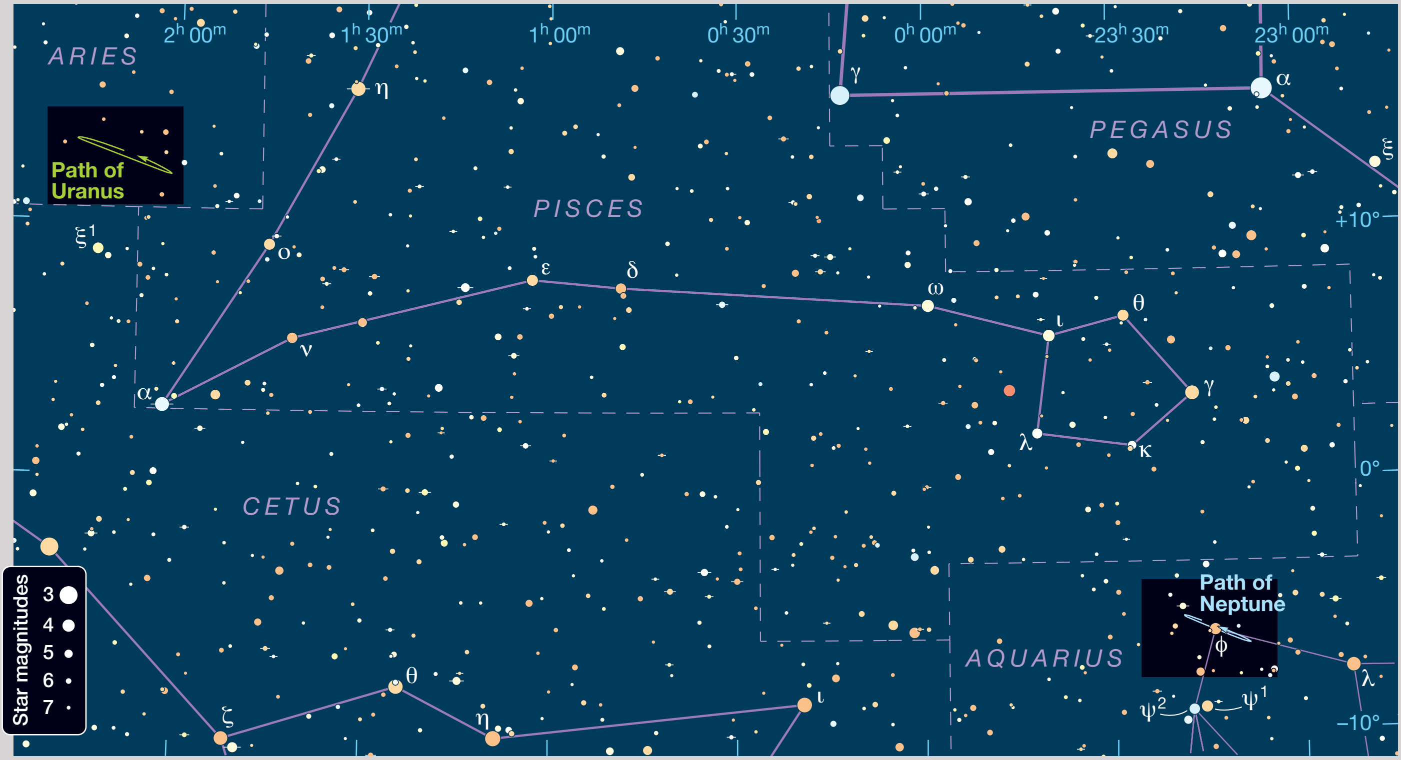




■ **FRED SCHAAF** has penned this column since 1993.

Cool Hunting

You've seen Uranus and Neptune — but have you found their moons?



The chart above spans almost 60°, or 4 hours of right ascension, from Aquarius to Aries. On the smaller, deeper charts on the facing page, use the ticks marking the start of each month to determine the positions of the planets for your observing date.

Uranus, the faintest planet visible to the naked eye, is curling westward through Aries this month, on its way to a late October opposition. The icy, stinky planet (its cloud deck contains hydrogen sulfide) rises in mid-evening as September opens and stands well up in the southeast near midnight at the end of the month. Glowing at magnitude 5.7, Uranus is just bright enough to be viewed without optical aid under dark skies. Binoculars easily show the planet, and a small telescope at moderate magnification will expose its 3.7″ (arcseconds) disk. In the right conditions and at higher magnifications, your telescope will also reveal a hint of cyan to the orb.

If you're not using a Go To mount, finding Uranus this fall will require a bit of star-hopping — there's no particularly bright star in the immediate vicinity of its orbital path. Your best starting points are Omicron (ο) Piscium, Xi (ξ) Arietis, or Xi[1] Ceti.

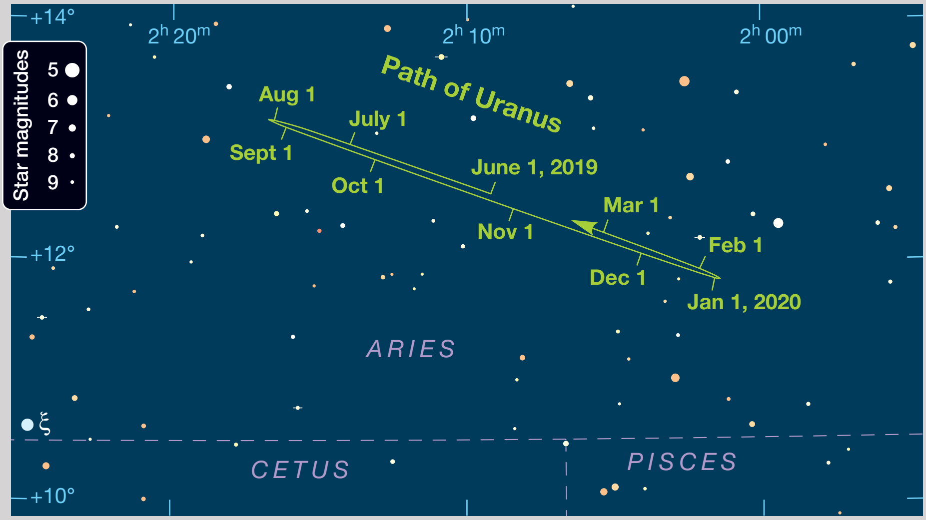
If you're up for a challenge, take a run at four of Uranus's major moons. They're faint, ranging from magnitude 15.0 to 13.9 from September 1st through opposition, so start with a 12-inch scope. Scattered light from Uranus can interfere with such dim targets, so you may want to use an occulting bar to hide the planet. Use a charting program and the *Sky & Telescope* Moons of Uranus observing tool (**https://is.gd/UranusMoons**) to plan your search.

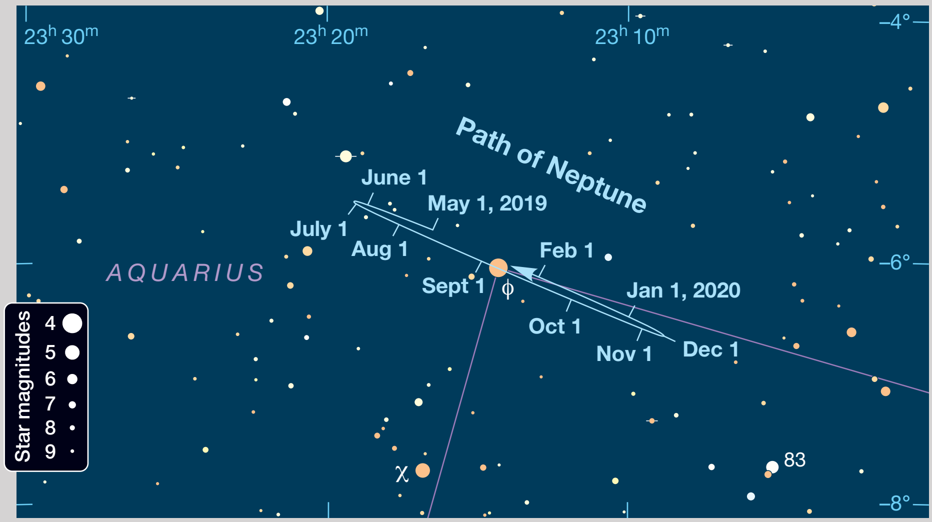
Unlike Uranus, which is fairly easy to find, Neptune requires a telescope (or large binos) and patience to see. Neptune began peeking over the eastern horizon in late March, rising with Aquarius in morning twilight. By the June solstice, it was reasonably well-placed for observation, though still a morning target. At the beginning of July, Neptune eased into the nighttime sky, and now, as it approaches opposition on the night of September 9–10, is perfectly positioned for evening viewing. On the night of September 5–6, with best views after local midnight, Neptune passes just 13″ from 4th-magnitude Phi (φ) Aquarii. Neptune's largest moon, Triton, comes even closer to the star. If you don't like star-hops, this is the night to let your Go To scope take you to Phi.

The difference between planet, moon, and star should be apparent in the eyepiece, even at low magnifications. At magnitude 7.8, Neptune shines more dimly than Phi but has a steadier, less "twinkly" light. A medium-aperture scope will reveal Neptune's 2.4″ disk and perhaps a hint of blue-gray. Triton, on the other hand, remains a speck compared to the other members of this trio, and seeing it under the best of circumstances can be difficult. Look for a modest 13.5-magnitude gray-white dot. Use the *Sky & Telescope* Triton Tracker (**https://is.gd/TritonTracker**) to help locate the tiny moon and let us know if you find it!

On the night of June 21–22, Neptune reached its easternmost point and began retrograde motion. The ice giant will continue to travel westward until November 27th, when it resumes prograde (eastward) travel.

FIND YOUR CLUB:
skyandtelescope.com/astronomy-clubs-organizations.

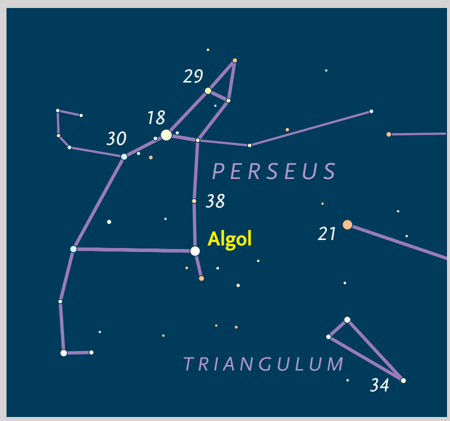




Minima of Algol

Aug.	UT	Sept.	UT
3	20:22	1	12:28
6	17:11	4	9:17
9	14:00	7	6:05
12	10:48	10	2:54
15	7:37	12	23:43
18	4:25	15	20:31
21	1:14	18	17:20
23	22:02	21	14:08
26	18:51	24	10:57
29	15:40	27	7:46
		30	4:34

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



▲ With the arrival of autumn in the Northern Hemisphere, Perseus climbs the northeastern sky in the evening. Every 2.7 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to estimate its brightness with respect to the convenient comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).

NASA's Juno spacecraft captured this image of Jupiter's Great Red Spot on December 21, 2018. Since then, the giant storm has begun to unfurl, with clouds peeling off its flanks.

NASA / JPL-CALTECH / SWRI / MSSS / GERALD EICHSTÄDT / SEÁN DORAN

Action at Jupiter

JUPITER APPEARS out of evening twilight on the 1st, already at its highest in the south. By the 30th, it sets around 10 p.m. daylight-saving time.

Any telescope shows 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 time and date.

All of the September interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for when Jupiter is at its highest in the evening hours.

On nights of steady seeing, look for the Great Red Spot (GRS). It began acting up in May, so you may be able to detect changes. Here are the times, in Universal Time, when the GRS should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Daylight Time is UT minus 4 hours.)

August 1: 8:41, 18:36; **2:** 4:32, 14:28; **3:** 0:23, 10:19, 20:15; **4:** 6:10, 16:06; **5:** 2:02, 11:58, 21:53; **6:** 7:49, 17:45; **7:** 3:40, 13:36, 23:32; **8:** 9:28, 19:23; **9:** 5:19, 15:15; **10:** 1:10, 11:06, 21:02; **11:** 6:58, 16:53; **12:** 2:49, 12:45, 22:40; **13:** 8:36, 18:32; **14:** 4:28, 14:23; **15:** 0:19, 10:15, 20:11; **16:** 6:06, 16:02; **17:** 1:58, 11:54, 21:49; **18:** 7:45, 17:41; **19:** 3:36, 13:32, 23:28; **20:** 9:24, 19:19; **21:** 5:15, 15:11; **22:** 1:07, 11:02, 20:58; **23:** 6:54, 16:50; **24:** 2:46, 12:41, 22:37; **25:** 8:33, 18:29; **26:** 4:24, 14:20; **27:** 0:16, 10:12, 20:07; **28:** 6:03, 15:59; **29:** 1:55, 11:50, 21:46; **30:** 7:42, 17:38; **31:** 3:33, 13:29, 23:25.

September 1: 9:21, 19:17; **2:** 5:12, 15:08; **3:** 1:04, 11:00, 20:55; **4:** 6:51, 16:47; **5:** 2:43, 12:39, 22:34; **6:** 8:30, 18:26; **7:** 4:22, 14:17; **8:** 0:13, 10:09, 20:05; **9:** 6:01, 15:56; **10:** 1:52, 11:48, 21:44; **11:** 7:40, 17:35; **12:** 3:31, 13:27, 23:23; **13:** 9:19, 19:14; **14:** 5:10, 15:06; **15:** 1:02, 10:57, 20:53; **16:** 6:49, 16:45; **17:** 2:41, 12:36, 22:32; **18:** 8:28, 18:24; **19:** 4:20, 14:16; **20:** 0:11, 10:07, 20:03; **21:** 5:59, 15:55; **22:** 1:50, 11:46, 21:42; **23:** 7:38, 17:34; **24:** 3:29, 13:25, 23:21; **25:** 9:17, 19:13; **26:** 5:08, 15:04; **27:** 1:00, 10:56, 20:52; **28:** 6:48, 16:43; **29:** 2:39, 12:35, 22:31; **30:** 8:27, 18:22.

Lunar Occultation

ON THE MORNING OF September 22nd, the last-quarter Moon temporarily hides Eta (η) Geminorum for observers in the American Southwest and Central America. Eta disappears behind the bright limb of the Moon and reappears at the dark limb as many as 70 minutes later, depending on location. For most, the reappearance will happen in a brightening sky, just at the edge of astronomical twilight.

More familiarly known as Propus, Eta is an *M*-type variable, moving from magnitude 3.2 to 3.9 and back over a period of 233 days. Occultations by the Moon can reveal the double nature of stars — the disappearance of a star is a more gradual, stepped event when a star is double — but Eta is already a known triple-star system. A magnitude-6.2 secondary, Eta Gem B, can be split with a 6-inch scope at moderate powers under transparent skies. The tertiary member, Eta Gem C, was detected only from the primary's radial velocity variations.

A grazing occultation is visible within 2 to 3 km of the predicted northern limit of the path of visibility. Observers near Austin and San Antonio, Texas, may be able to see Eta "blink" as the rugged northern edge of the Moon glides in front of it.

Although astronomers know Eta is a multiple-star system, observations of the event remain highly desired by the International Occultation Timing Association (IOTA). Timetables are available from the IOTA website (**https://is.gd/IOTApredict**). You can also calculate predictions and generate maps that show the precise disappearance-reappearance locations on the lunar limb, using IOTA's free software program, Occult (**https://is.gd/IOTAoccult**).

Some timings: **La Paz, Mexico,** *disappearance* 4:09 a.m., *graze* 4:31 a.m., *reappearance* 4:48 a.m. MDT; **Guadalajara,** *d.* 5:00 a.m., *r.* 6:11 a.m. CDT; **Mexico City,** *d.* 5:01 a.m., *r.* 6:23 a.m. CDT; **San Antonio, Texas,** *d.* 5:33 a.m., *gr.* 5:54 a.m., *r.* 6:12 a.m. CDT; **Austin,** *d.* 5:38 a.m., *gr.* 5:56 a.m., *r.* 6:11 a.m. CDT; **Brownsville,** *d.* 5:19 a.m., *r.* 6:23 a.m. CDT.

These times assume that the spot will be centered at System II longitude 315°. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 315° and 1⅔ minutes later for each degree more than 315°.

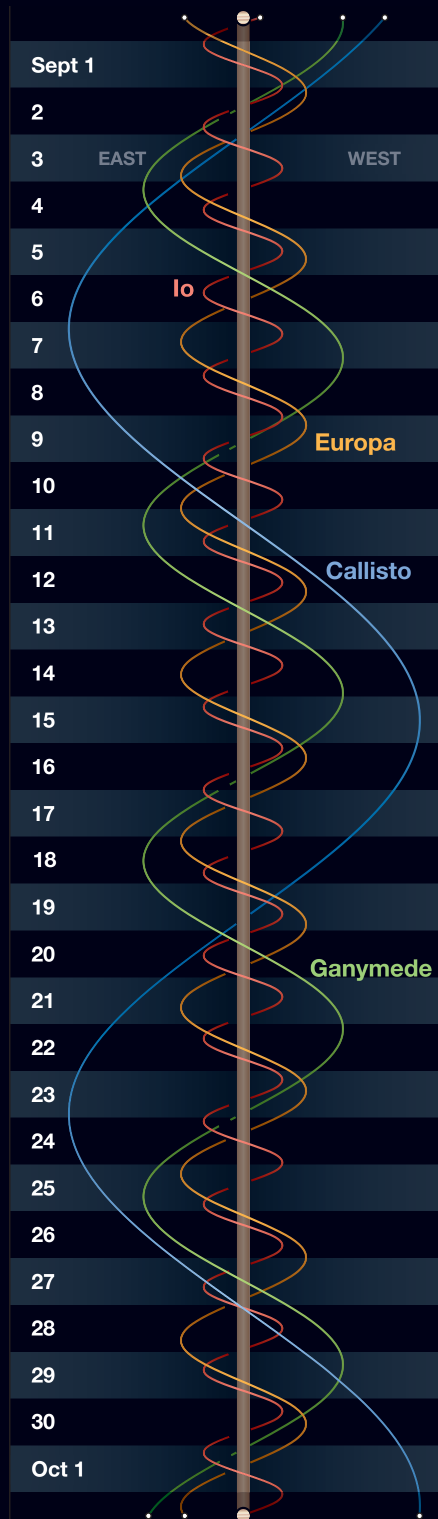
Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. Use a filter opposite in color to the feature you're trying to highlight. A blue or green filter slightly increases the contrast and visibility of Jupiter's reddish and brownish markings, like the GRS. Red filters can make Jupiter's bluish features easier to distinguish.

Phenomena of Jupiter's Moons, September 2019

Sept. 1	3:32	II.Tr.I
	6:01	II.Tr.E
	6:07	II.Sh.I
	8:38	II.Sh.E
	11:07	I.Tr.I
	12:23	I.Sh.I
	13:18	I.Tr.E
	14:35	I.Sh.E
Sept. 2	8:15	I.Oc.D
	8:17	III.Oc.D
	10:47	III.Oc.R
	11:46	I.Ec.R
	13:29	III.Ec.D
	16:04	III.Ec.R
	22:37	II.Oc.D
Sept. 3	1:07	II.Oc.R
	1:11	II.Ec.D
	3:43	II.Ec.R
	5:36	I.Tr.I
	6:52	I.Sh.I
	7:47	I.Tr.E
	9:04	I.Sh.E
Sept. 4	2:43	I.Oc.D
	6:15	I.Ec.R
	16:50	II.Tr.I
	19:19	II.Tr.E
	19:26	II.Sh.I
	21:58	II.Sh.E
Sept. 5	0:05	I.Tr.I
	1:21	I.Sh.I
	2:16	I.Tr.E
	3:32	I.Sh.E
	21:12	I.Oc.D
	22:09	III.Tr.I
Sept. 6	0:38	III.Tr.E
	0:44	I.Ec.R
	3:22	III.Sh.I
	5:56	III.Sh.E
	11:55	II.Oc.D
	14:24	II.Oc.R
	14:28	II.Ec.D
	17:00	II.Ec.R
	18:33	I.Tr.I
	19:50	I.Sh.I
	20:44	I.Tr.E
	22:01	I.Sh.E
Sept. 7	15:41	I.Oc.D
	19:12	I.Ec.R
Sept. 8	6:08	II.Tr.I
	8:37	II.Tr.E
	8:44	II.Sh.I
	11:16	II.Sh.E
	13:02	I.Tr.I
	14:18	I.Sh.I
	15:13	I.Tr.E
	16:30	I.Sh.E
Sept. 9	10:10	I.Oc.D
	12:15	III.Oc.D
	13:41	I.Ec.R
	14:46	III.Oc.R
	17:28	III.Ec.D
	20:04	III.Ec.R
Sept. 10	1:12	II.Oc.D
	3:42	II.Oc.R
	3:46	II.Ec.D
	6:18	II.Ec.R
	7:31	I.Tr.I
	8:47	I.Sh.I
	9:42	I.Tr.E
	10:59	I.Sh.E
Sept. 11	4:38	I.Oc.D
	8:10	I.Ec.R
	19:28	II.Tr.I
	21:57	II.Tr.E
	22:03	II.Sh.I
Sept. 12	0:36	II.Sh.E
	2:00	I.Tr.I
	3:16	I.Sh.I
	4:11	I.Tr.E
	5:27	I.Sh.E
	23:07	I.Oc.D
Sept. 13	2:10	III.Tr.I
	2:39	I.Ec.R
	4:39	III.Tr.E
	7:21	III.Sh.I
	9:56	III.Sh.E
	14:31	II.Oc.D
	17:01	II.Oc.R
	17:04	II.Ec.D
	19:36	II.Ec.R
	20:29	I.Tr.I
	21:45	I.Sh.I
	22:40	I.Tr.E
	23:56	I.Sh.E
Sept. 14	17:36	I.Oc.D
	21:08	I.Ec.R
Sept. 15	8:47	II.Tr.I
	11:16	II.Tr.E
	11:22	II.Sh.I
	13:54	II.Sh.E
	14:58	I.Tr.I
	16:13	I.Sh.I
	17:09	I.Tr.E
	18:25	I.Sh.E
Sept. 16	12:06	I.Oc.D
	15:37	I.Ec.R
	16:18	III.Oc.D
	18:50	III.Oc.R
	21:28	III.Ec.D
Sept. 17	0:06	III.Ec.R
	3:49	II.Oc.D
	6:20	II.Oc.R
	6:21	II.Ec.D
	8:54	II.Ec.R
	9:27	I.Tr.I
	10:42	I.Sh.I
	11:38	I.Tr.E
	12:54	I.Sh.E
Sept. 18	6:35	I.Oc.D
	10:06	I.Ec.R
	22:07	II.Tr.I
Sept. 19	0:37	II.Tr.E
	0:41	II.Sh.I
	3:14	II.Sh.E
	3:56	I.Tr.I
	5:11	I.Sh.I
	6:07	I.Tr.E
	7:22	I.Sh.E
Sept. 20	1:04	I.Oc.D
	4:35	I.Ec.R
	6:13	III.Tr.I
	8:44	III.Tr.E
	11:20	III.Sh.I
	13:56	III.Sh.E
	17:08	II.Oc.D
	22:12	II.Ec.R
	22:25	I.Tr.I
	23:39	I.Sh.I
Sept. 21	0:36	I.Tr.E
	1:51	I.Sh.E
	19:33	I.Oc.D
	23:03	I.Ec.R
Sept. 22	11:27	II.Tr.I
	13:57	II.Tr.E
	13:59	II.Sh.I
	16:32	II.Sh.E
	16:54	I.Tr.I
	18:08	I.Sh.I
	19:05	I.Tr.E
	20:20	I.Sh.E
Sept. 23	14:03	I.Oc.D
	17:32	I.Ec.R
	20:24	III.Oc.D
	22:58	III.Oc.R
Sept. 24	1:28	III.Ec.D
	4:06	III.Ec.R
	6:28	II.Oc.D
	11:23	I.Tr.I
	11:29	II.Ec.R
	12:37	I.Sh.I
	13:34	I.Tr.E
	14:49	I.Sh.E
Sept. 25	8:32	I.Oc.D
	12:01	I.Ec.R
Sept. 26	0:48	II.Tr.I
	3:19	II.Tr.E
	3:19	II.Sh.I
	5:52	II.Sh.E
	5:52	I.Tr.I
	7:06	I.Sh.I
	8:04	I.Tr.E
	9:17	I.Sh.E
Sept. 27	3:01	I.Oc.D
	6:30	I.Ec.R
	10:20	III.Tr.I
	12:53	III.Tr.E
	15:19	III.Sh.I
	17:56	III.Sh.E
	19:48	II.Oc.D
Sept. 28	0:22	I.Tr.I
	0:47	II.Ec.R
	1:34	I.Sh.I
	2:33	I.Tr.E
	3:46	I.Sh.E
	21:31	I.Oc.D
Sept. 29	0:59	I.Ec.R
	14:09	II.Tr.I
	16:37	II.Sh.I
	16:40	II.Tr.E
	18:51	I.Tr.I
	19:11	II.Sh.E
	20:03	I.Sh.I
	21:02	I.Tr.E
	22:15	I.Sh.E
Sept. 30	16:00	I.Oc.D
	19:28	I.Ec.R

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

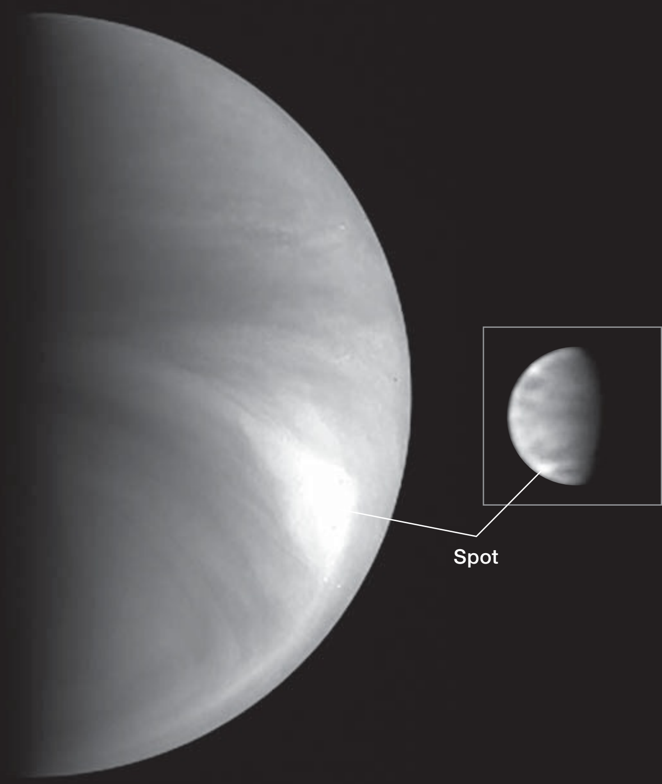
Jupiter's Moons



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.

The Mysterious "Star-Spots" of Venus

Could these bright patches be related to volcanism?



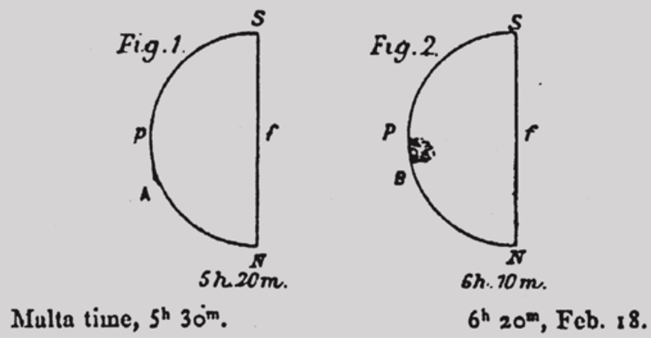
▶ The European Space Agency Venus Express probe recorded a bright feature through its UV filter on July 18, 2009 *(main image)*. The next day amateur Paul Maxson imaged the spot with a 10-inch reflector *(inset)*.

To the unaided eye, Venus is one of the most beautiful sights in the sky, outshining every celestial object except the Sun and the Moon with a pure white light. However, for telescopic observers the dazzling face of Venus is usually a disappointing sight compared with the richly detailed globes of Mars and Jupiter. An unbroken canopy of clouds overlaid by a thick layer of haze conceals the surface of Venus from prying eyes. It is not unusual for experienced observers working with powerful instruments under excellent conditions to find the planet utterly devoid of markings of any kind. When markings are visible, they are almost invariably diffuse, dusky shadings of low contrast. It's a small wonder that three centuries of attempts by visual observers to discern patterns in the clouds and determine the planet's rotation period all failed miserably.

On rare occasions, however, very distinct brilliant spots have appeared on Venus. These mysterious, short-lived features were dubbed "star-spots" by the British historian of astronomy Richard Baum (1930–2017), a skilled planetary observer who directed the Terrestrial Planets Section of the British Astronomical Association for two decades. Baum scoured the observational record and found several credible and intriguing accounts.

On April 17, 1873, the British amateur Roger Langdon reported "two exceedingly bright spots on the crescent — one close to the terminator towards the eastern horn, and the other in the centre of the crescent. These spots appeared like two drops of dew . . . glistening in such a manner as to cause the surrounding parts of the bright crescent to appear dull by contrast."

February 3, 1884: Belgian astronomer Charles Émile Stuyvaert saw a very luminous spot close to the limb of Venus near the southern cusp of the crescent. He compared its appearance to one of Jupiter's Galilean satellites in transit shortly after entering the disc of the planet.



▶ In February 1897, Reverend T. H. Foulkes detected a bright "hump" (A) and a white spot (B) while observing Venus from the island of Malta.

VENUS: ESA VENUS EXPRESS; INSET: PAUL MAXSON; DRAWING: T. H. FOULKES, COURTESY OF THE B.A.A.

February 18, 1897: Observing from the island of Malta with a 10-inch Newtonian reflector at 250×, the Reverend T. H. Foulkes reported "good air. Everything in favour of perfect observations. Had two most remarkable observations of Venus. . . . I distinctly saw a clearly defined 'hump' . . . like a lunar mountain on limb at full, very white. . . . a little further [south] appeared an intense white circular spot . . . exactly like one of Jupiter's satellites, coming on or off the disc."

April 17, 1940: Observing Venus in daylight near superior conjunction with a 5-inch refractor, Henry McEwen, the Glasgow engineer who directed the Mercury and Venus Section of the British Astronomical Association from 1895 until shortly before his death in 1955, recorded: "Good images . . . through thin cirro-stratus . . . Three shining points of light visible . . . reminiscent of [the lunar crater] Aristarchus on Mare Procellarum — an impressive sight!"

On March 19, 1985 I was observing Venus in evening twilight with a humble 4-inch reflector when I was struck by a well-defined spot on the limb of the crescent. It was so brilliant that it appeared to protrude into the surrounding sky, deforming the planet's limb in a fashion identical to Foulkes' description of the feature witnessed 88 years earlier. This seeming projection was an illusion known as irradiation, a physiological phenomenon caused by the spreading of excitation from the area of the retina that is actually stimulated by light. Irradiation occurs at the boundary between areas of markedly unequal brightness, causing brighter areas to appear to encroach upon fainter ones.

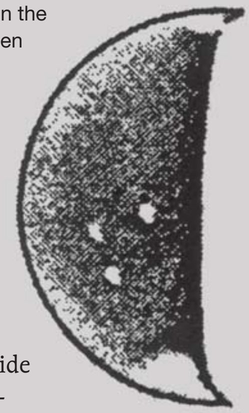
This extraordinary feature was captured on film 19 hours later by the British amateur David Greenwood, who was unaware of my observation in those days before the rapid communication made possible by the internet. Greenwood pointed out that the interval of time that had elapsed cast grave doubts on whether the phenomenon was atmospheric in nature or even the same phenomenon at all. He noted that the atmosphere of Venus rotates every 4 days, so in the 19-hour interval between our observations any atmospheric feature would have been displaced by about 70° of longitude.

So how could the location of such an undoubtedly real feature have remained virtually stationary? I can't help but think that it was somehow tethered to the planet's surface. The globe of Venus spins backwards on its axis once every 243 days, much slower than the 'super-rotating' overlying atmosphere. I wondered if upwelling plumes produced by volcanic eruptions account for the "star-spots" reported by telescopic observers throughout the past century.

The surface of Venus is peppered with hundreds of volcanic mountains, basaltic lava flows, and other features that make the planet's history of volcanism unmistakable. While most of the volcanoes appear to be long dead, in recent decades the emergence of several "smoking guns" suggests continuing volcanic activity. Radar mapping by NASA's Magellan orbiter during the early 1990s revealed a host of fresh-looking lava flows. More recently, the Infrared Thermal Imaging Spectrometer aboard the European Space Agency's Venus Express probe detected several transient hot spots.

▲ The late observer and historian Richard Baum is seen here with his venerable 4.5-inch Cooke refractor.

BAUM: RICHARD BAUM; DRAWING: HENRY MCEWEN, COURTESY OF THE B.A.A.



▶ Three "star-spots" in the clouds of Venus as seen by Henry McEwen on April 17, 1940.

Perhaps the most compelling evidence consists of the sudden, dramatic surges in the concentration of sulfur dioxide in the upper atmosphere of Venus detected by Venus Express and NASA's Pioneer Venus Orbiter. One of the principal gases released by volcanic eruptions on Earth, sulfur dioxide is rapidly destroyed by photochemical reactions in sunlight. Any increase of the gas in Venus's upper atmosphere can only signify a very recent origin.

A volcanic eruption would have to be extraordinarily violent to blast sulfur dioxide through the canopy of clouds and haze located 50 to 70 kilometers above the planet's surface. Many planetary geologists believe the planet's crushing atmospheric surface pressure, which is 90 times greater than Earth's, muffles volcanic eruptions on Venus. They envision eruptions on Venus as slow, oozing effusions of lava.

Another possibility is that a gust of charged particles from the Sun could create glows by energizing a patch of the planet's upper atmosphere. Alternatively, atmospheric waves, which trigger convective turbulence and are thought to transport material up and down, could briefly concentrate bright material to create the star-spots.

In this era of space probes and orbiting telescopes, mysteries endure that are accessible to the backyard astronomer. That's why I always have a sense of anticipation when I peer into the eyepiece of a telescope, even when it's pointed at a chronically unrewarding target like Venus.

■ Contributing Editor **TOM DOBBINS** has witnessed several transient features in the Venusian atmosphere during his nearly five decades of observing.

Foxfire Nights

Vulpecula's dearth of bright stars is offset by its wealth of deep-sky objects.

But if you tame me, then we shall need each other. To me, you will be unique in all the world. To you, I shall be unique in all the world.

— Fox to the title character in *The Little Prince*, Antoine de Saint-Exupéry, 1943

▲ The constellation Vulpecula, the Fox, was created by the Polish astronomer Johannes Hevelius for his 1687 celestial atlas *Firmamentum Sobiescianum*. Consequently, European star atlases published in the 18th and 19th centuries frequently depicted Vulpecula carrying Anser, the Goose, in its long jaws.

JOHANNES HEVELIUS, *FIRMAMENTUM SOBIESCIANUM* (1687) / PUBLIC DOMAIN

Vulpecula, the Fox, has no bright star to draw our eyes his way and is overshadowed by the showier constellations around him. Yet this inconspicuous star figure has an amazing wealth of deep-sky wonders. If you take the time to visit them and make them your own, then the Fox will hold a special place in your heart and never seem ordinary again.

Our first fiery splendor in the Fox is the constellation's brightest star, 4.4-magnitude **Alpha (α) Vulpeculae**, a red giant 80 times bigger across and 400 times more luminous than our Sun. Alpha is a lovely optical double designated Σ I 42, meaning the 42nd entry in the first appendix to F. G. W. Struve's double-star catalog. Its unrelated suns are more than 7′ (arcminutes) apart and are easily seen with steadily held binoculars. The colorful components are widely separated in my 4.1-inch refractor at 17×. The primary appears orange, and its 5.8-magnitude yellow neighbor sits north-northeast. The bright star is about 200 light-years closer to us than its apparent companion.

The open cluster **NGC 6800** is located 36′ northwest of Alpha. My little refractor at 17× reveals a very pretty sprinkling of faint stars spanning 15′. At 87× I count two dozen stars, the brightest strung along the outline of an oval with a large central void. My 10-inch reflector at 118× doubles the star count, but the edges of the cluster become very ill defined. William Herschel discovered this cluster while sweeping the sky with his 18.7-inch speculum-metal reflector in 1784. He aptly described the group as a cluster of coarsely scattered bright stars intermixed with faint stars.

NGC 6793 is a confusing open cluster 2.8° south-southwest of Alpha and 1.8° east-northeast of 1 Vulpeculae. It hides in a starry field that renders it tricky to pick out, which is probably why the object isn't plotted on many modern star atlases. William Herschel discovered the group in 1789 and called it a scattered cluster of considerably bright stars, pretty rich, of an irregular figure, above 15′ in extent. Yet most modern catalogs list the group as being only 6′ or 7′ in diameter.

My own notes reflect this ambiguity. While observing with my 4.1-inch scope at 17×, I logged a small, granular-looking patch with a few faint stars. At 87× the cluster showed two triangles of stars — one bright, one faint — plus a few very dim stars in 3½′. Outliers stretch the group to about 6′. The northernmost star in the bright triangle is the double star **h886**, its 10.5-magnitude primary

To celebrate 20 years of Sue French's stellar contributions to *Sky & Telescope*, we will be sharing the best of her columns in the coming months. We have updated values to current measurements when appropriate.

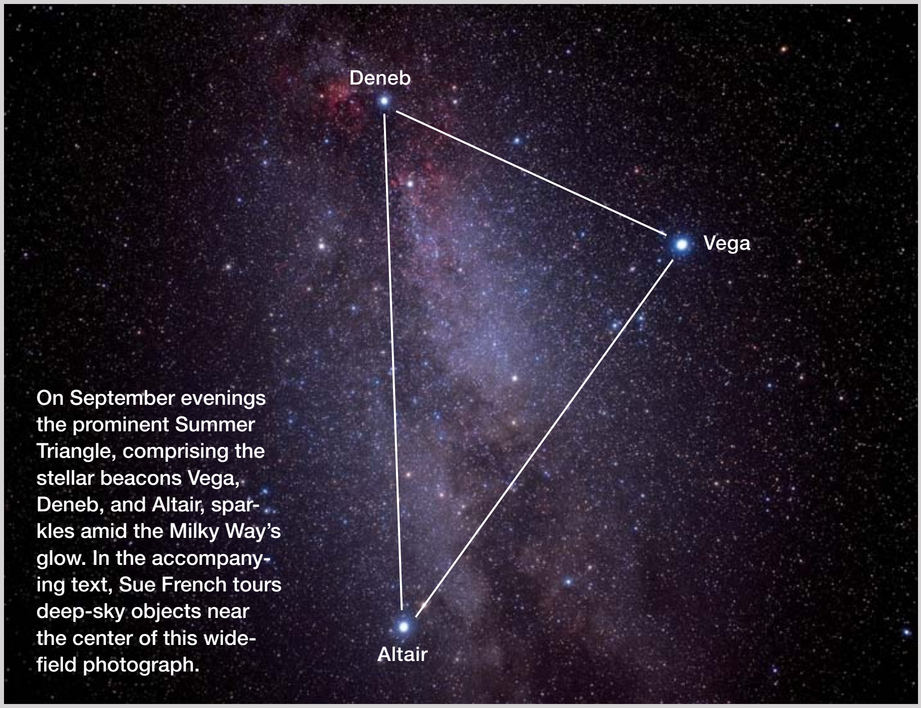
nestled against an 11.5-magnitude secondary to the northeast. With my 10-inch scope at 43×, I saw this same concentration of stars near the center of a larger and brighter collection with an 8th-magnitude star at its western edge. This makes the cluster about 20′ across, embracing 50 mixed bright and faint stars.

William Herschel obviously cataloged the bigger group. The *Catalogue of Open Cluster Data* (2004) lists NGC 6793 as being 18′ across with a 7′ core, so it seems that references giving a size of 7′ limit the cluster to the stars of the more highly condensed core.

Collinder 399 is a striking asterism commonly known as Brocchi's Cluster or the Coathanger. It has several stars bright enough to be seen with the unaided eye in a very dark sky. From my semi-rural home in upstate New York, I merely see a nebulous haze 4½° south of Alpha. Binoculars or a finder show six stars in a curved bar plus four more forming a hook to the south. Since the bar is 1.4° across, seeing the Coathanger in a telescope requires a low-power, wide-angle field of view.

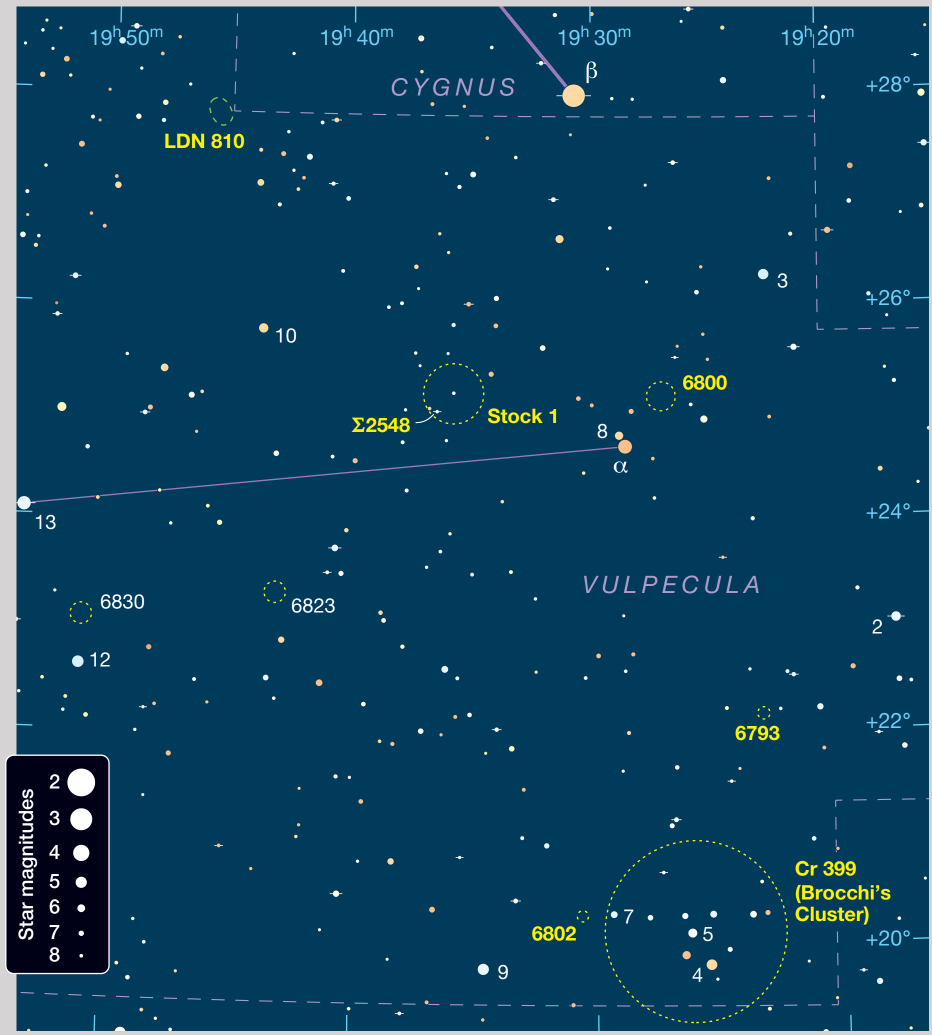
Stephan Ruchhöft from northern Germany reads *Sky & Telescope*'s German edition, *Astronomie Heute* [Editor's note: no longer in print]. Stephan wrote telling me that he "discovered" Collinder 399 while scanning the sky with binoculars. At the time he was planning a family trip to the Alps, which inspired him to see the star figure as a ski lift. The bar of the Coathanger is the ski lift's cable, and the hook is its chair. This inventive image has the advantage over the Coathanger of being seen right-side up in binoculars by Northern Hemisphere observers.

Just 18′ off the eastern end of the Coathanger's bar, we come to the open cluster **NGC 6802**. My little refractor at 28× displays a broad, north-south band of mist about 5′ tall. A pair of 9th- and 10th-magnitude stars lies 6½′ northwest, and another pair of 10th and 11th magnitude lies the same distance northeast. A smattering of extremely faint stars dots the haze at 87×. With my 10-inch reflector at 170×,



On September evenings the prominent Summer Triangle, comprising the stellar beacons Vega, Deneb, and Altair, sparkles amid the Milky Way's glow. In the accompanying text, Sue French tours deep-sky objects near the center of this wide-field photograph.

AKIRA FUJII



▲The author sees the dark nebula LDN 810 as the negative image of a snowman and thus calls it the Coalman.

NGC 6802 is a beautiful diamond-dust cluster rich in faint and very faint stars. It lies at an estimated distance of about 7,000 light-years, and it's dimmed by intervening dark clouds that seem to split the softly shining band of Milky Way in this area of the sky.

Now let's move 1.7° east-northeast of Alpha to **Stock 1**. Through my 4.1-inch scope at 17×, this is a large, loose cluster of 20 moderately bright and many very faint stars. An 8th-magnitude star sits at the heart of a core group measuring 30′ × 20′. This, in turn, is surrounded by a 1.4° halo of stars, mostly encircling the eastern half of the core. A reddish orange star adorns the western reaches of the cluster. Stock 1 contains many double stars. The brightest is **Σ2548**, located 14′ southeast of the cluster's central star. Its 8.5- and 9.9-magnitude components can be split at about 50×. A recent study indicates that most of this cluster's true members are roughly concentrated within the core group's ½° diameter.

Our final stop will be the dark nebula **LDN 810**, which I like to call the Coalman. The simplest way to find it is to scan 3.3° due east from Albireo, the beautiful gold-and-blue double star that marks the head of Cygnus, the Swan. With my 10-inch scope at 68×, I see a north-south oval of inky darkness containing only a few extremely faint stars. A slightly less conspicuous dark oval perched atop it turns the nebula into a filled-in 8 or the negative image of a snowman. The southern patch is about 9′ × 6′ and the northern one 6′ × 5′.

These are just a few of the foxy residents of Vulpecula. In the October 2006 issue, this tour continues with more vulpine delights, including the constellation's brightest planetary nebula and its finest cluster.

■ Contributing Editor **SUE FRENCH** penned this column for the September 2006 issue of *Sky & Telescope*.

Fox Hunt

Object	Type	Mag(v)	Size/Sep	RA	Dec.	*MSA*	*PSA*
Alpha (α) Vul	Double star	4.4, 5.8	7.1′	19^h 28.7^m	+24° 40′	1196	64
NGC 6800	Open cluster	—	15′	19^h 27.1^m	+25° 08′	(1196)	64
NGC 6793	Open cluster	—	7′ core, 18′ halo	19^h 23.2^m	+22° 08′	(1196)	(65)
h886	Double star	10.5, 11.5	8.2″	19^h 23.22^m	+22° 09.9′	(1196)	(65)
Collinder 399	Asterism	3.6	90′	19^h 26.2^m	+20° 06′	1220	64
NGC 6802	Open cluster	8.8	5.0′	19^h 30.6^m	+20° 16′	1220	64
Stock 1	Open cluster	5.2	34′ core, 80′ halo	19^h 35.8^m	+25° 10′	1196	64
Σ2548	Double star	8.5, 9.9	9.4″	19^h 36.5^m	+25° 00′	1196	(64)
LDN 810	Dark nebula	—	18′ × 9′	19^h 45.6^m	+27° 57′	(1172)	(64)

Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0. The columns headed *MSA* and *PSA* give the appropriate chart numbers in the *Millennium Star Atlas* and *Sky & Telescope's Pocket Sky Atlas*, respectively. Chart numbers in parentheses indicate that the object is not plotted.

T. A. RECTOR (UNIVERSITY OF ALASKA ANCHORAGE) / H. SCHWEIKER (WIYN AND NOAO / AURA / NSF)

Microquasars

They may be challenging to observe, but the visible companions in microquasars are exciting to pursue.

▲CYGNUS X-1 The microquasar with the brightest companion in our sample, Cyg X-1 was the first galactic system in which a black hole was identified. This Palomar Digital Sky Survey image is 1° across.

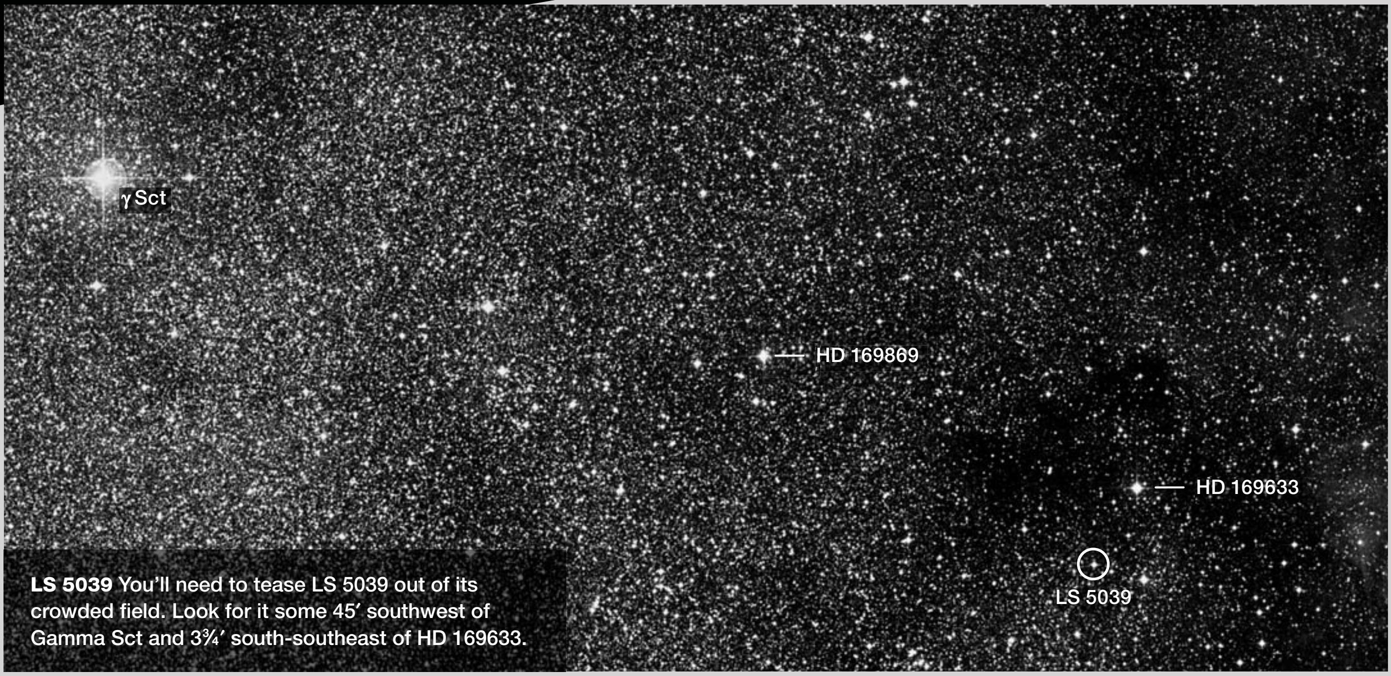
POSS-II / CALTECH / STSCI / PALOMAR OBSERVATORY

Every generation of astronomers is dealt a deep and profound mystery to solve. In the late 1970s, the mystery was the discovery of a "star" with very unusual properties, leading astronomers to suspect they were onto a new class of phenomena. This object, SS 433, was the 433rd listed in a 1977 catalog of Milky Way H-alpha emission stars compiled by C. Bruce Stephenson and Nicholas Sanduleak, astronomers at Case Western Reserve University. Subsequent observations showed that its optical spectrum exhibited peculiar emission lines; it also turned out to be a variable source at radio and X-ray wavelengths. But what clinched the mystery was the discovery of a somewhat elongated feature in the radio data. This combination of properties couldn't be reconciled to any single known model. At the time, no one could imagine that a miniature version of a remote quasar was sitting in our backyard.

By the end of the 1970s, a model attributing bipolar jets to explain the elongated radio emission was proposed. However, it wasn't until the early 1990s, when a double-sided radio jet was imaged emanating from a source near the galactic center, that the term "microquasar" firmly took hold to describe this particular class of object.

At the time of the discovery of SS 433, astronomers contemplated the following scenario to explain the complexity of its emission: a binary stellar pair in which a compact object, either a black hole or a neutron star, pulls in matter from its unevolved, or donor, companion. This matter spirals into an *accretion disk*, which heats up due to friction, around the compact object. The system's intense gravitational energy and (possibly) coiled magnetic field lines help launch a pair of bipolar jets. The jets can be accelerated to a significant fraction of the speed of light, and, when the geometry is just right, can *appear* to be traveling faster than the speed of light, a phenomenon described as *superluminal*. Once a working model was available, researchers set out to find as many examples of this type of object as possible to test their theories.

Only the companion stars are accessible to amateur astronomers (although accretion discs around the compact objects can contribute to the visible light output). To my knowledge, neither jets nor other features associated with microquasars can be seen in the eyepiece, one exception being SS 433's supernova remnant, W50. Nevertheless, bearing in mind how remarkable

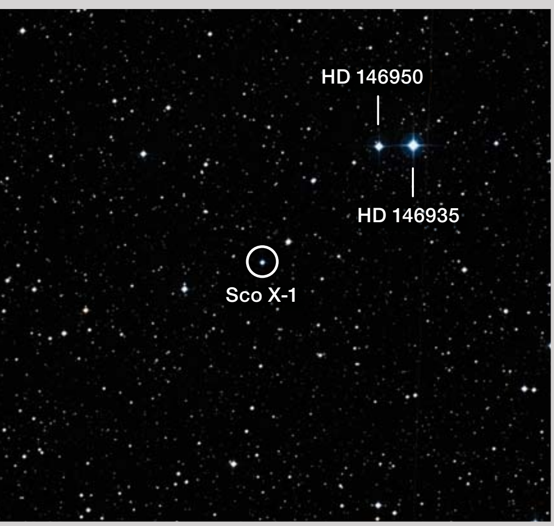


LS 5039 You'll need to tease LS 5039 out of its crowded field. Look for it some 45′ southwest of Gamma Sct and 3¾′ south-southeast of HD 169633.

these objects are, let's take a look at some of them.

One of the brightest X-ray sources in the sky is located in Cygnus, almost halfway from Sadr (Gamma Cygni) to Albireo (Beta Cygni), near Eta (η) Cygni. Discovered in 1964 by a sounding rocket equipped with Geiger counters, **Cygnus X-1** is the visually brightest of our sample, thanks to its donor companion, an 8.9-magnitude O9.7 blue supergiant. I've caught it in 20×80 binoculars, and it's easy to spot in most any telescope.

▼**SCORPIUS X-1** The first-ever X-ray source identified outside of our solar system, Sco X-1 lies about 8⅓′ southeast of a pair of 9th- to 10th-magnitude stars.



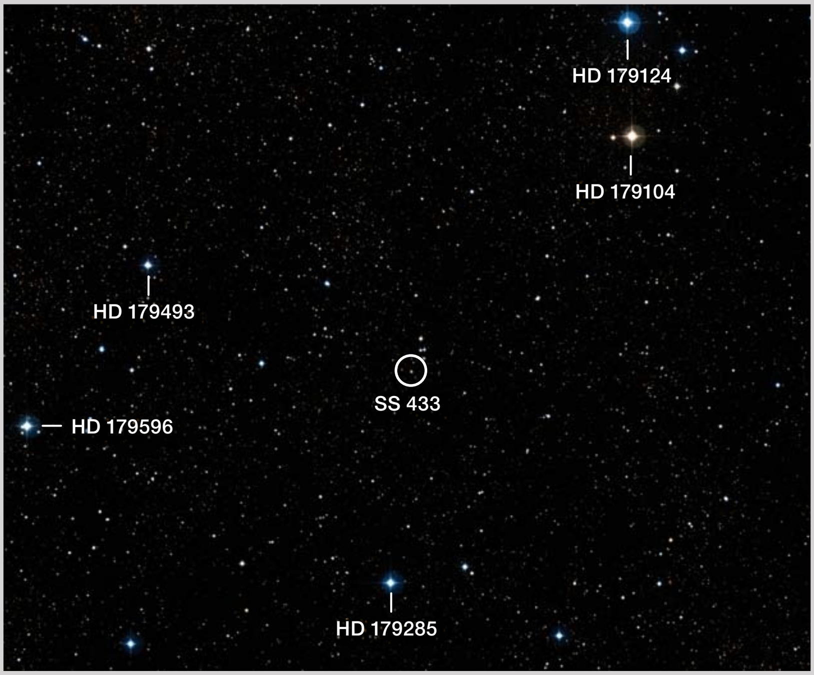
Next brightest for us is **LS 5039** at magnitude 11.3. It can be found 45′ southwest of 4.7-magnitude Gamma (γ) Scuti, in the southwestern corner of the Shield. You might spot it in 25×100 binoculars, but the higher magnification of a telescope is useful in this crowded field. In 2006 I used my 32-inch f/4 reflector to explore the dense star field in which it lies — I noted no other detail than its stellar appearance. LS 5039 resides 8,200 light-years from us, about a third of the way to the galactic center. It's one of only a few galactic microquasars known to emit very-high-energy gamma rays. Coupled with a jet pointed directly toward Earth, this has earned it the moniker "microblazar," akin to the better-known extragalactic blazars.

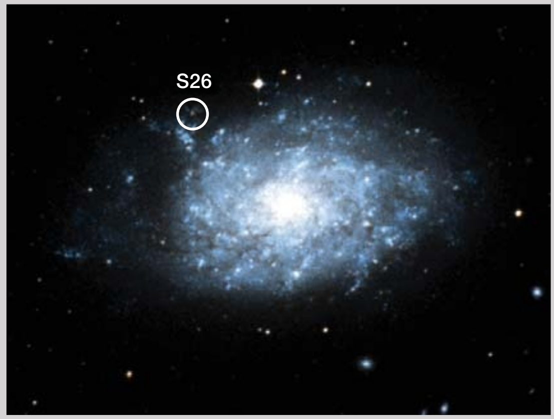
Scorpius X-1 is the brightest source of X-rays in the sky after our Sun. Discovered in 1962, it was the first X-ray object identified outside of our solar system (see *S&T:* Aug. 2019, p. 14). Its output at high-energy wavelengths is quite variable. The mass of the neutron star that powers its jets is most likely the canonical value of 1.4 solar masses, while the relatively small companion star has been estimated to be around half that. Sco X-1 lies some 9,000 light-years away in the northern reaches of the Scorpion — look for it slightly less than 5½° northeast of Graffias (Beta Scorpii). The visible companion shines at a moderately bright magnitude of 12.2, and can be easily spotted in a 4- to 5-inch scope.

V4641 Sgr, a variable star in Sagittarius, was long thought to be the closest black hole to Earth at 1,600 light-years. But new data revised the minimum distance to some 24,000 light-years, or about 15 times more distant, and some estimates place it even farther away. This means its jets are possibly the fastest measured to date in our galaxy. It's located almost 2° west of the top star of the Teapot's dome, 3rd-magnitude Lambda Sagittarii, and about 1 1/3° southwest of the magnificent globular cluster M28. At magnitude 13.7, it's one of the fainter microquasar companion stars we can see, made more difficult by its residence within the dense, central portion of the Milky Way. I managed to ferret it out using my 32-inch scope at the 2006 Okie-Tex Star Party.

This journey brings us back to **SS 433**. Though relatively dim at magnitude 14.2, it's visible in an 8-inch

POSS-II / CALTECH / STSCI / PALOMAR OBSERVATORY (2)





◀ **SS 433** The object that kicked off microquasar research, SS 433 is located some 10½′ north of HD 179285 and about 16′ southeast of 7th-magnitude HD 179104.

▲ **P13 AND S26 IN NGC 7793** The supernova remnant S26 lies on the northeastern edge of NGC 7793, which is where you'll find the extragalactic microquasar in our sample, P13.

POSS-II / CALTECH / STSCI / PALOMAR OBSERVATORY (2)

telescope. The donor star in SS 433 is a supergiant, while consensus leans toward a neutron star for the compact object. The pair orbits each other every 13.1 days. The jets precess like a spinning top over a period of around 163 days, producing a distinctive corkscrew pattern — the National Radio Astronomy Laboratory has made a "movie" that spans some 42 days of observation highlighting this effect: see **https://is.gd/ss433movie**. In November 2003 I located SS 433 using my 25-inch reflector and saw it as a stellar point with no detail. I estimated it to be magnitude 14.5 and a little fainter than a parallelogram of stars 1.5′ to its northwest. With the help of an O III filter, I managed to spot two of its eastern fragments in my 32-inch.

So is that the end of the story? Not quite. As often happens, once a new type of object is identified, scientists know what to look for and so they can extend their reach into more exotic locales. Several years ago, preparing for the Okie-Tex Star Party, I was researching targets and came across **P13** in NGC 7793, a galaxy in central Sculptor a little less than 5° south-southeast of Delta Scl. I can see moderate detail with my 32-inch reflector of this 9.3-magnitude spiral (type SA) at the relatively close distance of 12 million light-years, with a very open structure and a size of 9.1′ × 6.6′. A 1997 extensive survey of the galaxy identified multiple supernovae remnant candidates. Follow-up X-ray and radio observations showed that one of these, S26, contained both a point source and extended features, and was later identified to be a microquasar. P13 is considered to be the long-sought extragalactic analog to SS 433, but on a much bigger scale, spanning some 1,000 × 500 light-years. Although P13 itself is too faint to see, I easily spotted S26 as a 19th-magnitude stellaring on the northeastern edge of NGC 7793 in a 9-mm eyepiece at 361× at the Okie-Tex Star Party in late September 2016. Three of my fellow observers confirmed the sighting.

For those who love the complexity and interconnectedness of the night sky, understanding the history of microquasars, then pursuing and successfully observing them may evoke the Japanese term *yugen*: a nearly ineffable, deep emotional response to the mystery and beauty of the Universe.

■ **DAVE TOSTESON** has been an observer for more than 30 years. When he's not working as a family physician in Minnesota, he keeps busy by traveling to regional star parties and solar eclipses.

Microquasars

Object	Donor Companion	Spectral Type	Mag(v)	Orbital Period (d)	RA	Dec.
Cygnus X-1	HD 226868	*O*9.7I	8.9	5.6	19h 58.4m	+35° 12′
LS 5039	V479 Sct	*ON*6.5V	11.3	3.9	18h 26.3m	–14° 51′
Scorpius X-1	V818 Sco	*Oev* E	12.2	0.8	16h 19.9m	–15° 38′
V4641 Sgr	—	*B*9III	13.7	2.8	18h 19.4m	–25° 24′
SS 433	V1343 Aql	*A*7Ib	14.2	13.1	19h 11.8m	+04° 59′
P13	—	*B*9I	20.5	64	23h 58.0m	–32° 33′

Right ascension and declination are for equinox 2000.0.

 by Donald Vaughan

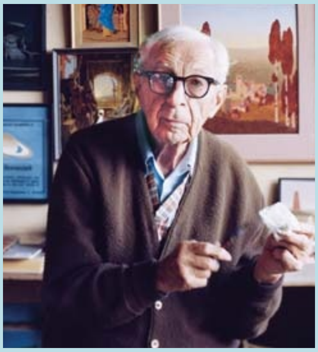
Postcards from the FUTU

Groundbreaking space artist Chesley Bonestell painted the future that we live in today.

July 2019 marks the 50th anniversary of the Apollo 11 Moon landing, a historic event that, with a single footstep, transformed what had been pure science fiction into one of humankind's most remarkable scientific achievements.

Conquest of the Moon, many years and millions of dollars in the making, had been a popular theme among astronomical artists for decades. Predominant among them was Chesley Bonestell, whose paintings beautifully conveyed the awe and majesty of our planetary neighbors as well as the technical complexity of their exploration.

From the 1940s through the 1980s, Bonestell was a ubiquitous cultural presence. His artwork graced book covers, science fiction magazines, and mainstream publications such as *Life* and *Collier's*, for which he illustrated articles by the likes of Willy Ley and Wernher von Braun. But in the



▲ **RED ROCK DESERT** In this illustration from *The Exploration of Mars*, co-authored by Willy Ley and Wernher von Braun in 1956, Chesley Bonestell placed astronauts in a landscape reminiscent of the deserts of the American Southwest.

◀ **INSPIRED START** Trained as an architect, Bonestell took up astronomical painting after viewing Saturn through the 12-inch refractor at Lick Observatory.

years following Bonestell's passing at age 98, public recognition of his name and influence began to wane. Endeavoring to reintroduce Bonestell to contemporary audiences, as well as cement his status as the grandmaster of modern astronomical art, filmmaker Douglass Stewart produced *Chesley Bonestell: A Brush with the Future*, the first documentary to explore the artist's life, career, and cultural influence.

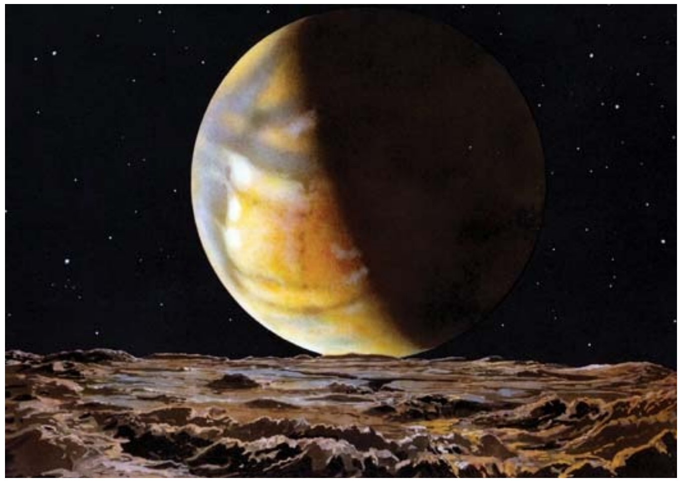
"Chesley Bonestell nurtured the inspiration to go out and explore what we see in the heavens above us," Stewart says.

“He was basically saying, ‘It’s out there, now go out and visit it yourself.’ It’s quite an accomplishment to have reached the American public in a way that captivated their imagination and touched that uniquely American spirit to explore new territories. I think that’s one of Bonestell’s greatest contributions to our society.”

It took Stewart nearly three and a half years to research, write, and produce *A Brush with the Future*, with vital insights from Bonestell biographer and fellow space artist Ron Miller, Bonestell historian Melvin Schuetz, and many others. The documentary premiered at the Newport Beach Film Festival in May 2018, winning the Audience Award for Art, Architecture and Design.

“I never met Chesley Bonestell, but as a young man I saw his paintings in science fiction magazines and on book covers,” Stewart says. “There is something absolutely unforgettable about his images, and that’s why they are so influential. Being in show business, I thought that someone surely had made a film about him, but no one had.”

PUBLIC DOMAIN



▲ **INFORMED ILLUSTRATION** French astronomer and artist Lucien Rudaux drew on his knowledge of both fields to portray the solar system, as shown in this depiction of Mars as seen from its moon Deimos. Bonestell owned and drew inspiration from Rudaux’s books.

Bonestell was born in San Francisco on January 1, 1888, and as a teenager survived the 1906 earthquake that destroyed much of the city and killed 700–800 people. A year earlier, he had gotten his first look at a world beyond our own when he viewed Saturn through the telescope at the Lick Observatory outside San Jose. Thrilled by what he had witnessed, he raced home to create his first astronomical painting, only to lose it in a fire sparked by the 1906 quake. The San Francisco catastrophe deeply affected Bonestell and served to inform much of his later work, including a painting created for *Collier’s* in 1950 depicting the nuclear destruction of Manhattan.

At the urging of his family, Bonestell attended Columbia University with an eye toward becoming an architect, but he left school in his third year. He nevertheless worked for a variety of architectural firms and found a mentor in Willis Polk, who was instrumental in shaping San Francisco both before and after the 1906 earthquake. Bonestell demonstrated great skill in combining his artistic ability with a deep understanding of architectural design to create renderings that helped laypeople easily understand even the most complex structures. This skill would prove invaluable when he worked with Ley and von Braun in designing realistic spaceships, space stations, and other futuristic hardware.

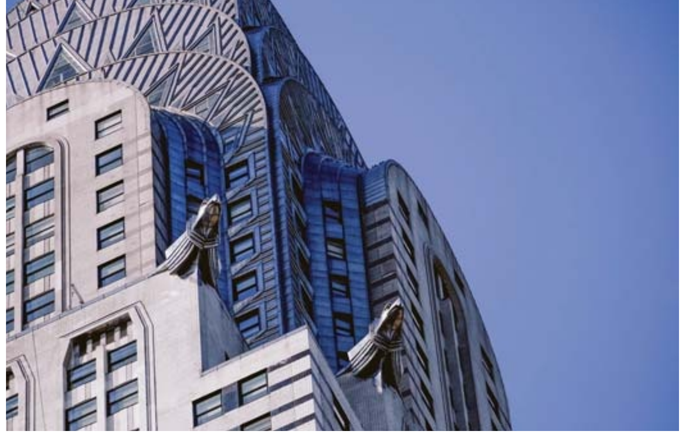
People who know Bonestell primarily as an astronomical artist are often surprised to learn of his architectural background. But Stewart notes that his fingerprints are all over a great number of well-known American buildings, including the Chrysler Building in New York, the U.S. Supreme Court Building, the New York Central Building (now known as the Helmsley Building), and several state capitols. He also was involved in the design of Filoli, the large California estate featured as a backdrop in the TV series *Dynasty*.

“Bonestell’s architectural background gave him a sense of precision, of a connection with the basic laws and rules of how the universe works,” observes Stewart. “He was a master of perspective, and those who really know astronomical art are still dazzled today by how he did things. Although he seemed to have had trouble with mathematics when he went to Columbia University, something clicked later on because he was able to take Wernher von Braun's calculations and convert them into technically accurate paintings that depicted what spaceships would look like and how they would perform. Everything about what he did can be traced back to his architectural background and that fantastic artistic talent he was blessed with."

Bonestell remained an avid amateur astronomer, hence the drive to portray our solar system and the technology of space exploration on canvas. According to Miller, Bonestell was influenced by a number of his peers, most specifically French scientist and illustrator Lucien Rudaux, who shared Bonestell's passion for stargazing.

"As an astronomer, Rudaux was highly regarded enough that there is a crater on Mars named after him," Miller says. "Rudaux brought a sense of matter-of-fact realism to space art that I think appealed to Bonestell, who owned Rudaux's books. There were others who worked in space art, but nobody really paid much attention to the accuracy or the reality of the landscapes. Rudaux brought his knowledge to it and that set his work apart. His paintings had a naturalism to them."

Indeed, on occasion Rudaux's works were even more scientifically accurate than Bonestell's efforts. Miller points to Rudaux's paintings of the lunar surface, which look very much like Apollo landscapes. "Rudaux explains in one of his books, with diagrams, why he made the mountains kind of



▲ **AN EYE FOR MODERNISM** New York architect William Van Alen hired Bonestell to work on designs for what was meant to be a 40-story hotel at 405 Lexington Avenue. The plans for the hotel were abandoned in favor of those for a tall office building, and Bonestell soon became involved with the design of one of the world's best-known skyscrapers, the Chrysler Building. Working with the artist Warren Straton, Bonestell designed the Art Deco façade and the sharp-beaked eagles that project from the corners of the building's 61st floor.

▼ **STEEP AND SHARP** Bonestell's paintings of the lunar surface featured tall, craggy mountains and craters with razorlike rims.

CHRYSLER BUILDING: WILLIAM WACHTER; LUNARSCAPE: CHESLEY BONESTELL PAINTINGS COURTESY OF BONESTELL LLC rolling," Miller says. "He looked through a telescope at the limb of the Moon and saw the mountains in profile, all nice and rolly. Bonestell had these books, but I think he made a wise decision to paint the Moon's mountains the way he did because, frankly, who would want to go to the Moon if it looked like South Dakota?"

In 1920, Bonestell and his second wife, opera singer Ruby Helder, moved to England, where Bonestell took a job with the *Illustrated London News*. He returned to the United States in 1926 and joined architect William Van Alen in designing the Chrysler Building (its famous gargoyles were a Bonestell flourish). Soon after his return to California, he was hired by Joseph Strauss to render the designs of the Golden Gate Bridge. His illustrations delighted city officials and the public alike, and were instrumental in ensuring the massive bridge's construction.

With a letter of introduction from Van Alen in hand, Bonestell next took his talents to Hollywood, where he quickly became one of the film industry's premiere matte painters, making an impressive $1,100 a week. He created the matte painting of the massive Notre Dame cathedral featured in the 1939 version of *The Hunchback of Notre Dame*, and worked with Orson Welles on *Citizen Kane* (producing the matte painting for Kane's palatial estate, Xanadu) and *The Magnificent Ambersons*.

It was producer George Pal, however, who made the best use of Bonestell's skills. Aware of Bonestell's astronomical paintings, he hired the artist to create realistic planetscapes and other pieces for *Destination Moon*, *When Worlds Collide*, *The War of the Worlds*, and *Conquest of Space*, which was based in part on the book of the same title written by Willy Ley, with illustrations by Bonestell. It has been rumored that Bonestell also worked on *2001: A Space Odyssey*. This is untrue, though Michael Benson reports in *Space Odyssey: Stanley Kubrick, Arthur C. Clarke, and the Making of a Masterpiece* (Simon & Schuster, 2018) that director Stanley Kubrick turned to the works of Bonestell, Luděk Pešek, and others for inspiration on how to depict cosmic immensity. In *A Brush with the Future*, Douglas Trumbull, special photographic effects supervisor on *2001: A Space Odyssey*, details how the look of the Moon's surface became a bone of contention between him and Kubrick. Trumbull thought the Moon

▶ **OTHER WORLD VIEWS** *(Top)* Perhaps following Rudaux's lead, Bonestell presented solar system bodies from unusual perspectives. In 1944, *Life* magazine published a series of his paintings that showed Saturn as it might appear from its various moons. The scene here shows the view from Titan, Saturn's largest satellite.

▶ **RETURN TRIP** *(Middle)* The cover of the October 1960 issue of *The Magazine of Fantasy & Science Fiction* featured a reprint of Bonestell's 1959 painting "Unloading Empty Fuel Tanks on the Moon."

▶ **SOOTHSAYER IN SPACE** *(Bottom)* Bonestell's 1949 depiction of the surface of Pluto seems eerily prescient. The jagged, snow-covered features he envisioned aren't so distant from the giant ice mountains revealed by the New Horizons spacecraft in July 2015.

CHESLEY BONESTELL PAINTINGS COURTESY OF BONESTELL LLC (3)

"When Bonestell got involved, things went from intellectual to emotional. He helped move the space program along by giving people the complete idea in a very inspiring way."

would feature soft, rolling hills. Kubrick preferred the craggy, dramatic look of Bonestell's lunar paintings and, of course, that's what wound up in the film.

Science fiction buffs may have been delighted to see Bonestell's contributions to their favorite films, but the general public came to know his name primarily through his magazine work. He painted dozens of covers for popular sci-fi pulps such as *Galaxy Science Fiction*, *Astounding Science Fiction*, and *The Magazine of Fantasy & Science Fiction*, as well as covers and illustrations for the most prestigious general interest magazines of the era. In 1944, for example, *Life* published a series of Bonestell paintings depicting Saturn as seen from its various moons — a view readers had never imagined before. Collaborating with von Braun, he created a remarkable series of paintings for *Collier's* illustrating the future of spaceflight.

"What the *Collier's* series did — as well as all of Bonestell's space art before it — was to show that spaceflight could be done with the technology and materials available then," observes Miller, who knew Bonestell and authored two books about the artist. "All you needed was money to go into space. It was a revelation. Bonestell made spaceflight immediate."

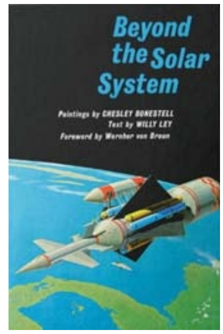
Stewart agrees, noting, "Chesley Bonestell had that unique ability to take scientific data and turn it into something that people could see, understand, and appreciate. Technical people like von Braun and Ley were mathematicians to their core. They had a message and a plan, and I think Bonestell supplied the missing piece that was necessary for people to get the big picture. When Bonestell got involved, things went from intellectual to emotional. He helped move the space program along by giving people the complete idea in a very inspiring way."

Bonestell died on June 11, 1986, an unfinished painting on his easel. Upon the passing of his widow, third wife Hulda von Neumayer Ray, in 1998, his estate fell into disarray because he left no heirs (his daughter, Jane, had died in 1989). "An attorney representing the estate reached out to Fred Durant, who was then the assistant director of aeronautics at the Smithsonian National Air and Space Museum, to inquire just who Bonestell was," Miller reports. "Fred discovered that all of Bonestell's records — albums, tens of thousands of slides and transparencies, awards, sketches — were about to be dumped."

Durant made an offer for everything in Bonestell's studio aside from the paintings, and deposited the extensive archive in Miller's home, where it sat for nearly six years. "I devoted a room to it, but it really needed to be archivally preserved and I didn't have the time or the space for that," Miller says. Durant and Miller eventually found a benefactor in Microsoft cofounder Paul Allen, who formed Bonestell LLC to preserve and promote Bonestell's work and legacy, and handle requests from books and magazines regarding the use of Bonestell's art.

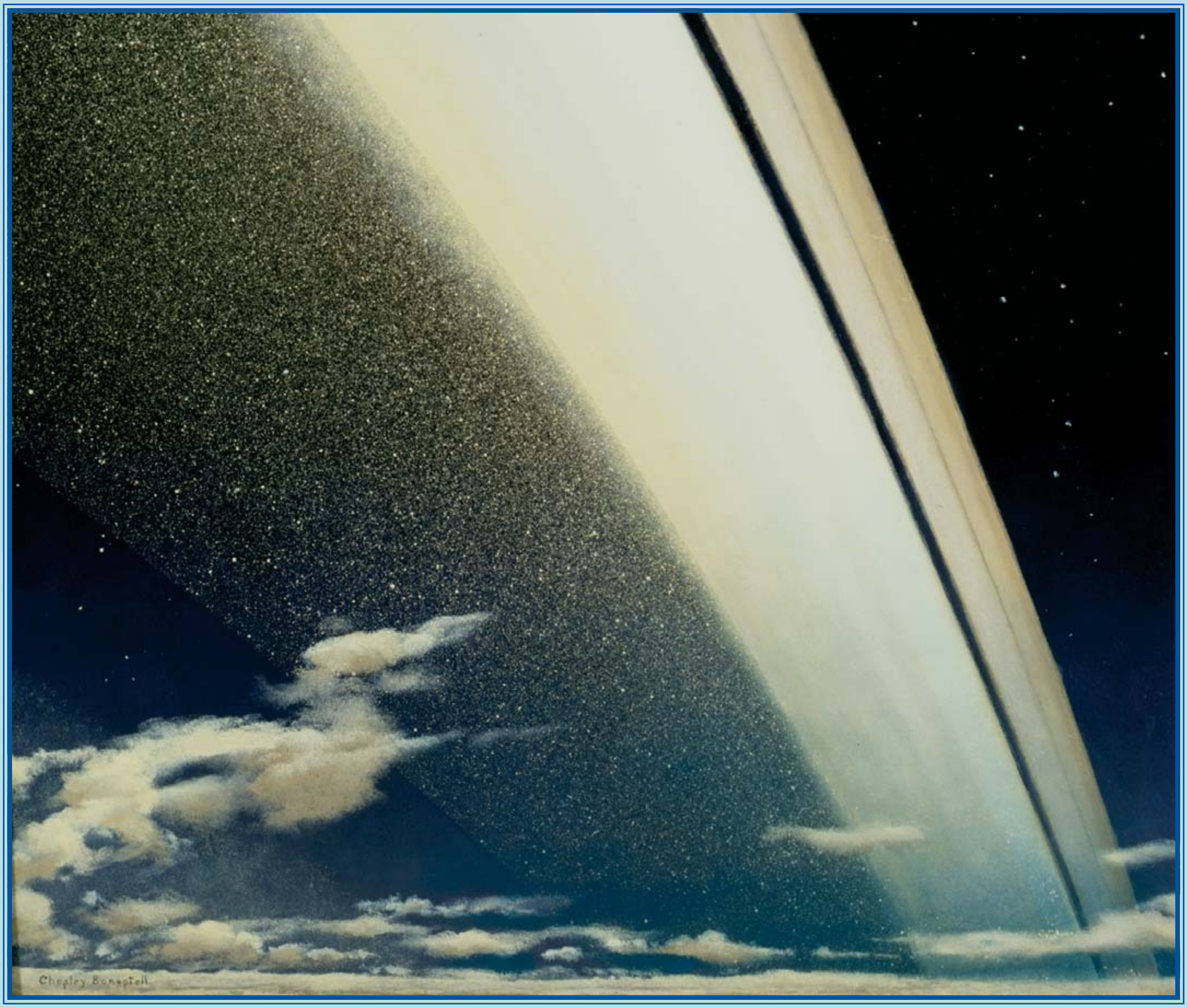
Chesley Bonestell was the rare astronomical artist who lived to see many of the futuristic concepts he illustrated become reality. He was alive when Neil Armstrong and Buzz Aldrin took their first tentative steps on the Moon. While the spacecraft and hardware used in these endeavors may not have looked exactly like the ships and technology he painted,

▼ **MINIMUM WASTE** Like corporations today, Wernher von Braun was concerned with a spacecraft's reusability. Bonestell's 1956 painting shows a landing craft raised into take-off position on the surface of Mars.



▲ **BETWEEN THE COVERS** Bonestell created riveting magazine illustrations, many of which were republished in books. He collaborated many times with author Willy Ley and rocket scientist Wernher von Braun to produce popular astronomy and space science books.

CHESLEY BONESTELL PAINTINGS COURTESY OF BONESTELL LLC (3)



▲ **STAGGERING VIEW** Bonestell's imagination marked his artistic endeavors from the beginning of his career to the end. His 1944 solar system series for *Life* magazine included this memorable view of Saturn's rings as viewed from the planet's cloud deck.

the spirit was there. One must assume that Bonestell felt tremendous pride in the fact that his art played a significant role in our ongoing reach for the stars.

During his life, Bonestell — who Miller estimates created thousands of illustrations and paintings over his career — was awarded a bronze medal by the British Interplanetary Society and inducted into the International Space Hall of Fame. In 1951, his collaboration with Ley, *The Conquest of Space*, won the International Fantasy Award for Nonfiction at the annual International Science-Fiction Festival Convention, or Festivention, in London. After his death, the accolades continued with Bonestell's induction into the Science Fiction Hall of Fame in 2005. He also has a crater on Mars and an asteroid named after him.

"There is something uniquely American about Chesley Bonestell," says Stewart. "He is a testament to the human spirit, not only in terms of creativity and inspiration, but also because he went out and did it. He just kept going, painting in his studio even to his last day. That's a wonderful legacy of an extraordinary life."

■ **DONALD VAUGHAN** is a lifelong sci-fi fan who has appreciated Chesley Bonestell since childhood. His writing has appeared in *Military Officer Magazine*, *Boys' Life*, *Writer's Digest*, and *Artists Magazine*. He lives in Raleigh, North Carolina.

FURTHER READING: To learn more about *Chesley Bonestell: A Brush with the Future*, visit **chesleybonestell.com**.

The ZWOptical ASIair

This device eliminates the need for a laptop when imaging.

▲ The ASIair glows red from its internal LED as it images M42, the Orion Nebula from atop the author's Losmandy Gemini GOTO mount. The tiny computer, pared with a tablet or smartphone, can control up to four accessories, including an imaging camera, a guide camera, a Go To mount, and a filter wheel or focuser. A debayered exposure of M42 appears on the iPad screen running the control app in the foreground.

ALL PHOTOS BY THE AUTHOR

ZWOptical ASIair

U.S. Price: $179.95
astronomy-imaging-camera.com

What We Like

Compact size
Attractive pricing

What We Don't Like

Limited camera compatibility
Connectivity issues

SEVERAL YEARS AGO I reached a milestone in deep-sky astrophotography in terms of comfort and convenience. I bought a USB extension cable and was able to control and monitor my long-exposure imaging while seated in the comfort of my warm, mosquito-free van just a few feet away from my telescope. I was able to monitor the autoguiding by looking out the window at numbers on my ST4's tracking display and see each exposure as it downloaded to my laptop at the end of the USB cable.

Now I've reached another milestone. I can settle into the van and slew my computerized mount to a target, set an exposure sequence, acquire a guide star, and calibrate the autoguider. Within minutes, I'm taking exposures and seeing an auto-stretched preview of each one as it completes. A familiar-looking onscreen graph displays the guiding corrections. And if my imaging involves targeting the same object on multiple nights, I can plate-solve the field and accurately compose the shot to match the scene recorded on earlier nights.

Oh, and that USB cable? Not needed . . . I did all of this wirelessly and without a conventional computer. My laptop stayed in its case. The closest thing to a computer required was an iPad.

Between my gear and my iPad was the ZWO ASIair, a small, wireless USB hub and Raspberry Pi computer that can be operated using an iPhone, iPad, or Android device via a WiFi connection.

On-board Computer

As noted, the ASIair is small and lightweight, measuring just 3¾ × 2¾ × 1 inches. Each corner has a small rubber foot, though the unit is intended to be attached to a telescope OTA or mount using a supplied pair of hook and loop fasteners. The package is so small that it will fit practically anywhere on a scope or mount. Four USB 2.0 ports are located at one end of ASIair as well as an Ethernet jack that enables fast transfer of images stored on the device to your computer after an imaging session. A side-mounted earphone jack and HDMI port is used strictly for "debug" purposes according to the manual.

Even though ASIair is compact, there are lots of features to get to know before an imaging session can begin. Control of the unit is done entirely from your wireless device, as there are no buttons or switches on the ASIair itself. And while the ASIair is capable of record-

▲ *Left:* This small inline voltage convertor supplied with ASIair converts 12 volts DC to 5 volts, providing up to 3 amps to power the ASIair. Velcro on the bottom allows attaching the convertor to a telescope or mount. *Right:* Four USB ports and an Ethernet socket are clustered at one end of the ASIair case. The USB sockets can accommodate an imaging camera, a guide camera, a Go To mount connection, and a filter wheel or a powered focuser. The Ethernet port can be used to download image files to a computer.

ing individual images of the Moon and planets, it cannot record video files, even if the ASI camera used with it is capable of producing them. It's intended for deep-sky astrophotography only.

Wireless control is quite reliable with ASIair, though the WiFi range is fairly limited. The device offers either 2.4G or 5G speeds, with 5G allowing faster data transfer but over shorter distances. Both speeds worked well when I was seated in my vehicle parked next to my telescope, but my iPad would often lose the connection when I was indoors with the telescope just 15 feet outside. ZWO recommends a signal amplifier (WiFi booster) if you experience lost connections. Your controlling device must have 5G compatibility in order to achieve the highest transfer speeds.

Two cables are included with ASIair: a one-meter (39-inch) USB-to-RS232 cable for connecting the unit to a wide range of Go To equatorial mounts and a 50-cm Micro-USB B power cable. ASIair requires 5-volts DC and a small 12-volt-to-5-volt DC transformer is included. Several versions of the *SkySafari* app are recommended to steer your Go To mount to target objects, so be sure your mount is among those that are supported by this app. The list of compatible mounts is fairly long, and I had no problems controlling both my Losmandy G11 mount with its Gemini 2 Go To electronics, and an iOptron Z25 center-balance mount.

The USB sockets are used to connect four devices, including an imaging camera, a guide camera, the Go To mount interface, and either a filter wheel or electric focuser. Although some of the compatible cameras have internal USB hubs, the manual states that each device must have a separate cable plugged into ASIair. This change forced me to modify my usual setup in which my guide camera is attached to an off-axis guider and then connected to my ZWO ASI071MC camera's USB hub using a short USB cable. A longer USB cable was required for the greater distance between the camera and ASIair.

Although image acquisition is controlled from your iOS or Android device, the actual image files are saved to an included 32-gigabyte MicroSD card inserted in a slot at one end of ASIair.

The MicroSD card is the "hard drive" of the ASIair and contains its operating system software as well as 25 gigabytes of storage space. A keyword that should be associated with this MicroSD card is fingernail — the card is as small as one, and you'll need a certain amount of fingernail length to remove it from the ASIair card slot.

After imaging, you can transfer your images to a computer for post-processing using the Ethernet connection, or by removing the tiny card and inserting it into a supplied USB card reader. Although removing the card from the unit is rather easy, the MicroSD card slot on ASIair requires particular care when inserting the card back into its slot. A space between the card slot and the ASIair case makes it easy to miss the card slot and slide the card directly inside the ASIair housing. This happened twice when I attempted to reinsert the card. I was eventually able to get the card to fall out without opening the case by shaking the unit. Afterwards, I made sure to wear my reading glasses so I would be sure to *precisely* insert the card correctly.

The manual recommends backing up the card in case it is lost or corrupted, but a better suggestion may be to purchase an additional card or two

◀ The ASIair basic package includes the unit seen at center, as well as the 12V-to-5V DC Convertor and cables (far left). A 32-gigabyte MicroSD memory card (top) is where the operating software and up to 25 gigabytes of images are stored. The USB card reader to its left permits offloading images to a computer. The ZWO ASI120MM Mini autoguider (middle right) is also available as part of a bundled kit totaling $318. The author's ZWO ASI071MC is seen to the upper right.

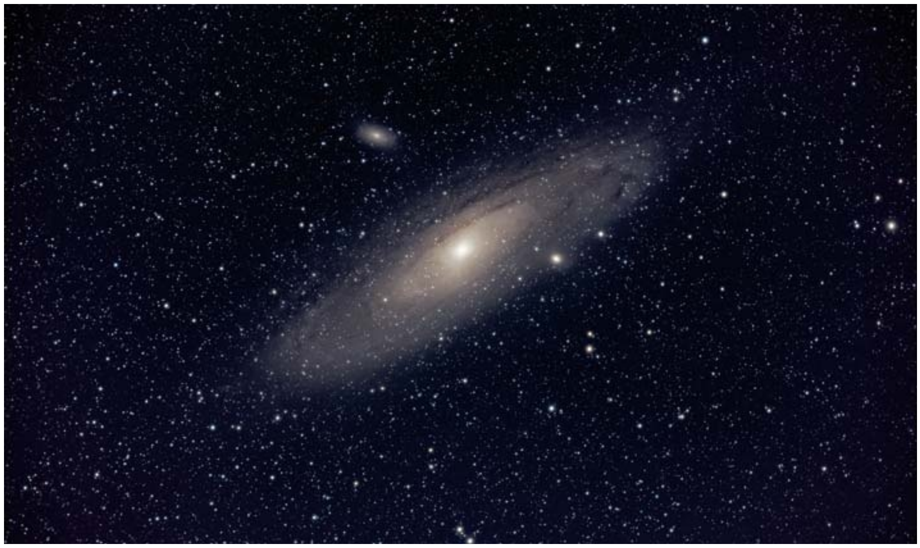
and have them ready to use in case the first card is lost, as they are inexpensive. Imagine being out at a remote site and removing this tiny card, only to drop it in thick grass in the dark. You would be without both the software to run your ASIair imaging setup and storage space for your images. This scenario fortunately never occurred while I was testing the ASIair, but I couldn't help thinking it was only a matter of time.

ASIair has some rather narrow compatibility requirements when it comes to imaging cameras and especially guide cameras, though more cameras are compatible with more recent releases of the ASI software. Even if you already have an ASI camera, ASIair compatibility is limited to the ZWO ASI USB 3.0 cameras. Other brands, and even ZWO's own ASI USB 2.0 cameras, are incompatible as main imaging cameras. A software upgrade in May 2019 allows the use of Nikon and Canon DSLR and mirrorless cameras with ASIair. After installing the update, I was able to successfully link to and control my Nikon cameras using the ASIair's control app.

An even shorter list is associated with compatible guide cameras, as they too are limited to the manufacturer's own models, though not all of them. Currently only ZWO's Mini USB 2.0 guiding cameras can autoguide with ASIair. The *ASIair* app wouldn't see my Starlight Xpress Lodestar X2 guide camera.

I used my main one-shot color camera, the ZWO ASI071MC as the imaging camera with the ASIair capability, and

▼ The Micro-USB power input jack on ASIair was prone to power disconnects. An HDMI jack at right is stated to be intended for "debugging" purposes.



▲ Attached to an iOptron Z25 mount, the ASIair executed all the exposures to produce this shot of M31 using an ASI071MC and an ASI120MM Mini guide camera.

ZWOptical provided an ASI120MM Mini guide camera for my tests (an option offered as a packaged bundle for $318). I found the small 120MM camera very sensitive and easy to operate. The guider's chip is located very near the front of the camera's housing, which permits the unit to easily come to focus in my off-axis guider and all my guidescopes.

Setting Up

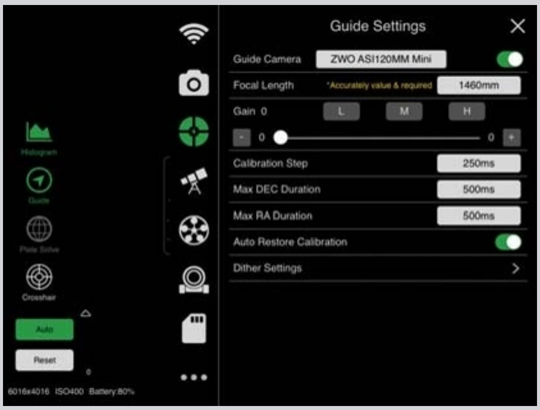
Assembling the ASIair for the first time is very straightforward, but its imaging sequence routine takes some getting used to. ZWOptical has an online manual and several tutorial videos on the company's website showing its operation as well as a Facebook page where representatives answer tech-support questions. I highly recommend checking them out as you learn to use ASIair. The most recent software upgrade features pop-up messages as soon as the app is opened that inform users what each on-screen feature does — a big help to get you going. The drawback is that these helpful pop-ups dissappear after your first use of the app.

The first step is to download the free *ASIair* app to your Apple or Android device, and, as mentioned above, you must also have a compatible *Sky Safari* planetarium app capable of controlling your specific mount.

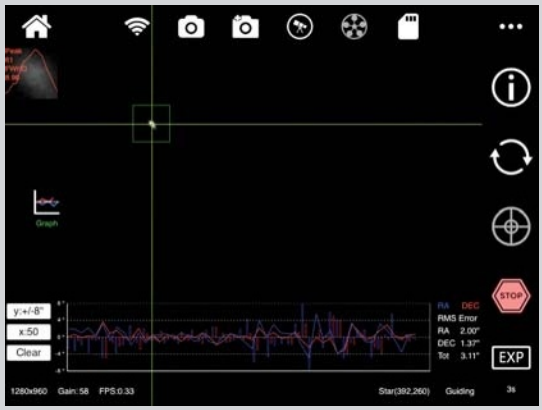
Plug in the USB cables from your main imaging camera, guide camera, and Go To mount into ASIair's USB ports. Connect the 12-volt DC power supply plugs into the jack on the 12V-to-5V convertor, and the Micro-USB B cable goes from the voltage convertor into the ASIair unit itself. A red LED on ASIair activates, confirming

▼ The supplied 32-gigabyte MicroSD is inserted into a slot on the underside of ASIair. *Inset:* Use caution when inserting the card into its slot, because it can slip between the reader and outer casing. The author recommends purchasing several additional cards as backups.

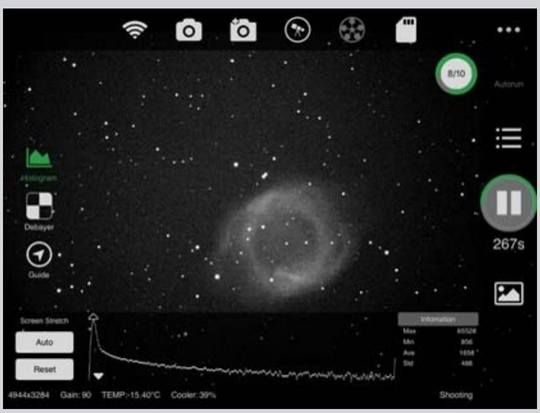
◀ The control app *ASIair* for both iOS and Android devices is just as it states, "as easy as 1, 2, 3." Upon launching the app, you are first prompted to connect to the device through a WiFi connection. After that, simply select each of your cameras, the mount, a filter wheel, and focuser by clicking each icon along the top of the screen.



▲ Clicking the guiding icon opens the autoguider settings, where the guide camera is selected and specific details are input, including the focal length of your guide scope or off-axis guider. Selecting the Auto Restore Calibration switch will permit the app to recall the last guiding settings used.



▲ Once the autoguider is calibrated, select the crosshair icon at the right, click on a star in the autoguider preview screen, and click the start button, and the unit will begin guiding. A helpful graph plots its corrections at the bottom of the screen.



▲ Much like shooting with a traditional computer or laptop, the *ASIair* app displays each exposure after it is completed. A green outline grows clockwise around the exposure button (right) to show the progress as frames in the programmed series are completed.

▲ The app includes an extremely handy plate-solving feature that helps you recompose images when targeting the same object over multiple nights.

▲ This image of IC 1805 in Cassiopeia consists of ten 600-second exposures made with the setup seen on page 66.

the unit is receiving power. After about 15 seconds, the WiFi activates and is detectable by your tablet or phone. In darkness the LED also lights up the entire ASIair case with a gentle red glow.

Select "ASIair" in the list of available WiFi connections on your device and launch the *ASIair* app. Along the top of the screen is a series of setup icons: main camera, guide camera, mount, filter wheel, SD card, and three dots which open more connections, including a focuser icon. Click through each and enter the specifics of your equipment. For example, click the telescope icon to select your specific Go To mount and initiate its connection. You can then use *SkySafari* to slew to targets.

Once everything is connected, click on Preview at the right of the screen, which opens the operations area of the app, containing the Focus, Preview, and Autorun commands. Focus the image from the main and guide cameras by monitoring the peak values and FWHM readings. Once focus is set, open the guide settings on the left side of the screen and calibrate the autoguider. This section of the app appears very similar to the popular *Phd2* guiding program with its camera connection interface and graph showing guide corrections.

When all devices are communicating with the ASIair and autoguiding is operating, you can then program and execute an image sequence.

As each exposure completes, the file is saved in FITS format to the MicroSD card. You can preview images in the app, which contains an automatic Screen Stretch function (and automatic debayer feature, if you're using a color camera) that displays a very compelling preview of your shot.

▼ ZWOptical offers the ASIair paired with an ASI120MM Mini guide camera, a sensitive guider with a 1,280 × 960-pixel CMOS array.

One of the few problems I had with ASIair involved an intermittent connection at the Micro-USB B power jack on the unit. The ASIair would sometimes lose power due to this apparent loose connection, resulting in the freezing of the app and subsequent restarting, occasionally rebooting the device itself. I added a cable tie near the jack to prevent undue movement of the plug in the socket, but this helped only marginally. Perhaps the device requires a sturdier power jack design? WiFi connection was occasionally lost when moving around the mount with my iPad. The 5G connection, while giving fast transfer speeds, was most susceptible to disruptions caused by objects between the ASIair and the operating device.

A warning for users with older tablets: The app would occasionally lock up as a full-resolution, debayered image from my ASI071MC's 16-megapixel detector was downloading when controlling the device with my old second-generation iPad. Deselecting the debayer option eliminated the problem, as did downloading smaller region-of-interest images in full color. Testing with a more recent iPad eliminated this problem.

Summing It All Up

Does a device like ASIair mean that I forget about my more conventional deep-sky imaging setups and procedures? That's a personal choice each imager can make. I can say that once I got everything up and running it took very little time to learn to navigate the *ASIair* app and make my mount, guider, and imaging camera do everything it could do when using a computer. I quickly became accustomed to its layout and operation.

The ASIair is a small package with high-tech capability costing less than the cheapest laptops on the market today. It should be of particular interest to astrophotographers who travel to dark-sky sites, as well as to beginners more familiar with apps and tablets. And while connectivity and compatibility issues were annoying, my advice there is to stay tuned — ZWOptical has more planned improvements for the device, including the support of additional cameras and mounts.

■ Contributing Editor **JOHNNY HORNE** often reviews imaging equipment for *Sky & Telescope* from his home in Stedman, North Carolina.

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Bartol's Beefy "BlueShift"

Here's a mount with Go To technology designed from scratch.

MANY AMATEUR TELESCOPE MAKERS have built their own equatorial mounts. Indeed, in the days before the Dobsonian revolution, German equatorial mounts were the most common type for amateur telescopes. They tended to be made from pipes and other plumbing parts.

When Southern California amateur Thomas Bartol made his first telescope, a 10-inch f/5.6 Newtonian in 1986, he built a machined-aluminum equatorial mount for it and used it to successfully view Halley's Comet. He also became enamored of Jupiter and particularly its moon shadow transits, which he had never heard of before witnessing one unexpectedly.

His homemade mirror turned out to be very good, about 1⁄20th wave, and provided such excellent views that Tom quickly felt the urge to record those views photographically. However, even his better-than-average mount wasn't stable enough for serious astrophotography. "Though I could have purchased one of the very good mounts available to amateurs at the time, I've always been a maker," Tom says. "So, starting in 1999, I began a long-term quest to design and build my own robotic telescope mount."

Note the word "robotic" there. That's right: Not only did Tom decide to build a tracking mount stable enough for photography, he decided to computerize it, too. I can count the number of people I know who have done that on the fingers of one hand, with a couple of phalanges left over.

Tom reports, "At the outset neither I (nor my loving and patient wife!) had any inkling of the 18-year journey: the friends I would make, the machine shop I would build, the lathe I would restore, what I would learn, or how much my passion would grow along the way (and infect others around me!)." But he stuck with it, and he wound up with the gorgeous — and massive — mount you see here.

The mount, which he calls "BlueShift," weighs in at 300 pounds. That's a bit much to carry around, so Tom built a hand-cranked forklift to load the equatorial head in and out of his vehicle and wheel it from the vehicle to the observing site.

▲ Tom poses in the machine shop where he built his mount.

◀ Tom Bartol's "BlueShift" German equatorial mount is a wonder of design and engineering.

▶ **(A)** The mount started out as a pile of raw steel and bronze. **(B)** This rough bronze plate became a precision worm gear. **(C)** The worm gears require precision cutting to minimize tracking errors. **(D)** Tom's fine machining is evident in every part of the mount.

ALL PHOTOS BY TOM BARTOL

What makes it so massive? The size of the parts, for one. The right ascension axis uses an 11.5-inch bronze worm gear with 576 teeth, and the declination axis incorporates a 9-inch worm gear with 450 teeth. (He designed and machined both in his own shop.) The axle shafts, outer case, counterweights, and mount base are all machined from stainless steel. Brushless DC motors direct-drive the worm shafts on each axis, with servo feedback provided by an optical shaft encoder having 40,000 pulses per revolution.

That alone is a machining marvel, but Tom then proceeded to computerize the whole thing, using a small Raspberry Pi for a controller, industrial pic-servo motion control boards from Jeffrey Kerr LLC (**jrkerr.com**), and an Ultimate GPS module. He wrote the control software in *Python* and has made it all available as open source on **GitHub.com**. *SkySafari* running on a smartphone connects to the robotic controller over WiFi to provide touch-screen control of all Go To functions.

A mount this hefty requires a hefty tripod. Tom uses a Software Bisque Paramount Pyramid Portable Pier. As Tom says, "You can't be too solid for astrophotography."

So how does this magnificent concert of machining and electronics perform? Like a dream. Tom took it to Smith's Ferry, Idaho, to view the total solar eclipse of 2017, with photographic results seen below at left. Plus he has imaged many other deep-sky objects, and the mount performs beautifully.

It took 18 years from start to finish, but the experience has been one of constant reward. Of his long journey, Tom says, "It's interesting to note that when I began in 1999, many of the technologies that have made my project such a success did not yet exist."

And now, thanks to Tom's persistence and adaptability, BlueShift not only exists, but excels and astounds. When I jokingly noted that this mount could probably make a Volkswagen track if you could just bolt it on, Tom's response was, "The angular contact bearings on the right ascension axis are rated at over 16,000 pounds static load each, so a Volkswagen would be too easy!"

I'm gobsmacked. Anybody have a spare Hubble to put on this thing?

Watch a video of Tom assembling BlueShift at **https://is.gd/blueshift**.

Contact Tom at **t.m.bartol@gmail.com**.

■ Contributing Editor **JERRY OLTION** would supply the Volkswagen just to watch it happen.

▲ The Go To controller is built around a small Raspberry Pi computer.

◀ Tom photographed the 2017 solar eclipse with his homemade 10-inch Newtonian on his homemade equatorial mount.

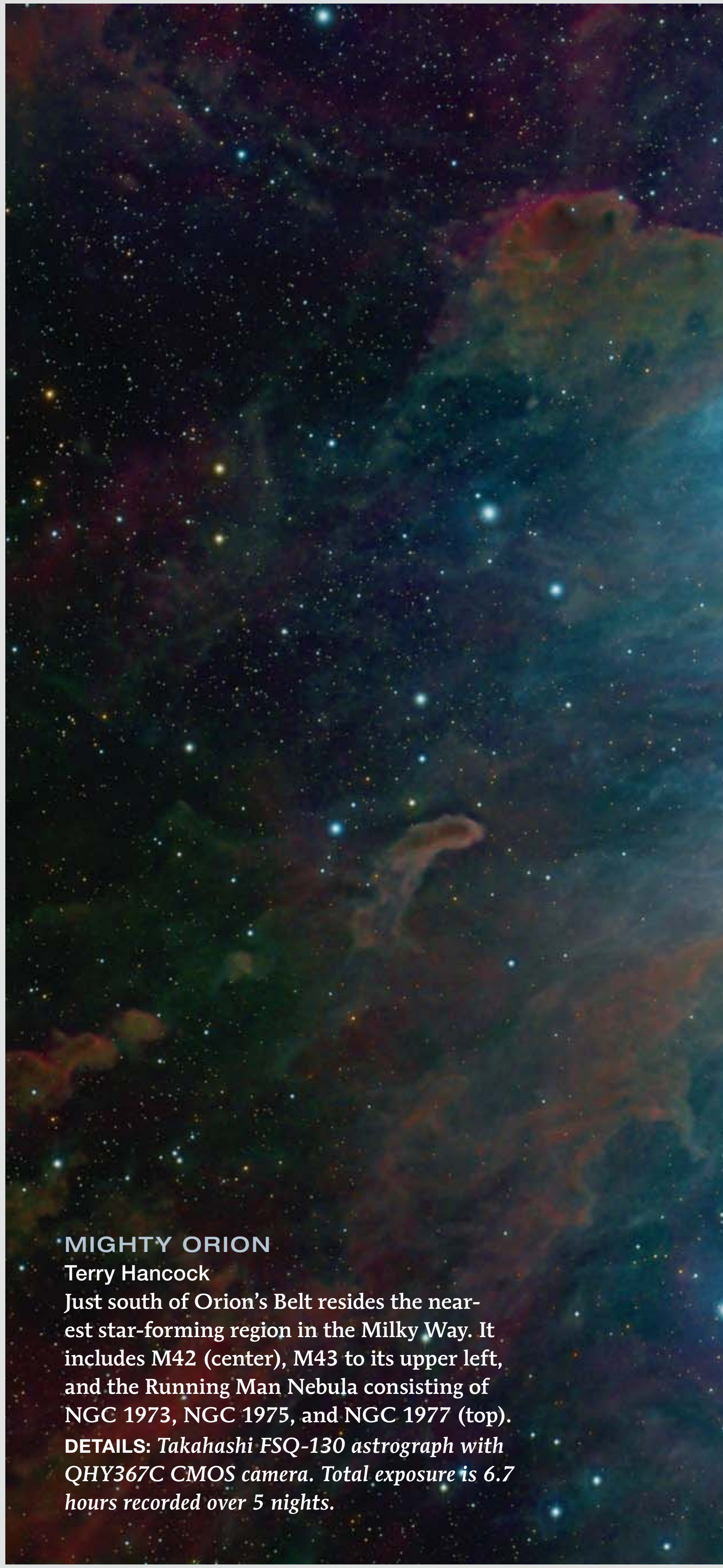
▶ The mount is too heavy to carry, so Tom built a forklift to move it.

▽ LUNAR SPLENDOR

Jason Weathers

The young crescent Moon seen here sports several large features just visible to the naked eye. Mare Crisium is seen at upper right, with craters Atlas (top), Gutenberg (middle), and Janssen (bottom) just emerging into daylight along the sunrise terminator.

DETAILS: *Celestron SP-C6 6-inch Newtonian reflector with RisingTech G3-6300KMA video camera. Stack of 839 frames from a one-minute video recorded on June 6th.*



MIGHTY ORION

Terry Hancock

Just south of Orion's Belt resides the nearest star-forming region in the Milky Way. It includes M42 (center), M43 to its upper left, and the Running Man Nebula consisting of NGC 1973, NGC 1975, and NGC 1977 (top).

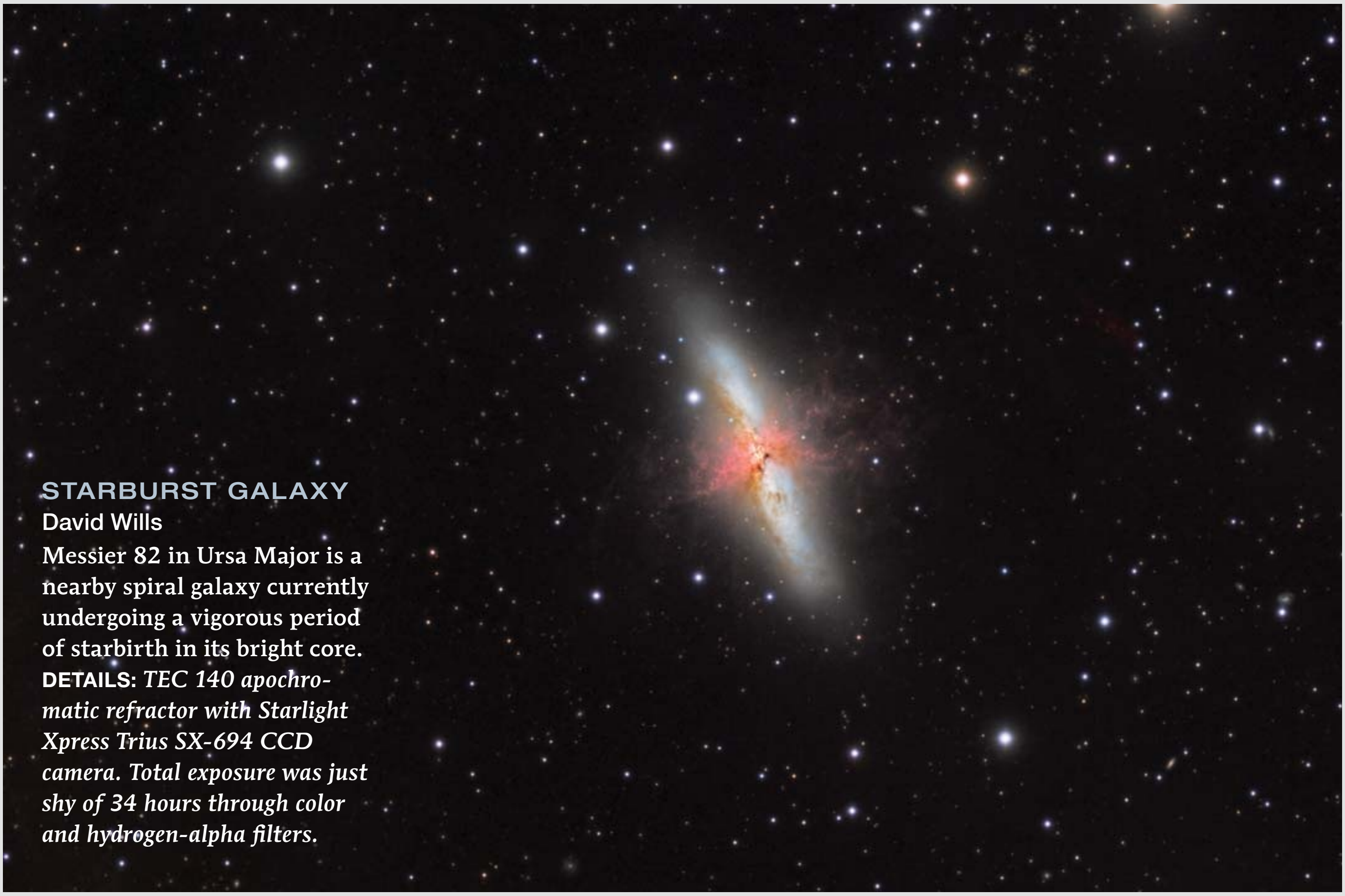
DETAILS: *Takahashi FSQ-130 astrograph with QHY367C CMOS camera. Total exposure is 6.7 hours recorded over 5 nights.*

▷ WISPY COLORS

Leonard Higgins

This brilliant iridescent cloud made a brief but picturesque appearance over Napa, California, in the morning hours of May 13th.

DETAILS: *Canon PowerShot G16 point-and-shoot camera with integrated zoom lens. Exposure was 1⁄2000 second at 14 mm, ISO 80.*



STARBURST GALAXY

David Wills

Messier 82 in Ursa Major is a nearby spiral galaxy currently undergoing a vigorous period of starbirth in its bright core.

DETAILS: *TEC 140 apochromatic refractor with Starlight Xpress Trius SX-694 CCD camera. Total exposure was just shy of 34 hours through color and hydrogen-alpha filters.*

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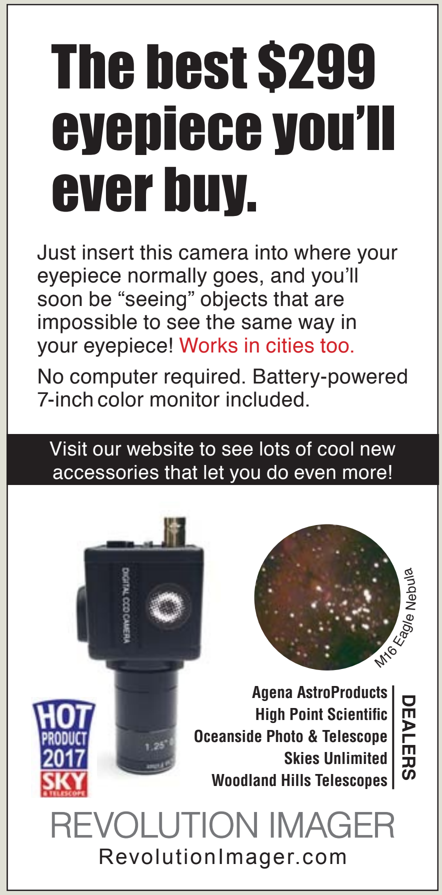

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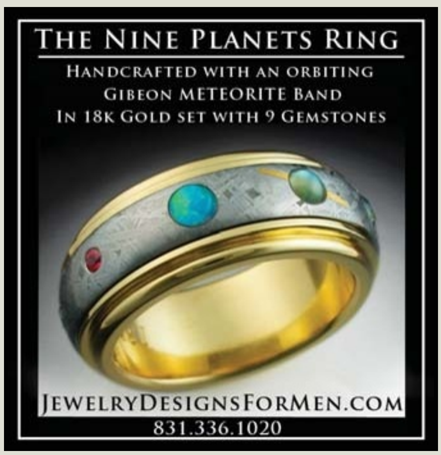

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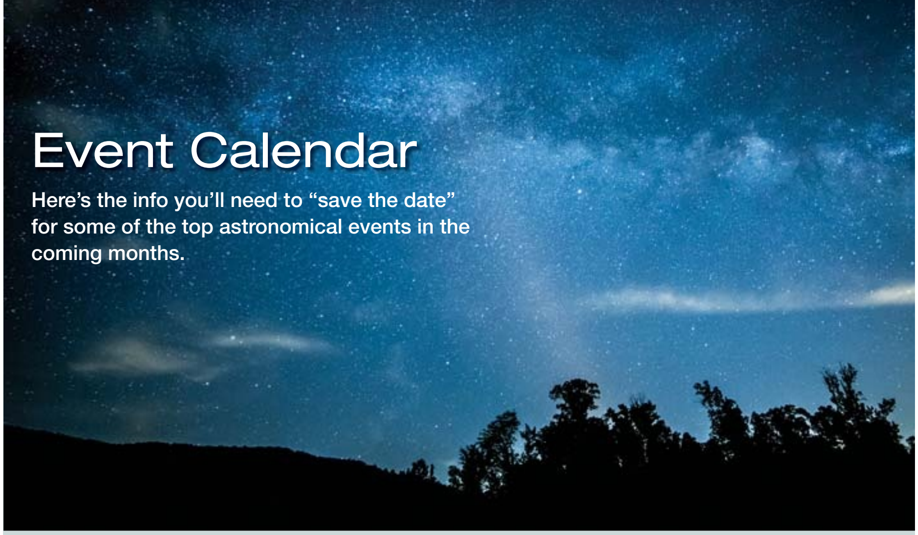

Event Calendar

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

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

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

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

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

August 22–25
STARFEST
Ayton, ON
nyaa.ca/starfest.html

August 24–31
MERRITT STAR QUEST
Merritt, BC
merrittastronomical.com

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

September 19–22
RTMC ASTRONOMY EXPO
Big Bear City, CA
rtmcastronomyexpo.org

September 21–29
OKIE-TEX STAR PARTY
Kenton, OK
okie-tex.com

September 26–29
GREAT LAKES STAR GAZE
Gladwin, MI
greatlakesstargaze.com

September 27–29
EASTERN IOWA STAR PARTY
Dixon, IA
https://is.gd/EIowa

September 27–29
BLACK FOREST STAR PARTY
Cherry Springs State Park, PA
bfsp.org

October 20–27
PEACH STATE STAR GAZE
Deerlick Astronomy Village, GA
atlantaastronomy.org/pssg

October 21–26
ELDORADO STAR PARTY
Eldorado, TX
eldoradostarparty.org

October 21–27
STAUNTON RIVER STAR PARTY
Staunton River State Park, VA
chaosastro.org/starparty

October 22–26
ENCHANTED SKIES STAR PARTY
Magdalena, NM
enchantedskies.org/essp

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

STEPHEN RAHN

No More Worlds to Conquer?

It's time for advanced amateurs to think more like professionals.

Amateur astronomer Dave Jurasevich discovered the Soap Bubble Nebula in 2008.

T. A. RECTOR / UNIVERSITY OF ALASKA, ANCHORAGE AND H. SCHWEIKER / WIYN AND NOAO / AURA / NSF

RECENTLY I HEARD FROM A disheartened astrophotographer. After mastering deep-sky imaging with amateur equipment, he came into some money and bought a professional-grade setup, with a large Schmidt camera and a top-quality mount. He was taking beautiful images of nebulae and galaxies but found himself exhausted, bored, and frustrated.

Part of his problem was the time commitment. No longer limited by his equipment, he was spending 40 hours accumulating sub-exposures for each image, then many hours processing them. And although his pictures were gorgeous, they were just like the best pictures taken by others. What, he wondered, was the purpose?

The answer, I said, was to change direction and think more like a professional astronomer.

In the 20th century, amateurs and professionals pulled apart. Professionals had special photographic plates, autoguiders, photometers, and (later) CCD cameras, while amateurs made do with film SLRs. It was impressive when amateur pictures showed anything at all. Once bigger telescopes became affordable in the 1980s, many of us took the "aesthetic path" and just enjoyed the wonders of the sky with our eyes and cameras, no longer trying to contribute anything to scientific inquiry.

It's time to turn back to science. Sure, we can all take amazing pictures. But for the first time since the Victorian era we also have access to celestial objects not well known to science and opportunities to make real discoveries.

Step 1 is to budget your time and effort. Few amateur astronomers can afford to become full-time, unpaid professionals like Percival Lowell. Good equipment doesn't obligate you to spend all your time observing. Adopt specific projects so you don't feel compelled to observe *everything.*

Step 2 is to connect with people and sources of information. Contact a nearby university's astronomy department and let them know you have advanced equipment and skills. Join an organization that coordinates amateur scientific work such as the AAVSO (**aavso.org**), ALPO (**alpo-astronomy.org**), or BAA (**britastro.org**). Learn to use professional tools, such as NASA's huge, searchable astronomy library at **ui.adsabs.harvard.edu**, and SIMBAD, an online encyclopedia of deep-sky objects at **simbad.u-strasbg.fr**.

Step 3 is to plan projects. One option is to *map and explore.* Little-known deep-sky objects are within your reach. Faint emission nebulae and dark nebulae are obvious targets. Amateur Giuseppe Donatiello recently discovered a dwarf galaxy as a smudge on his picture of a field in Andromeda (*S&T:* Mar. 2019, p. 9). Consider also galactic cirrus (*S&T:* Apr. 2019, p. 57), also known as integrated flux nebulae, which amateurs regularly photograph but no one has yet adequately mapped.

Another is to *patrol for changes.* Image the same area repeatedly and look for novae, variable stars, asteroids, and other transient objects. Some variable nebulae await discovery, and distant galaxies often host supernovae.

A third option is to *advance the technology.* Although our equipment works well, we can still invent optical and electronic tools and especially software. Things as basic as autoguiding algorithms remain on the frontier of development. Software needs to be bundled and integrated, too (see, for example, **astronomylinux.ap-i.net**, an amateur project).

The fruit of your efforts could enhance many people's enjoyment of the sky. And who knows? Along the way you might just light upon something no one else has ever seen.

■ **MICHAEL COVINGTON** is author of *Digital SLR Astrophotography* and other books. By day he develops natural language processing software in Athens, Georgia.

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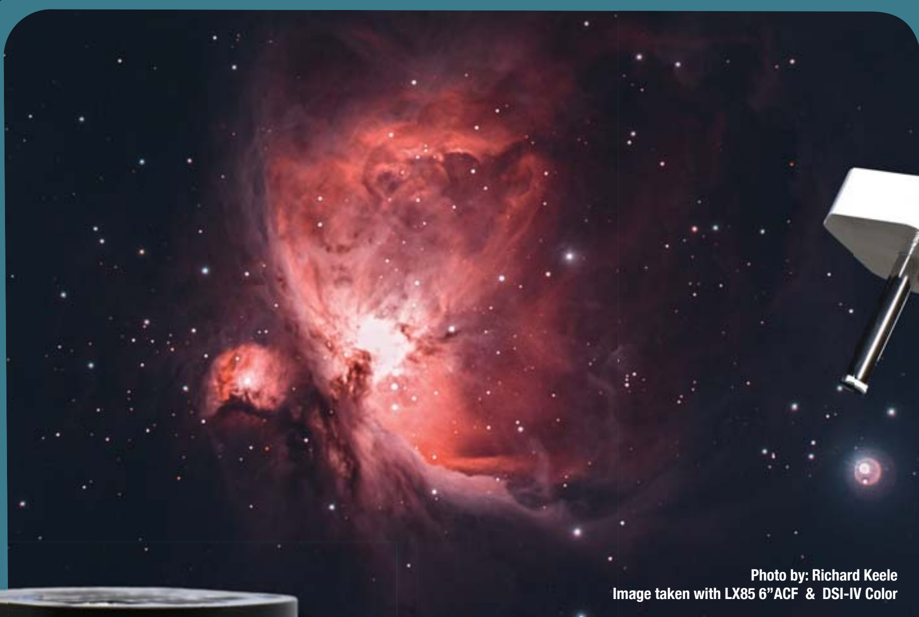

Photo by: Richard Keele
Image taken with LX85 6"ACF & DSI-IV Color

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