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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

August 2018 VOL. 136, NO. 2

RICHARD S. WRIGHT, JR.

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ON THE COVER

A series of stellar pulses likely launched the Cat's Eye's shells.

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The People's Eclipse

TOTAL SOLAR ECLIPSES CAN BE privileged affairs. Only those with the means could observe the 2016 eclipse that swept across Indonesia and the Central Pacific — unless they lived there — or the 2015 eclipse that swung up the North Atlantic between Greenland and continental Europe. The same will hold true for the next three total solar eclipses, in 2019, 2020, and 2021, which for viewing will require being on a ship in far southern seas; on remote land in Chile, Argentina, or Antarctica; or on a dedicated eclipse flight (arguably the most exclusive of all).

But last summer's Great American Eclipse was for everyone. Yes, it was only visible in the United States, but no matter where you found yourself in the country that day you could enjoy at least a partial eclipse. As Alex Young notes in his article on science conducted during and after the eclipse (page 14), tens of millions witnessed totality and perhaps 100 million saw a partial. That puts it in the running as the most-watched eclipse in history.

Totality as seen from Glendo, Wyoming on August 21, 2017

But it was more than that. Its accessibility enabled everyday people to participate in science to a degree unprecedented during an eclipse.

Citizen science ranged across the board that summer day. More than 10,000 volunteers contributed to the GLOBE Observer program, using a custom smartphone app to take photos and record weather data during the event. As part of NASA's Eclipse Ballooning Project, 55 teams of high-school and college students released weather balloons that captured the first-ever live video footage of an eclipse — from 100,000 feet. For the Citizen CATE effort, crews operating more than 60 telescope rigs along the path of totality shot images of the Sun's corona for an upcoming "movie" of the corona's evolution. Two other groups monitored how the eclipse altered radio transmissions. (See more details on all these endeavors in Young's article.)

Some amateurs conducted their own experiments. Don Bruns successfully reprised Arthur Eddington's historic test of relativity during the 1919 total solar eclipse (page 22). Don's narrative includes a sidebar by his twin brother Ron, who investigated whether the sky close to the totally eclipsed Sun became, as Edmund Halley had claimed way back in 1715, bluer. See also Fred Myers's nostalgic temperature study (page 84), a repeat of measurements he'd taken 45 years before during an eclipse on Prince Edward Island.

All in all, the dazzle of August 21, 2017, was as ecumenical an eclipse as one could imagine. It probably got more people in this country to "look up" than any other astronomical event in American history. From that perspective, the one in 2024 can't come soon enough.

Peter

Editor in Chief

SEAN WALKER / *S&T*

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If you...
Lvoe a chalnelge you wlil lvoe atsphrotophgray
Are you an astrophotographer in waiting?
Capturing stunning pictures of the night sky is hugely rewarding. But there's more to astrophotography than just taking pictures - it's about optimising your equipment, tuning the tracking of your mount and bringing all the components together with a single control software. It's also about sharing the tips and tricks you pick up along the way, and showing friends and family the incredible images you've captured.
Our powerful cameras and intuitive software make astrophotography accessible without compromising on the freedom and flexibility you need to make your setup your own. After all, its up to you to find the best way to image with your equipment from your site.
Astrophotography can be a challenging hobby - it's not easy to capture faint objects hundreds of thousands, or even millions of light years away. That's why our beginner-friendly cameras and live-stacking software help to get you started on your journey. When you are ready, you can push yourself and your set up to the limit with our sensitive, cooled CCD cameras. Is it time you rose to the challenge?
ATIK
CAMERAS
Guiding discovery
Image credits: Simon Großlercher

Diamond Ring Effect

I've been doing street-corner astronomy in downtown Baltimore for 30 years. Thousands of passersby have peered through my 8-inch Meade telescope at the Moon, Jupiter, Saturn, and more. I've recruited dozens to the hobby and, I hope, at least a few to the science. But on April 6th I had a first: I presided over the marriage proposal of Morgan Ritter to Elizabeth ("Libby") Nichols.

The two of them had looked at Jupiter through my scope on their first date — an event significant enough for Morgan that he wanted to propose at my scope, and he had a plan.

As he envisioned it, Libby would look for Jupiter through the scope (in this case my 3-inch refractor) and see nothing. Then I would lean into the eyepiece and say, "You don't see it? It's very bright." She'd look again and still see nothing (because I'd leave the lens cap on). At this point Morgan would hand her a little telescope he had fashioned so that when she looked through it she would see a screen on which was printed "Will You Marry Me?"

Long story short, Morgan's plan worked perfectly, including winning a big "YES!" from Libby.

Herman M. Heyn • Baltimore, Maryland

▲ A relative of Morgan Ritter and Libby Nichols captured this example of a sidewalk astronomer practicing a little "street-corner engagement."

Going Through a Phase

Jerry Oltion's "Big, Bold, Bright, and Beautiful" (*S&T:* May 2018, p. 22) was perfect for visual observers like me. I've been doing visual astronomy for about 18 years, and I'd say that I fit simultaneously into several categories. I'm still in the intermediate phase, looking for more targets and more challenges. I'm a deep-sky hunter on nights when I set up in a dark sky at my cabin near Palomar Mountain. And some nights I'm just a tourist, looking for lovely objects.

Thanks for the article, I'm looking forward to more like it.

Mike Bertin
Irvine, California

Cosmic Recipe

In "The Dark Energy Enigma" (*S&T:* May 2018, p. 14), a graphic shows the actual distribution of the three components of the universe: baryonic matter, 5%; dark matter, 26%; and dark energy, 69%.

However, all that represents only one portion of the observable universe. Indeed, the two most abundant particles, photons and neutrinos, don't appear in this graphic. These particles don't have mass (or perhaps it's infinitesimal, as in the neutrino), but they do have energy.

Albert Einstein told us: $E = mc^2$. Thus, these photons and neutrinos should count for a certain percentage in the balance of the universe. So besides baryonic matter, dark matter, and dark energy, there should be a fourth category for "bright energy": gathering the equivalent in mass of the energy conveyed by the photons and neutrinos.

What is the explanation for this "omission"?

Francis Humbert
Lunéville, France

Camille Carlisle replies: *The omission of neutrinos and photons is intentional: they don't have enough of an effect to be included. Percentage breakdowns vary slightly depending on the source, but if we go by Figure 16 at https://it.ly/2InZwPr, then in today's universe neutrinos contribute 0.1% and radiation contributes 0.005%. Thus, astronomers generally exclude them from the energy-mass density breakdown.*

Maya and Meteors

Your article on the relation of a Maya king's accession to a 6th-century meteor shower (*S&T:* Apr. 2018, p. 36) reminded me of an amazing sight my wife and I witnessed on March 13, 1989. We were camped on the shore of the Usumacinta River in the midst of ruined Maya cities. My small shortwave radio had already warned us that a powerful solar outburst was on its way to Earth. As soon as dusk fell, the night sky above the opposite bank was lit up with a beautiful orange and green aurora borealis. As we watched, a brilliant meteor shot across the display, dropping sparks.

What would the ancient Maya rulers and astronomers have made of this astounding, once-in-a-lifetime event? If they'd seen it, they might have recorded it in the inscriptions. But we'll probably never know.

Michael D. Coe
Professor of Anthropology, Emeritus
Yale University
New Haven, Connecticut

Hawking Remembered

I appreciated your remembrance of Stephen Hawking (*S&T:* June 2018, p. 11), yet it didn't capture the shock I experienced when I first read about his work

BEN NICHOLS

in your magazine (Aug. 1977, p. 84).

For many — maybe most — there have been dramatic events in life for which we remember exactly where we were and what we were doing. For me they include JFK's assassination, Tranquility Base, the fall of the Berlin Wall, and 9/11. And reading about Hawking — I can see it exactly.

General relativity, quantum mechanics, and thermodynamics: three independent bodies of physical theory. Hawking combined the first two, and the results looked like the third. It was completely stunning. Even to a chemistry student like me this was obviously deeply profound.

Bob Wieting
Simi Valley, California

Hot or Not?

The advertisement for Stellarvue's SV152T telescope (*S&T:* Apr. 2018, p. 5) proudly proclaims that it is a "*Sky & Telescope* Hot Product 2018." I went to the company's website to learn more and found that the first ones won't be available until December 2018.

I think you should review the guidelines for what determines a Hot Product. I would think that a Hot Product should actually be available. The Stellarvue scope is awesome and probably deserving of an award, but Hot Product is just a tease.

Larry Metcalf
Columbia, South Carolina

Vic Maris, President of Stellarvue, replies: *I realize now that our website makes it appear that the SV152T won't be available until December, but that's not the case. These telescopes are being delivered, but the waitlist is long. If you order one now, it might be December until you get it.*

The SV152T is individually hand-crafted in our California shop, and the time it takes to perfect each surface of each element varies widely. We fill orders entirely on a first-come, first-served basis, and our scopes are often waitlisted. So thanks for the opportunity to clarify what the date means. S&T *made no mistake in designating the Stellarvue SV152T as a Hot Product — it obviously is!*

FOR THE RECORD

- In 75, 50 & 25 Years Ago (*S&T:* May 2018, p. 7), it was Mr. Hughes, not Hodges, who lost the court case for ownership of the Willamette meteorite.
- In the Great Red Spot predictions for May 5th (*S&T:* May 2018, p. 49), the correct meridian-crossing times are 8:05 and 18:05.
- In the sidebar "George Hale's Telescopes Today" (*S&T:* June 2018, p. 40), the Hale reflector is at Palomar Observatory, not Mount Wilson.

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

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

1943

1968

1993

August 1943

Spectral Bonanza "The biggest prism ever made has been successfully cast by the Bausch and Lomb Optical Company in Rochester. It is to be used with the Schmidt-type Burrell telescope of the Warner and Swasey Observatory of the Case School of Applied Science at Cleveland. The prism, 26 inches in diameter and weighing 260 pounds, is graduated in thickness from 1.5 to 3.25 inches. . . .

"The instrument will be used in the photography of spectra which will help solve mysteries on the nature of starlight, stellar temperatures, and radial velocities."

Full-aperture objective prisms on Schmidt cameras have proven a powerful survey tool, as in searches for quasars and the automated spectral typing of stars. Many thousands of spectra can be recorded in a single image. Since 1967 the Case School has been Case Western Reserve University. The Burrell Schmidt was moved to Kitt Peak in 1979. Larger objective prisms have been made, including two for the 1.2-meter UK Schmidt Telescope in Australia.

August 1968

Extragalactic Clouds "In 1964, Dutch radio astronomers announced the discovery of numerous fast-moving clouds of neutral hydrogen gas in high galactic latitudes. . . . Most astronomers have regarded these clouds as material falling into the galactic disk from outside. But Frank J. Kerr [at the University of Maryland says] these hydrogen clouds may instead be in orbital motion around our galactic system. . . .

"After the observed radial velocities of the individual clouds are corrected [for the Sun's motion around our galaxy], the residual motions are consistent with the hypothesis that the hydrogen bodies are traveling around the galaxy in their own highly inclined orbits. His collaborator W. T. Sullivan made extensive calculations of many such paths with different orbital elements."

August 1993

Venus in 3D "The landscape of Venus is rich in topographic variety. Volcanoes, craters, mountains, and chasms provide evidence of numerous episodes of geologic activity dating back at least several hundred million years. A critical part of the interpretation of this record is understanding the three-dimensional shape of the features now exposed at the surface. . . .

"The pictures here have been produced in anaglyphic form: when viewed through the supplied glasses, you can perceive the third dimension of height."

Thus Jeffrey J. Plaut, a team member working with radar data from the Magellan spacecraft's survey of Venus, introduced an article featuring 3D images of the planet's surface. In a publishing first for the magazine, red-blue viewing glasses were bound into each copy.

◀ NASA's Insight Mars lander awaits launch in the foggy predawn hours at the Vandenberg Air Force Base in California.

SPACE

Insight Lander Heads to Mars

NASA'S INSIGHT MARS LANDER launched aboard an Atlas V rocket on May 5th, rising through the predawn fog from the Vandenberg Air Force Base in California. The spacecraft's name stands for Interior Exploration Using Seismic Investigations, Geodesy, and Heat Transport. Prime contractor Lockheed Martin Space based the spacecraft design on the Phoenix lander, which dropped near the Martian north pole in 2008.

Insight should arrive at Mars on November 26th after an interplanetary cruise of nearly 500 million km (300 million miles). The spacecraft will make a direct descent to the planet's surface. About 6 minutes after entering the Martian atmosphere, Insight will use — as Phoenix did — a combination of aerodynamic drag, parachutes, and radar-triggered thrusters. However, compared to Phoenix, Insight is more massive (358 kg or 789 pounds), arrives at higher velocity (6.3 km/s or 14,100 mph), and has a higher-elevation landing site (which means there's less atmosphere to slow its speed).

Planetary scientists have longed for a chance to probe the deep interior of Mars. Understanding the circumstances of the Red Planet's formation — its bulk composition and the size of the eventual core, mantle, and crust — requires the kind of dedicated geophysical investigation that principal investigator Bruce Banerdt (Jet Propulsion Laboratory) first conceived in the late 1980s. Insight will soon conduct those experiments with a trio of key instruments. The Seismic Experiment for Interior Structure (SEIS) will detect marsquakes with exquisite sensitivity. The Heat Flow and Physical Properties Probe (HP^3) will drive a bullet-shaped "mole" up to 5 m (17 feet) deep into the Martian soil to calculate the rate at which heat is escaping from the planet's deep interior. And the Rotation and Interior Structure Experiment (RISE) will use two transponders to precisely track the planet's rotation and, over time, help determine the orientation of the Martian polar axis. "To me that's as close as you can get to magic and yet still be science," says Banerdt.

The selected landing location, centered at 4.5°N, 135.9°E in western Elysium Planitia, is near the equator to ensure strong sunlight for the solar-cell panels. The location was also selected for its flat, relatively rock-free terrain and loose soil. Insight does have a couple of cameras, but any panoramas will probably show a boring landscape. But the Red Planet's geological beauty isn't just skin deep — the interior is what will tell us the true character of our neighbor world.

■ J. KELLY BEATTY

● Learn more about Insight's mission at https://is.gd/marsinsightlaunch.

IN BRIEF

CubeSats Launch with Insight

Along for the ride with Insight are twin technology-demonstration microsatellites called Mars Cube One (MARCO) A and B, the first CubeSats to visit interplanetary space. Each spacecraft comes equipped with solar panels, cold-gas thrusters, an X-band antenna, and an ultra high-frequency receiver. Both spacecraft also have star trackers and wide- and narrow-field cameras. The satellites deployed successfully from spring-loaded launchers located on the Centaur upper stage and phoned home shortly after their release, indicating that their solar panels and communications antennas were functioning. The duo will fly past the Red Planet come November and attempt to relay data from the lander's descent to the Martian surface, transmitting data from Insight to Earth at 8 kilobits per second. While the success of the Insight mission isn't dependent on MARCO, the CubeSats will test key technologies for communication relays, which could act like "black box" data recorders for future landings.

■ DAVID DICKINSON

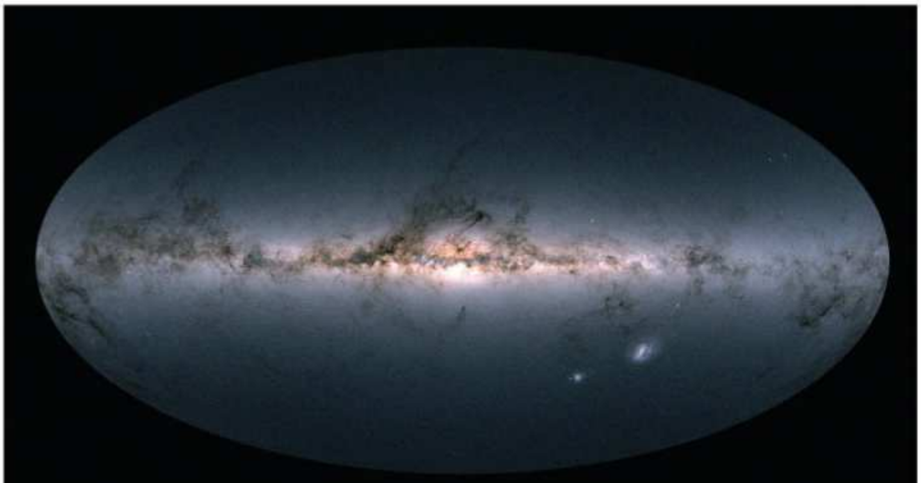
SPACE

TESS Mission Launches Successfully

A NEW PLANET-HUNTER is on its way to search for new worlds: The Transiting Exoplanet Survey Satellite (TESS) launched successfully on April 18th at 6:51 p.m. EDT aboard a SpaceX Falcon 9 rocket. The mission will survey nearly the whole sky for exoplanets.

TESS launched just in time, as NASA's Kepler will run out fuel within several months. Like Kepler, TESS will be looking for the brief dips in starlight created when exoplanets transit their stars. But unlike Kepler, which aimed toward a small field containing more than 150,000 mostly faraway stars,

PAULINE ACALIN



◀ This graphical representation of Gaia's all-sky data is based on measurements of 1.7 billion stars.

STARS

Gaia Maps 1.7 Billion Stars, Widens Cosmic Census

ON APRIL 25TH, European astronomers published the second release of data (DR2) from the European Space Agency's Gaia satellite. The resulting catalog is the most extensive and precise yet, containing data on 1.7 billion stars.

Based on 22 months of data collection, Gaia's DR2 consists of precise parallaxes, and thus geometric distances, to more than 1.3 billion stars, as well as positions and brightnesses of almost 1.7 billion stars. That's a huge leap compared to the mission's first data release in 2016 (*S&T:* Jan. 2017, p. 10), which contained 2 million stellar distances. Moreover, the newly published distances rely solely on Gaia's own measurements — in DR1 Gaia's measurements had to be augmented by data from the 1990s-era Hipparcos satellite observations.

The satellite spins continuously around its axis as it orbits the Sun, enabling its two telescopes to scan great circles on the sky, observing about 100,000 stars every minute. The optics feed three instruments: one for astrometry (to determine stars' positions and *proper motions* across the sky), one for photometry (to measure the stars' colors and effective temperatures), and one for spectroscopy (to measure bright stars' *radial velocity* toward or away from Earth and to assess their composition). At Gaia's heart is a CCD with 848 million pixels, the largest digital camera ever used in space.

Thanks to spectrometry, Gaia's DR2 contains estimates of the effective temperature, radius, and luminosity of 76 million stars, as well as time-dependent measurements for more than 550,000 variable stars. Closer to Earth, Gaia also observed about 14,000 known solar system objects, most of them asteroids. On the other end of the distance scale, the database contains positions and brightnesses for more than half a million quasars. Their near-zero parallax means they serve as useful references for Gaia's celestial coordinate system.

More data releases will follow DR2, with the final Gaia catalog — the definitive stellar catalog for the foreseeable future — scheduled to be published in late 2022.

■ JAN HATTENBACH

For additional images and an animated view of the Hyades star cluster, visit https://is.gd/gaiaDR2.

TESS will be examining 200,000 stars near Earth. The planets TESS finds around these stars will be more easily studied through follow-up observations on the ground and in space.

The spacecraft will be the first to operate in a lunar-resonant orbit dubbed P/2, circuiting Earth every 13.7 days — half the Moon's period. This orbit is extremely stable, requiring a minimum of fuel, and maximizes TESS's ability to view the entire sky. It also allows TESS to send full-frame images back to Earth on every close pass. Following initial testing, TESS will begin surveying the sky with a series of 27-day exposures.

TESS has funding approved for two years of operations, but principal investigator George Ricker (MIT) says the spacecraft is built to last for 10 to 20 years. The mission cost less than $200 million to develop, excluding launch expenses.

During its first year, TESS will observe the Southern Hemisphere sky; each 24° × 24° field of view will overlap on the ecliptic pole. TESS will then switch to the Northern Hemisphere sky for its second year. While going around the north celestial pole, some of TESS's observations will come full circle, following up on the region of Kepler's first four years of data collection.

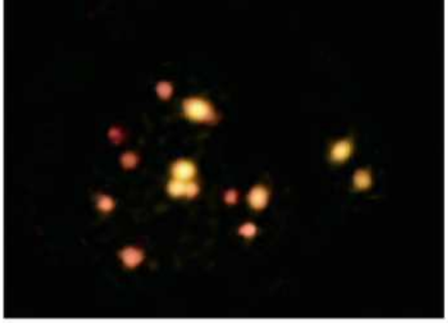
■ ELIZABETH HOWELL

▶ TESS launched on April 18th aboard a SpaceX Falcon 9 rocket.

GAIA: GAIA DATA PROCESSING AND ANALYSIS CONSORTIUM (DPAC) / A. MOITINHO / A. F. SILVA / M. BARROS / C. BARATA (UNIV. OF LISBON, PORTUGAL) / H. SAVIETTO (FORK RESEARCH, PORTUGAL); TESS LAUNCH: SPACEX

STARS

14 Galaxies Might Have Become Largest Cluster in the Universe



▲ ALMA imaged 14 galaxies swarming like fireflies in a massive protocluster that existed 1.4 billion years after the Big Bang.

AT LEAST 14 GALAXIES congregating just 1.4 billion years after the Big Bang might have become one of the most massive structures in the universe — if we could observe it to the present day.

Each galaxy in this *protocluster* is alight with stars forming 50 to 1,000 times more quickly than the Milky Way; the complex as a whole has the mass of 10 trillion Suns. The fact that these galaxies came together in such a massive structure so early on challenges our ideas of how clusters form.

Clusters, the largest gravitationally bound structures in the universe, contain hundreds or thousands of galaxies tethered together by their massive halos of dark matter. As galaxies are coming together, such a group is called a protocluster, and its future isn't guaranteed — depending on its environment, it might yet fall apart. But in the case of protocluster SPT 2349–56, the team reports in the April 26th *Nature*, the 14 galaxies are close enough together that the still-growing structure would probably have survived to the present day.

The protocluster was first seen as a bright, millimeter-wavelength smudge by the South Pole Telescope. Follow-up observations by the Atacama Large Millimeter/submillimeter Array (ALMA), combined with Spitzer observations at infrared wavelengths, resolved the smudge into at least 14 galaxies forming stars out of huge gas reservoirs.

While most protoclusters discovered so far are about as bright as theoretical models predict, SPT 2349–56 is 10 times brighter. Computer simulations haven't been able to make protoclusters producing as many stars as SPT 2349–56 does.

That said, the authors acknowledge theory's limited scope. Allison Noble (MIT), who wasn't involved in the study, agrees that current models haven't yet probed large enough scales to predict such an extreme case. Nevertheless, this protocluster, and any others like it, will help astronomers better understand how the universe grew its largest structures.

■ MONICA YOUNG

GALAXIES

Do Supermassive Black Holes Wander the Milky Way?

NEW SIMULATIONS SUGGEST that galaxies like the Milky Way could be home to a dozen big black holes.

A gigantic black hole sits at the center of the Milky Way and most other large galaxies. But when galaxies merge, their central black holes can find themselves with an eviction notice.

Astronomers have increasingly realized that evicted black holes only migrate to the new galaxy's core in a small fraction of mergers. The problem is especially acute when one of the galaxies is much smaller than the other. By implication, then, the outskirts of big galaxies should play host to a large number of supermassive black holes.

To understand the implications for galaxies like the Milky Way, Michael Tremmel (Yale University) and colleagues used the Romulus set of simulations, which follows the growth of cosmic structure in a cube of computerized space some 80 million light-years on a side. The team watched the development of Milky Way–mass galaxies and their interaction with their fellow stellar metropolises from soon after the universe's birth (when galaxy mergers were far more common) to today.

The team reports in the April 20th *Astrophysical Journal Letters* that, of 26 Milky Way–mass galaxies, each plays host to on average 4 to 20 supermassive black holes; roughly five of the black holes (again, on average) lie within 30,000 light-years of the galaxy's center.

When a merger in the simulation deposited a black hole near the plane of the galaxy's disk, the black hole gravitationally interacted with stars and gas and quickly sank to the core. Black holes following orbits that kept them far from the galaxies' disks, where they encountered few stars or gas, never migrated inward.

But if the Milky Way does host giant black holes in its outskirts, they're likely well outside the disk. Furthermore, the team estimates that our solar system would come across one of these wanderers every 100 billion years or so — nearly 10 times the age of the universe.

■ CAMILLE M. CARLISLE

IN BRIEF

Helicopter to Fly with Mars 2020 Rover

NASA has announced that a small, autonomous helicopter, named Mars Helicopter Scout, will make the journey to the Red Planet with the Mars 2020 rover. It may become the first mission to fly on another planet. Tucked away under the rover during descent, the helicopter will be deposited on the Martian surface shortly after landing. Weighing in at 1.8 kg (4 lbs), the baseball-size helicopter will whip its rotor blades at 3,000 rpm (10 times the rate of a helicopter on Earth) to create lift in the tenuous Martian atmosphere. As a technology demonstrator, the helicopter won't carry science instruments, but it will have two cameras that could prove valuable in mapping terrain. Funded for $23 million early this year, the helicopter is expected to last 30 days, during which NASA plans at least five short flights. The first flight will make an initial vertical climb of 3 meters (10 feet). Subsequent sorties will feature journeys up to 90 seconds in duration that range over several hundred meters.

■ DAVID DICKINSON

ALMA (ESO / NAOJ / NRAO), B. SAXTON (NRAO / AUI / NSF)

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COSMOLOGY

Hawking Takes on the Multiverse

STEPHEN HAWKING'S LAST cosmology paper, published posthumously with Thomas Hertog (KU Leuven, Belgium) in the *Journal of High Energy Physics*, might solve the cosmological problem of *eternal inflation*.

A lot of evidence suggests that, just a tiny fraction of a second after the Big Bang, the infant universe experienced inflation, a brief, fantastic growth spurt. Our pocket of space — what we call the observable universe — experienced a quantum fluctuation and spontaneously exited inflation. But according to most theories, inflation wouldn't have stopped everywhere at once. Beyond what we can observe, most of space will keep stretching at an exponential rate forever.

Eternal inflation implies that our cosmos is one of an infinite variety of pocket universes, known as the multiverse. Each one follows an infinite variety of physical laws. But an infinite multiverse hypothesis may pose a problem: Hawking argued it isn't testable.

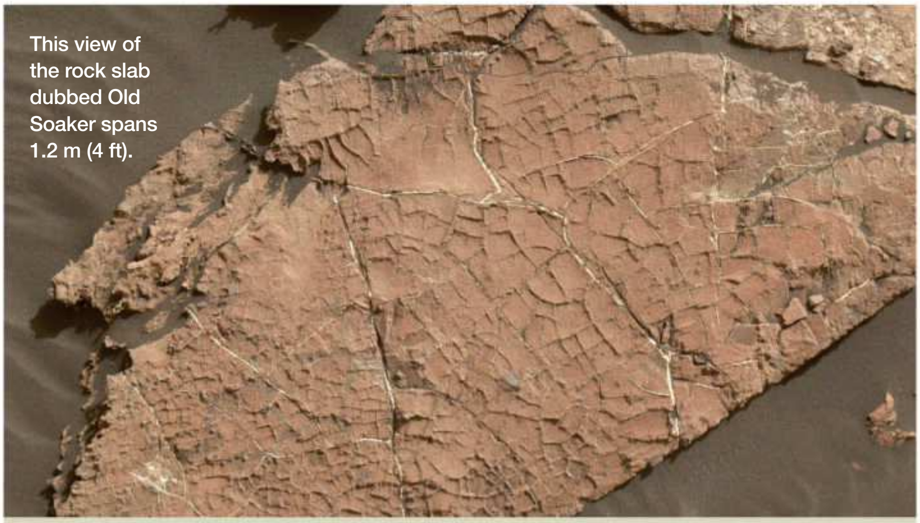
The problem, Hawking and Hertog write, could stem from the fact that previous theories have treated quantum effects as fluctuations in a universe dominated by relativity. Instead, the scientists argue, relativity should break down in the early universe.

To show this, they first simplified the math, formulating a universe without matter or energy and with an overall saddle-shaped geometry. We don't live in such a universe, but it's a common starting point for new cosmological theories. As is often done in string theory, they then treat this universe as a hologram: 3D equations reduce to 2D quantities on a surface. (This doesn't mean our universe *is* a hologram, just that we can mathematically treat it like one.) Rather than reducing a spatial dimension, though, Hawking and Hertog removed time. Relativity is no longer necessary in a timeless universe; quantum theory reigns.

When Hawking and Hertog solved the equations that govern this universe, they came to an astounding conclusion: The universe that emerges from inflation is finite. We still live in a multiverse, but now it's one with limited possibilities, which makes it more easily testable.

However, Alexander Vilenkin (Tufts University) urges caution in interpreting these results, noting that the simplified mathematical treatment, and the conclusions Hawking and Hertog derive from it, might not apply to our real, more complicated universe. "I am sure Thomas Hertog will try to go beyond this model," Vilenkin adds, "but it is hard to tell how successful this is going to be."

■ MONICA YOUNG



This view of the rock slab dubbed Old Soaker spans 1.2 m (4 ft).

NASA / JPL-CALTECH / MSSS

SOLAR SYSTEM

Mud Cracks on Mars Reveal Lake's History

NASA'S CURIOSITY ROVER spotted polygonal shapes on the surface of rocks on Mars in January 2017. Now, analysis confirms that these are cracks in dried mud, which shed light on the history of the lake that once filled Gale Crater.

Nathaniel Stein (Caltech) and colleagues found that the cracks formed during fluctuations in the water level of a lake that existed there about 3.5 billion years ago. The results appear in *Geology*.

Curiosity landed on the northern side of the crater in 2012 and has slowly been making its way south. Close to the crater's center, it took pictures of a rock slab nicknamed Old Soaker, as well as a similar nearby slab dubbed Squid Cove. A polygonal network of cracks in the red mudstone on these slabs' surfaces looks like what you'd expect from wet sediment that contracted as it dried.

The cracks are filled with sediment that has a chemical composition matching the underlying rock. Most likely, the cracks were filled in shortly after they formed as the lake level rose again. Sediment suspended in the water would have slowly settled into the cracks.

"These cycles of rise and fall likely happened many times before the region finally dried out for good," Stein says.

The history of Martian water will continue to unfold as the rover encounters ever-younger material on its way up the Murray Formation, the mountainous region in the crater's center.

■ JULIE FREYDLIN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QHYCCD
QHY174M-GPS
Selected by the NASA New Horizons Team
Now that the New Horizons spacecraft has flown beyond the orbit of Pluto, its next target will be MU69, the most distant object ever imaged remotely by a spacecraft. To make the flyby of MU69 a success, preliminary observations were needed to determine its approximate shape and exact orbit. Such a measurement from Earth required precise timing of exposures taken by multiple observers during an occultation that would last at most 2-3 seconds. The QHY-174M-GPS cameras selected by NASA provided highly accurate timing of multiple exposures per second at 5 different sites, all synchronized to the same time base, enabling an estimate of the unusual shape of the distant object. See: https://www.nasa.gov/feature/nasa-s-new-horizons-team-strikes-gold-in-argentina
QHYCCD makes over 50 models of CCD and CMOS cameras for amateurs and professionals starting at just $99. Find a Premier U.S. Dealer of QHY products at:
http://www.qhyccd.com/USA

2017 ECLIPSE RESULTS by C. Alex Young

Shadow Science

MAJESTIC SIGHT Last August, millions of people across the U.S. witnessed their first total solar eclipse. This composite image, taken from Mitchell, Oregon, shows amazing structure in the corona and even reveals details on the night side of the Moon feebly illuminated by sunlight reflected by Earth.

As the Moon's shadow crossed the U.S. last year, researchers mounted intense campaigns to study every aspect of the dramatic event.

Last year's total solar eclipse was a rare spectacle. Such events aren't rare in a *global* sense — they happen about every 18 months somewhere on Earth. But last year the Moon's shadow raced coast to coast across the continental United States and thus touched a swath of populated, accessible land 4,000 km (2,500 miles) long. Tens of millions of people witnessed totality on August 21, 2017, and an estimated 100 million saw the Sun partly covered, making it one of the most observed solar eclipses ever.

PETER ANIOL / MILOSLAV DRUCKMÜLLER / SHADIA HABBAL

The rarity of that day's event also allowed for unprecedented science. Besides studying the Sun's outer atmosphere during totality, many researchers also looked at the rich and dynamic interaction between the Sun and Earth with new focus and detail. Some of these studies have provided first-time observations of phenomena predicted for more than 50 years.

Much of the scientific attention during the eclipse focused on the corona, a thin plasma of highly charged particles shaped by the Sun's magnetic fields. The lower corona, the region within 1 to 3 solar radii of the photosphere, is the birthplace of space weather, solar flares, coronal mass ejections, and particle eruptions, all of which have a direct impact on our technology and our ability to work and live in space.

Space physicists routinely use spacecraft to observe the corona by occulting the Sun's brilliant disk with an occulting mask inside a telescope. However, these coronagraphs don't allow us to view the lower corona because the instruments are plagued by the diffraction of light from the solar disk. This limitation gets worse when the distance between the occulting mask and the camera is relatively short.

Fortunately, during a total solar eclipse, the Moon serves as a natural coronagraph that's nearly 400,000 km from Earth (the camera). Once the lunar disk completely blocks the Sun, we can use telescopes on the ground and in the air to obtain crisp images of the corona in visible light, right down to the silhouetted lunar limb.

Solar Layers

The brilliant *photosphere* is what we think of as the Sun's "surface," though technically it's the lowest level of the solar atmosphere. At visible wavelengths the photosphere is a million times brighter than all the layers of the atmosphere above it. Moving outward, the solar atmosphere becomes less dense but more complicated. In the *chromosphere*, magnetic pressure begins to dominate over gas pressure and the temperature rises nearly tenfold from the photosphere's 6000 kelvin.

At the top of the chromosphere, this temperature increase becomes dramatically steep. It shoots to more than 50,000K through the narrow *transition zone* and then up to 2,000,000K within the *corona*, the filamentary "crown" of plasma that extends millions of kilometers from the Sun.

This brings up one of the great mysteries of the Sun: Counter to our intuition, the temperature increases high above the white-hot photosphere. How does this happen? Energy must be flowing into the corona from below. Related to this is the mystery of what accelerates the solar wind's continuous stream of charged particles and magnetic field and drives it outward into interplanetary space.

"We also don't know why the corona is so well structured — it looks very organized, very combed," adds Amir Caspi (Southwest Research Institute). Given current understanding, he notes, "It should be a tangled mess."

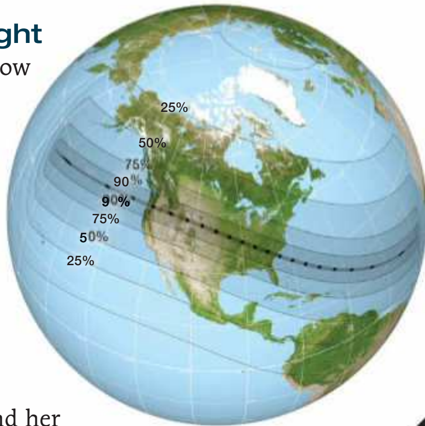
Solar physicists are still trying to determine the exact mechanisms involved, but we know it has something to do with magnetic energy being stored and released in the corona. We see this release of stored energy most dramatically as intense flashes of light (*solar flares*), as billion-ton blobs of solar material and magnetic field (*coronal mass ejections*, or CMEs), and as blasts of ultra-relativistic charged particles (called *solar energetic particle events*).

The rarity of the event allowed for **unprecedented science,** including first-time observations of phenomena predicted for more than 50 years.

These "space weather" phenomena, along with the heating of the corona and the solar wind's acceleration, all come from the lower corona. This is where all the action happens — and it's only observable during a total solar eclipse.

Almost all the experiments performed during last August's event promise to provide exciting results, but the reality of science is that often the work goes on long after the experiment ends. Here we'll take a look at some of the observations and early findings made during the eclipse and presented during professional meetings over the past year — as well as what others hope to find after sifting through their unprecedented troves of data.

Probing the Corona's Light



◀ **SHADOW ZONE** The Moon's umbral shadow crossed the contiguous United States from coast to coast during the total solar eclipse on August 21, 2017. Lines parallel to the central path denote the fraction of the Sun's area covered by the Moon. Dark spots along the path mark the umbra's location at 10-minute intervals.

▼ **VIEW FROM SPACE** The Moon's umbral shadow and surrounding penumbra created a distinct dark spot on North America during the August 2017 total solar eclipse. These views are from NASA's Deep Space Climate Observatory, positioned 1.5 million km from Earth.

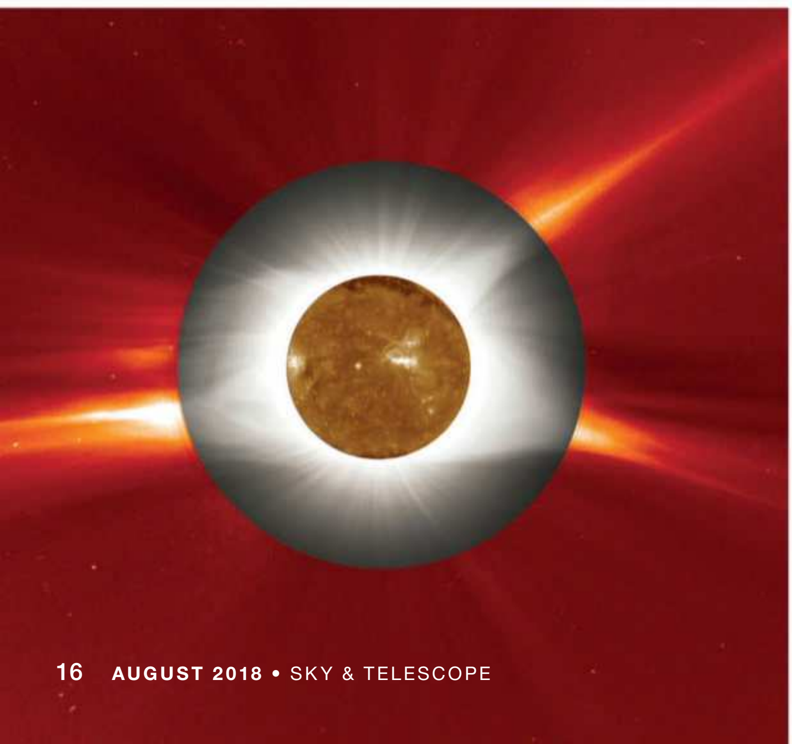
As the Moon's 110-km-wide shadow raced at supersonic speed across the U.S., any given location within the path had at most 162 seconds of totality. That's not much time to make detailed and often intricate observations of the corona's faint, complex structure.

Some of this work focused on the corona's temperature. Shadia Habbal (University of Hawai'i) and her team isolated emissions from highly ionized atoms, especially iron, that yield the temperature, density, and motion within the corona. They identified pockets of material from prominences that were relatively cool (at temperatures typically found in the chromosphere) despite having been pushed up into much hotter coronal regions.

This finding addresses a longstanding question about the fate of such material during coronal mass ejections: Apparently it survives the corona's searing environment, even as it travels outward into interplanetary space. This result places new, strong constraints on physicists' models of CMEs and the role they play in space weather.

Meanwhile, a Williams College team led by Jay Pasachoff also looked at both the white light scattered off coronal electrons as well as emission from highly ionized atoms. Combining these observations with those from Habbal's team provides observations at six different locations along the path of totality and covers a span of 34 minutes.

▼ **SOLAR SWEET SPOT** Spacecraft like NASA's GOES 16 can observe the Sun's brilliant photosphere (center), and others like the venerable Solar and Heliospheric Observatory can record streamers in its outer corona (shown in red). But to study the innermost corona, the complex region within about 1½ million km of the Sun, researchers must use the fleeting views available during totality — such as the telescopic view shown here, taken from Salem, Oregon.



These observations confirm that coronal temperatures cluster around two distinct values. The 1,000,000K corona consists of plasma that's expanding away from the Sun, while the 2,000,000K corona is plasma confined by magnetic arches or loop-like structures that are anchored to sunspot regions in the photosphere.

Several teams of solar physicists recorded complementary observations from the ground and aircraft in a spectral range only feasible near and during totality: infrared wavelengths from around 1 to 6 microns. Two main goals were observing the chromosphere in visible light and measuring infrared spectral lines from coronal plasma. The latter serve as fingerprints of the magnetic field that permeates and shapes the solar corona. We can measure magnetic fields in the solar photosphere quite well but doing so in the corona is notoriously difficult.

To observe the chromosphere, a team led by Paul Bryans, Phil Judge, and Steven Tomczyk (High Altitude Observatory) measured what is called the *chromospheric flash spectrum*. Seconds before and after the corona's appearance, the chromosphere briefly becomes visible as a brilliant crimson arc along the Sun's limb. The Moon was moving across the solar disk at 211 km per second (472,000 mph) as projected onto the Sun, so by taking observations 100 times per second, the researchers could record a spectrum for every 2 to 4 km of movement

MAP: NASA / SVS / ERNEST T. WRIGHT; SHADOW SERIES: NASA / DSCOVR / EPIC; SUN LAYERS: SUN: NASA / GOES 16 / SUVI / DAN SEATON; INNER CORONA: JAY PASACHOFF / RON DANTOWITZ / WILLIAMS COLLEGE ECLIPSE EXPEDITION / NATIONAL GEOGRAPHIC / NSF / NASA SPACE GRANT (MA); OUTER CORONA: NASA / SOHO / LASCO CONSORTIUM by the Moon's limb across the chromosphere during its fleeting visibility before and after totality. These infrared observations reveal structures not observed by the wavelengths seen with space-based observations.

To measure coronal emission lines with sufficient precision and sensitivity required a different kind of approach, because our atmosphere's light absorption and its own heat interfere with these observations. To get good data, a team led by Jenna Samra (Harvard) and Edward DeLuca (Smithsonian Astrophysical Observatory) placed their spectrometer in a Gulfstream V jet that carried it to an altitude of 13.7 km (45,000 feet). There they measured — for the first time — spectral lines from 1.4 to 4 microns that are sensitive to the strength of coronal magnetic fields. In fact, two of the lines had never been recorded before.

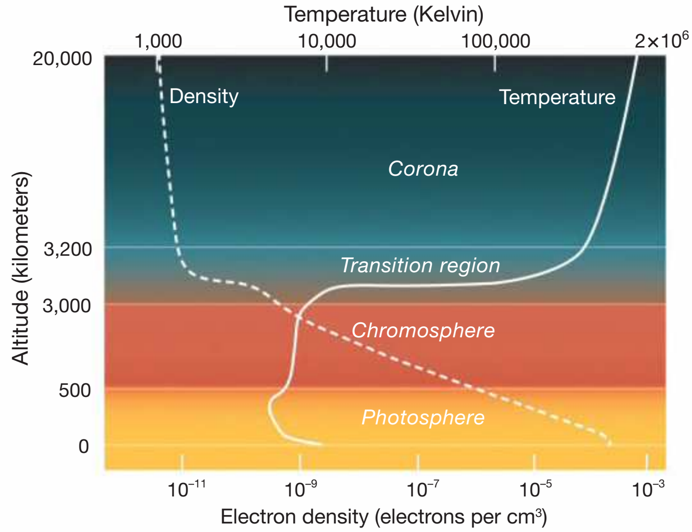
Also working in the stratosphere were Caspi and his team, who used two WB-57 aircraft to observe the eclipse. This wasn't the first time that researchers literally chased the Moon's shadow — for example, a supersonic Concorde flight in 1973 immersed itself in totality for 74 minutes! Although more modest, the two NASA planes flew in a staggered formation that offered an uninterrupted view of the corona for 7½ minutes from an altitude of 15.2 km, putting them above more than 85% of Earth's atmosphere.

Solar physicists suspect that different types of magnetic

waves propagate upward into the corona and drive its temperature to million-degree levels. These waves move rapidly and so require observations with very high time resolution and very low background light to record any faint changes in their structure and strength. The white-light and near-infrared cameras in the WB-57 provided that, taking images 30 times per second. The result was a huge amount of data that have yet to be analyzed fully. But Caspi has promised that if the waves are there, his team will find them.

The Shadowed Ionosphere

Standing in the Moon's umbral shadow offers an otherwise unobtainable view of the Sun's atmosphere. Closer to home, that same shadow provides a unique laboratory



▲ **COMPLEX LAYERS** The zone from the Sun's photosphere to its lowermost corona is less than 10,000 km deep, yet it is a region of remarkable transitions in pressure and temperature that solar physicists do not yet fully understand. Only during total solar eclipses can all of this important region be studied.

GRAPH: NASA

that lets us study energy flow from the Sun to our planet's surface and the dynamics of Earth's upper atmosphere.

Imagine being in space above Earth, looking down on our planet during last August's eclipse. From this vantage, the Moon's shadow plays a different role. The day-and-night cycle of incident sunlight is a main driver of our atmosphere's daily changes — from the very edge of space down through the mesosphere and stratosphere to the troposphere, where air finally interacts with land and water. During the day, the Sun's ultraviolet radiation breaks down neutral atoms in the upper atmosphere, creating the electrified soup of

electrons and ions called the *ionosphere*. This broad layer reacts to changes in the intensity of sunlight, the encroaching solar wind above (space weather), and Earth below (terrestrial weather).

The ionosphere both refracts and transmits radio waves,

Expanded Roles **for Citizen Scientists**

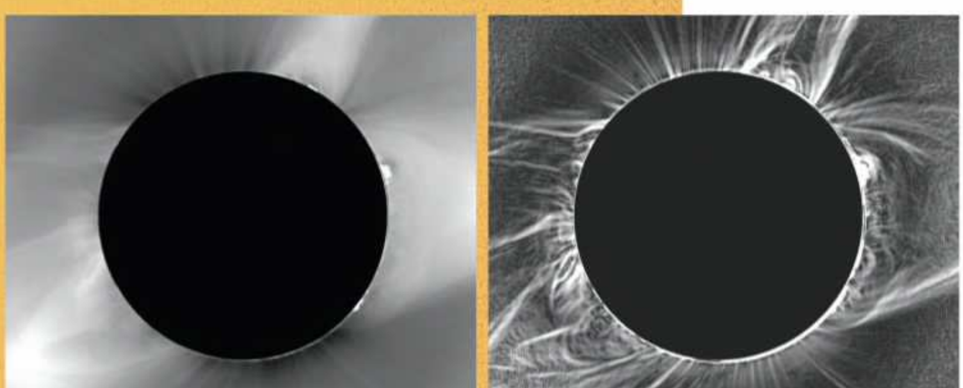
Thanks to the relative ease of getting to the path of totality last year, citizen scientists played a key and arguably powerful role. Some teams studied the Sun's corona and chromosphere, while others monitored the response of Earth's ionosphere and neutral atmosphere to the rapidly changing incidence of sunlight.

The Citizen CATE (Continental-America Telescopic Eclipse) project extended the idea of multiple observations to the max. A team led by Matt Penn (then at National Solar Observatory) brought together amateurs and professionals to operate 68 nearly identical setups strung along the eclipse path from Oregon to South Carolina (*S&T:* Jan. 2016, p. 29). The resulting images from 61 successful stations are being combined to yield an 82-minute-long record of the corona's appearance and its evolution. Challenges still remain in combining and analyzing these thousands of images, but the end result promises to be the longest scientific-quality observation of the solar corona in history.

Two programs studied the changes in the propagation of radio signals just before, during, and after the eclipse. Eclipse Mob provided radio receivers to more than 500 citizen scientists across the U.S. The volunteers monitored special transmissions to note how radio propagation varied across the country due to the eclipse. In the Ham Radio Science Citizen Investigation (HamSCI), led by Nathaniel Frissell (New Jersey Institute of Technology), investigators and ham-radio operators studied how the Moon's shadow created temporary "night-like" propagation conditions in the ionosphere at multiple frequency bands.

GLOBE Observer, a NASA-led citizen science program, enlisted the help of more than 10,000 volunteers nationwide. They used a customized smartphone app to collect more than 20,000 cloud observations, 60,000 photos, and 80,000 air-temperature measurements that will answer the question "How Cool Is an Eclipse?"

▼ The Citizen CATE Experiment deployed 68 teams with identical telescopes and cameras all along the eclipse path. Remarkably, 61 of them obtained usable high-quality images during totality. The view here is shown in raw (left) and enhanced versions.



CITIZEN CATE EXPERIMENT 2017 TEAM

depending on their frequency. Changes in the ionosphere affect the propagation of radio communications and consequently can sometimes disrupt signals bounced around Earth or sent into space. Given the huge impact this can have on communication and navigation systems, understanding the physics and behavior of the ionosphere is important.

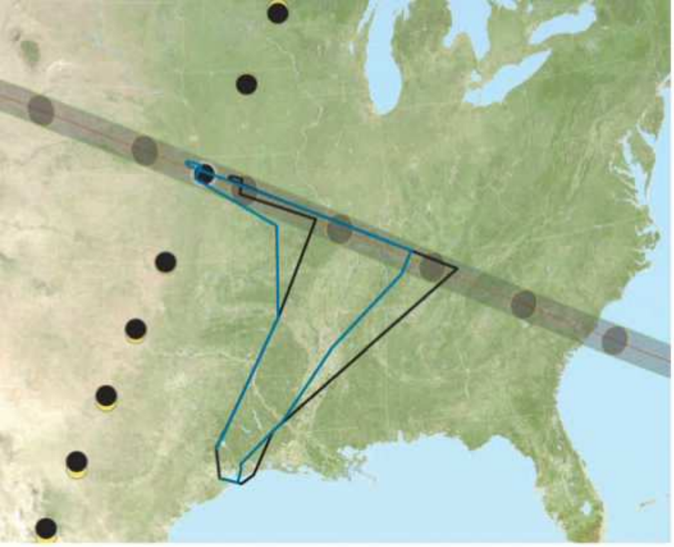
As the influx of solar radiation changes between day and night, structures and waves form throughout the ionosphere that are constantly moving horizontally and vertically. A total solar eclipse creates a relatively local but well-understood and well-defined shadow across the globe. As the Sun is covered, the decrease in ultraviolet and X-ray sunlight causes the ionization rate to plummet and a drop in the total electron content (TEC) in the ionosphere — an electron hole, in effect.

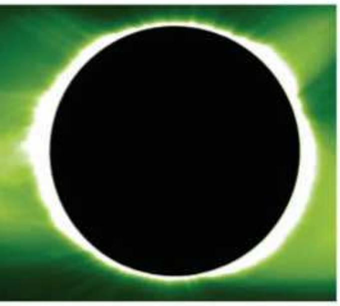
Researchers have studied the impact of eclipses on the ionosphere for almost a century, but their measurements have been sparse and often inconclusive. By contrast, 2017's eclipse allowed for both large- and small-scale measurements, yielding the most complete picture of the ionosphere ever imaged. It offered us a giant controlled experiment to study how the ionosphere changes in response to a brief but abrupt shutting off of sunlight.

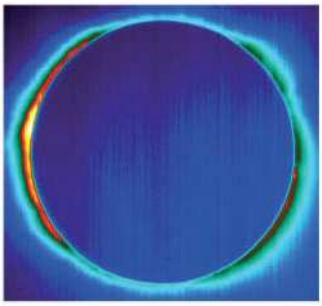
Gregory Earle (Virginia Tech) and his team used computer models to predict how the ionosphere's structure would change, and thus how differently radio signals would propagate, in response to the eclipse's shadow. They predicted the formation of a TEC hole and a change in the transmission properties of the ionosphere that enabled radio signals to travel farther. This is exactly what happened. Ham radio operators across the country were able to talk during the shadow's coast-to-coast crossing despite being up to 4,000 km apart — all the way from South Carolina to California. Ordinarily that's possible only at night, whereas typical daytime distances (depending on the frequency used) are only 100 to 1,000 km.

But the team's work also indicates that the way the ionosphere reacts when plunged into darkness depends on other solar factors. In collaboration with colleagues at the Naval Research Laboratory and University of Michigan, and drawing on fundamental studies of the ionosphere from previous decades, the researchers found that how the ionosphere will respond depends on what's going on in solar active regions and whether the Sun has recently emitted flares.

Others also saw interesting changes in the ionosphere. A team led by Philip Erickson and Shunrong Zhang (MIT) modeled how the ionosphere would respond to the eclipse and then tested that result with radio observations at Haystack Observatory in Massachusetts. Their models did well in describing ionospheric variations due to changes in ionization as the sunlight diminished, but the resulting dynamics proved difficult to understand. For







▲ **TO THE STRATOSPHERE** A flight crew prepares one of two NASA-owned WB-57 aircraft for a test run from Ellington Field in Texas. The planes tracked the eclipsed Sun with visible-light and infrared cameras.

◀▲ **SHADOW CHASERS** Based at Ellington Air Force Base north of Houston, two of NASA's WB-57 aircraft chased the Moon's shadow along staggered flight paths that provided 7½ minutes of corona observations.

◀ **WARMTH OF THE SUN** Using specially equipped NASA planes flying at high altitude, investigators captured the totally eclipsed Sun in visible light (at left, filtered green to improve coronal contrast) and at thermal-infrared wavelengths.

FLIGHTPLAN: NASA; THERMAL-INFRARED IMAGES: NASA / SWRI / AMIR CASPI / DAN SEATON; JET: NASA / SWRI / AMIR CASPI

example, they found significant differences in how the ionosphere responded in longitude and latitude — and even saw changes in the propagation characteristics in magnetically connected ionospheric regions over South America.

One of the most exciting results was confirmation of a prediction made almost 50 years ago. In 1970, George Chimonas (then at University of Toronto) deduced that a bow wave would form in the ionosphere — much like the wave created by a boat moving through water — as the Moon's supersonic shadow sped across Earth. Chimonas reasoned that electrons would rush in to fill the ionospheric hole, altering the total electron content just behind the umbral shadow.

Observations during the 2017 eclipse confirm this bow wave's creation unambiguously for the first time. Researchers measured changes in the ionopsphere's TEC as the shadow raced along that matched what would happen if a bow wave had sped through. Furthermore, Earle's team detected a corresponding wave much deeper in Earth's atmosphere, in the thermosphere layer just above the surface.

All of these eclipse-induced phenomena have given scientists tools to probe the nooks and crannies of the complex ionospheric pie with keen new insight. The ionosphere has a substantial impact on our technological way of life, and the shadow cast during last year's eclipse has brought us closer than ever before to understanding this critical region.

Effects Near the Ground

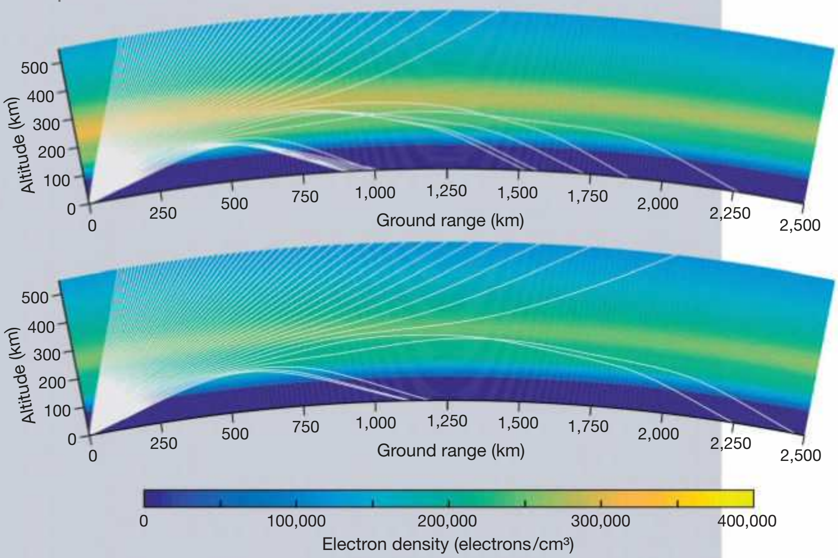
The environment closest to us, from the stratosphere to the ground, was also "illuminated" by the Moon's shadow, creating changes in the intensity of sunlight in the lower atmosphere.

Earth scientist Jay Herman (University of Maryland) and colleagues took the opportunity to carefully measure the role of clouds as regulators and reflectors of solar energy by using the Moon as a giant, impenetrable cloud. Using images from NASA's Deep-Space Climate Observatory (DSCOVR) spacecraft, like the ones shown on pages 16 and 17, they found that the amount of sunlight on Earth fell by 10% during the eclipse. By comparison, on any given day the global variation is less than 1%. The team is a long way from explaining this drop; the researchers think it'll take them a couple of years to understand what's going on.

"Big-picture" views of how Earth looked during totality came from a novel effort called the Eclipse Ballooning Project. Under the leadership of Angela Des Jardins (Montana State University), 55 teams of high-school and college students across the country launched instrumented weather balloons that climbed to altitudes of roughly 30 km (100,000 feet) in the stratosphere.

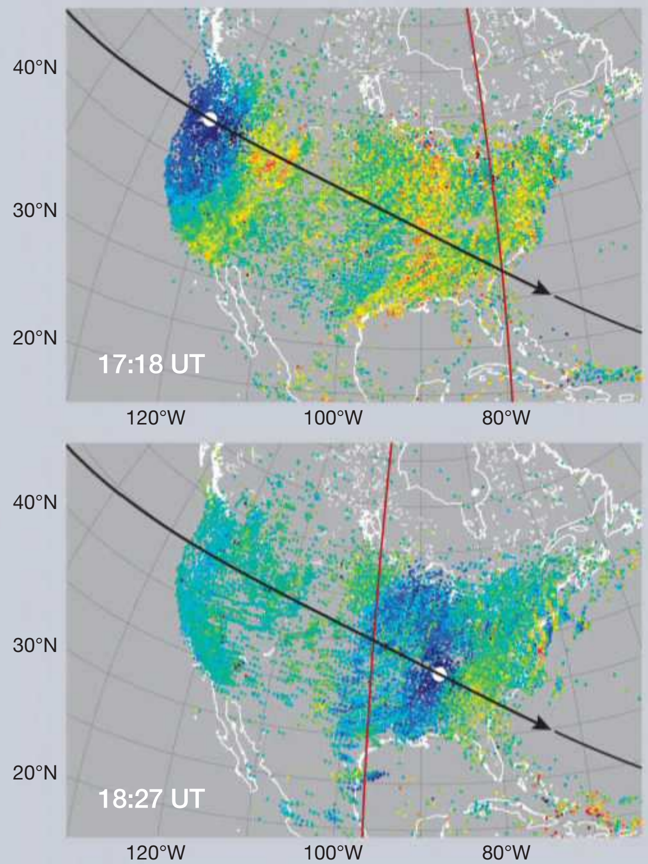
The cameras they carried aloft provided the first-ever live eclipse video from that altitude and showed that the top of the *planetary boundary layer*, the region of the atmosphere that interacts with Earth's surface, dropped nearly to its nighttime altitude during totality.

Meanwhile, Kevin Knupp led a team from University of Alabama, Huntsville, that monitored a pronounced reduction in turbulence, wave motions, and wind speed within the boundary layer. These eclipse-induced changes were similar to what occurs during the slower afternoon-to-evening transition near and after sunset.



▲ **LONG-DISTANCE CALL** Computer models predict how far 10.5-megahertz radio signals should propagate through the ionosphere (yellow band) during normal daylight (upper panel) and during totality. When the Sun's light is cut off near mid-eclipse (lower panel), a "hole" in the ionosphere's electron population allows the signals to propagate much farther.

▼ **MAKING WAVES** The sudden drop in sunlight caused electron counts in the ionosphere to plummet and triggered a set of bow waves captured by radio telescopes. As it crossed the U.S., the ionospheric "hole" changed from circular to V-shaped to linear. Also plotted are the path of totality (black line), location of the Moon's umbral shadow (white circles), and local noon meridian (red line).



Lessons Learned

Although the 2017 eclipse is already a year gone, scientists have just begun to understand their observations of it. We gained unprecedented coverage of the solar corona and chromosphere and how the Sun interacts with Earth. Even with the limited results we have so far, it's clear that the favorable geography afforded by last year's event has revolutionized eclipse science. We'll get another, very similar opportunity in April 2024, when the Moon's shadow travels across Mexico, moves onward through Texas, the Ohio River Valley, upstate New York, and New England before exiting North America in northeastern Canada.

In the interim scientists won't ignore the total solar eclipses in 2019 and 2020 (the paths of which cross South America) and in 2021 (which tracks across Antarctica). For all of these, researchers will have two new NASA spacecraft at their disposal. GOLD (short for Global-scale Observations of the Limb and Disk) was launched this

IONOSPHERE MODELS: MAGDALINA MOSES / GREGORY EARLE / VIRGINIA TECH; BOW WAVES: SHUNRONG ZHANG / MIT

past January 25th and provides global views of the ionosphere from its 35,800-km-high geosynchronous altitude. A complementary mission set to launch this summer, the Ionospheric Connection Explorer (ICON), will orbit at a much lower altitude and probe the ionosphere directly.

By the time 2024 arrives, solar and Earth scientists should have fully digested what they learned from last year's eclipse and have readied new instruments, techniques, and models for another all-out assault. In fact, by the time the Moon's shadow again crosses U.S. soil, NASA's Parker Solar Probe will be flying through the Sun's outermost atmosphere — just as observers back on Earth are enjoying another chance to look at that magnificent corona.

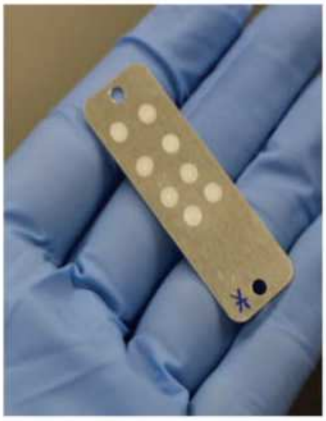
So when 2024 comes, solar and terrestrial scientists will be ready. Every total solar eclipse offers only one shot to get it right — there are no do-overs.

■ After venturing to Charleston, South Carolina, for last August's eclipse, **C. ALEX YOUNG** returned to his job as Associate Director for Science in the Heliophysics Science Division at NASA's Goddard Space Flight Center. He's also a frequent and enthusiastic public lecturer.

MOON SHADOW: MONTANA SPACE GRANT CONSORTIUM: METAL CARD: NASA / AMES RESEARCH CENTER / TRISTAN CARO

Future Martian **Invasion?**

Some of the balloons lofted during the 2017 eclipse carried samples of harmless bacteria. The middle of the stratosphere has pressures and temperatures similar to those on the Red Planet's surface — and during the eclipse sunlight intensity also dropped to levels comparable to that on Mars. So the eclipse provided a unique environment to test how well these hardy microorganisms from Earth would handle the harshness of Mars.



▲ Small metal cards like this one, infused with samples of bacteria, were carried by balloons high into the stratosphere during 2017's total solar eclipse.

BALLOON'S-EYE VIEW A camera carried by a balloon captured the Moon's shadow (lower left) from an altitude of some 30 km (100,000 feet). Students from Montana State University launched the balloon during last August's eclipse from near Rexburg, Idaho.

A Picture-Perfect **Eclipse** Experiment

TWENTY STARS To create this image, the author subtracted the light from the Sun's corona, making the stars more visible. The author then used 20 stars (circled; one not shown here) in his final analysis. The two stars closest to the Sun were captured in 0.09-sec exposures. A stellar pair so close to the Sun's limb won't happen again until 2252.

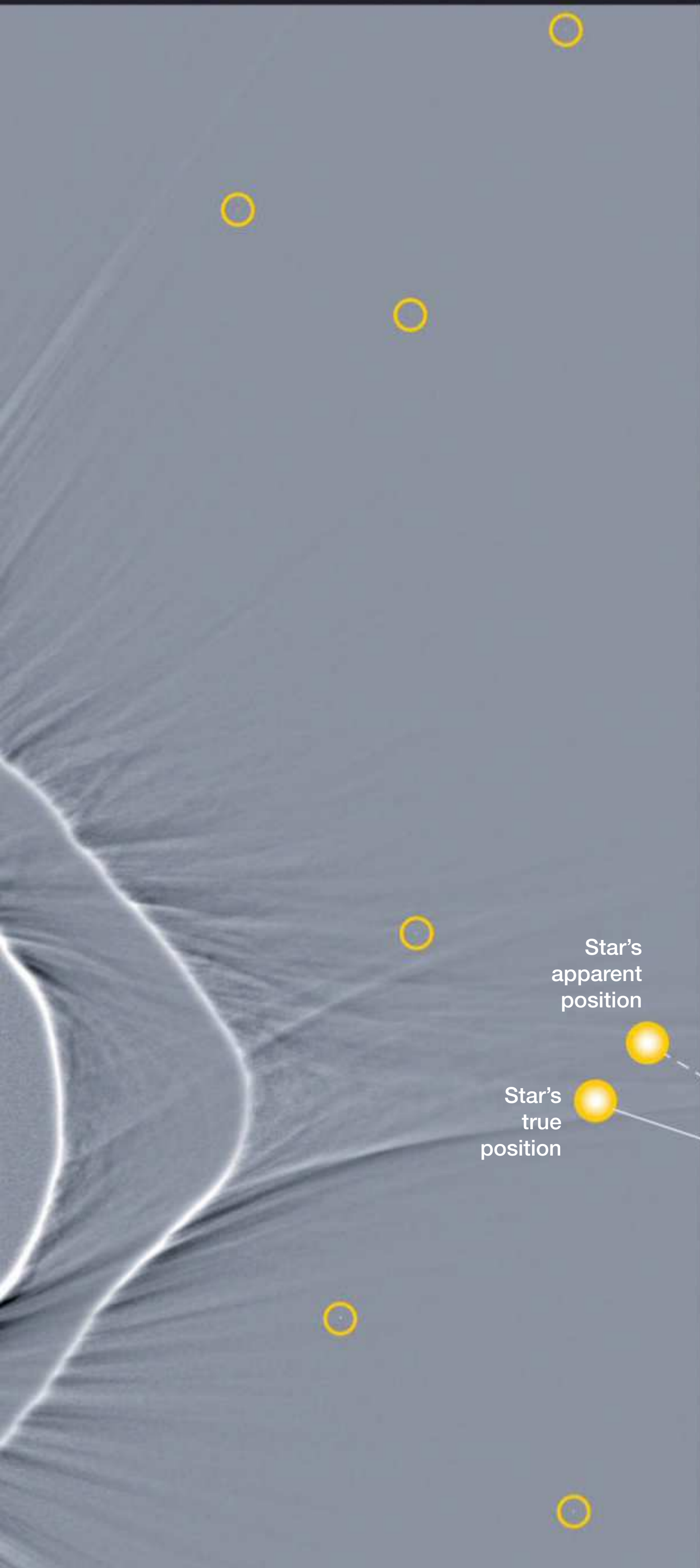
In August 2017 author Donald Bruns set out to redo Eddington's famous test of general relativity. The results were an astounding success.

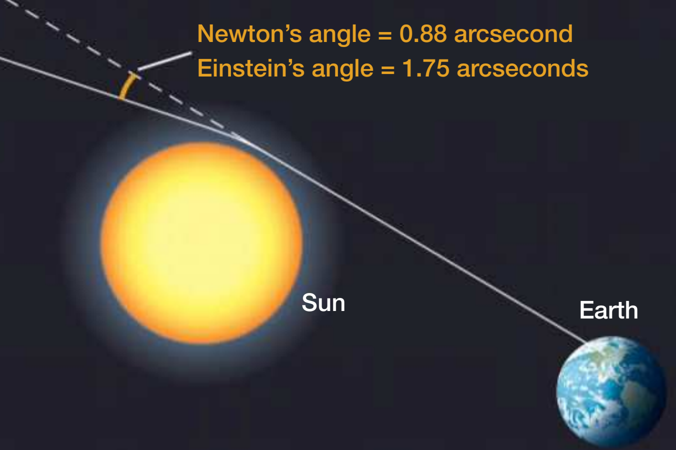
Two years ago, in the August 2016 issue of *Sky & Telescope*, I explained that I was going to set up an experiment to measure the gravitational deflection of stars during the Great American Eclipse. And I did just that: After traveling to Wyoming for the occasion, I experienced perfect conditions that led to an incredibly precise result.

For the first time since Sir Arthur Eddington was involved in two expeditions to witness the 1919 eclipse, this experiment went just as planned, with no weather or equipment problems. While there is no new science in this result, being able to reproduce a difficult experiment after nearly 100 years was a wonderful experience.

According to Einstein's general theory of relativity, mass warps spacetime, creating what we experience as gravity. This warped spacetime terrain bends the paths that massless photons travel. Because of gravity's influence, stars very near the Sun's disk will appear in slightly different positions than if the Sun weren't there. Of course, the Sun is so bright that we can't normally see this effect, but a total solar eclipse provides the perfect opportunity.

I began my preparations two years before the eclipse, after I found out that no one had attempted the experiment since 1973. That was back when they still used glass photographic plates; modern technology, I assumed, would make the experiment much easier. I was wrong! Granted, I didn't have to worry about precise star positions — modern star catalogs took care of that — or transporting equipment to a remote continent: I was able to drive to my site on Casper Mountain. But I still had to worry about things like calculating the right exposure times and getting good weather. And, since the eclipse only lasted 148 seconds, there was no time to correct any last-second errors.





▲ **ANGLE OF LIGHT** The Sun's gravity deflects the apparent positions of stars near its limb by a small amount, as predicted by Einstein's general theory of relativity. (Diagram not to scale.)

ECLIPSE: DON BRUNS; ANGLE DIAGRAM: LEAH TISCIONE / S&T; SOURCE: DON BRUNS

▲ **THE BIG DAY** The author *(left)* prepares on the morning of the eclipse. The tripod is bolted to a cement base topped with a commemorative mosaic eclipse design built by Steve Lang, which features the Sun, inner corona, and stars. A group *(right)* assembled at Lions Camp to watch the eclipse.

Just for this experiment, the manufacturers graciously loaned me a Tele Vue-NP101is apochromatic refractor, a Finger Lakes ML-8051 CCD camera, and a Bisque MyT Paramount field tripod. I already owned a MyT mount. With help from my cousin Steve Lang, I chose to set up a week early at the Lions Camp near Casper because of the high altitude and prospect of clear skies. On eclipse day, the camp hosted visitors from around the world, from England to Latvia and New York to Texas. We all thoroughly enjoyed the eclipse and celebrated together after totality.

The Winning Formula

The key to success in this experiment was to plan ahead and practice — something every amateur astronomer already knows to do when attempting to image a transient event. I did everything I could ahead of time, from verifying electrical power when the lights were turned off during totality to bolting the tripod legs to a concrete base so the polar alignment would not accidentally change. My site was in a grassy field protected by tall trees, so there was no wind at all.

I followed a detailed checklist, too. For example: "Remove solar filter." I didn't want to forget anything in the excitement leading up to totality.

On two nights before the eclipse, I was able to perform a good polar alignment and take calibration images. I left the telescope and camera setup untouched for four days, with a little guard fence around it. Since all of the visitors knew what I was doing, they left it alone. In fact, there were a few other telescopes set up early around the camp, and no one had any problems.

On eclipse day, I had a weather station set up to record temperature, pressure, and humidity, so I could correct for atmospheric refraction. I also had the software play a chime after each exposure during the experiment. Hearing this every few seconds was comforting and allowed me to enjoy the spectacle with family and new friends.

I started the detailed image processing back home in San Diego. Looking at the images, I could see all the stars that I was hoping for and more. I had decided on my procedure ahead of time, and modern software helped me complete all

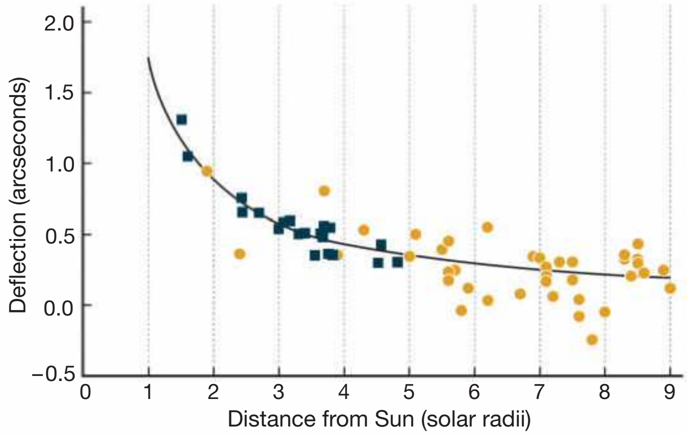
Does the Sky Change **During an Eclipse?**

After watching the total solar eclipse of 1715, Edmund Halley reported seeing the sky become bluer near totality. Was that an optical illusion or reality? Modern observers have since measured the sky's color and brightness during eclipses, but they typically use photometers that integrate over the entire sky. I wanted to collect data, resolved over time and angle from the Sun, to determine just how significantly the sky's appearance would change.

My twin brother, Don, recruited me to join him and conduct this experiment while he focused on light deflection. The equipment was compact and easy to set up at my site near the eclipse centerline in Esterbrook, Wyoming. I attached a wide-field (70° FOV) lens to an SBIG ST-i-C camera with built-in RGB filters and mounted it to a Meade equatorial drive fitted with an occulting disk. The disk allowed me to take sky photos before,

▲ **SKY SETUP** Ronald Bruns, the author's twin brother, used a wide-field lens on an SBIG ST-i-C camera to measure the sky's color and brightness before, during, and after totality.

THE BIG DAY (2): STEVE LANG; SKY BRIGHTNESS SETUP: RON BRUNS



◀ **DEFLECTION ANGLE** The author used data collected in 1973 (yellow circles) and his own data collected in 2017 (blue squares) to calculate how the deflection angle changes with position. The apparent positions of stars farther from the Sun's limb are deflected less than those nearer the Sun, and the constant describing this relation in relativity is 1.7512. The author's data line up nearly perfectly with Einstein's prediction.

of the analysis in just a few months. I used both *MaxIm DL* and *Astrometrica* software to measure the precise positions of stars, including only those stars that gave good signals and weren't distorted by the corona or neighboring stars. The two programs use different methods for their calculations, and because I had no reason to prefer one over the other, I averaged their outputs. This procedure led to an amazingly accurate result.

I used calibration images taken during the brief totality to improve the accuracy of the analysis. For these, I had the telescope point about 7° from the Sun, where there is little gravitational deflection. The computerized mount, controlled via automatic scripting, enabled me to take these calibration images on both sides of the Sun. Sufficient calibration had proved a problem for previous eclipse expeditions, due in part to the time involved for manual setup, but modern technology easily resolved that issue.

Moment of Truth

According to the mathematics of relativity, deflection caused by the Sun's gravity decreases with the distance from the Sun's center as 1.7512 arcseconds divided by the distance in solar radii. But past attempts at measuring the deflection constant weren't very good, averaging 1.9 arcseconds and ranging from 1.2 to 2.7 for previous eclipses.

After careful analysis of my eclipse images, I measured a deflection constant of exactly 1.7512 arcseconds. A perfect conclusion to a perfect eclipse! Granted, it's a coincidence that my measurement landed exactly on the correct value — my uncertainty is about 3%. But it's still reason to celebrate: The measurement achieved the best precision ever by a wide margin. The results are available in a more technical format as a paper published in the April 12th issue of *Classical and Quantum Gravity.*

By coincidence, the best-ever optical measurements of the gravitational deflection of starlight came only four days after LIGO detected the first gravitational-wave signal from a collision of two neutron stars (*S&T:* Feb. 2018, p. 32). These two astounding phenomena had both been predicted decades earlier by the equations of relativity: All in all August 2017 was a good month for Einstein!

■ **DONALD BRUNS**, a retired physicist, received the American Astronomical Society's 2018 Chambliss Amateur Achievement Award for his careful work in replicating Eddington's famous experiment.

Another **Chance**

The next decade will see four solar eclipses with longer durations of greatest eclipse:

July 2, 2019
(**4** min, **33** sec)
South America

April 8, 2024
(**4** min, **28** sec)
North America

August 2, 2027
(**6** min, **23** sec)
Africa

July 22, 2028
(**5** min, **10** sec)
Australia/
New Zealand

I hope other amateurs will take these opportunities to undertake some science of their own and experience the same excitement!

during, and after totality. The camera was set to cycle through exposures of varying length every 10 seconds, starting 8 minutes before totality began until 8 minutes after it ended. Afterwards, I analyzed only those images from each cycle that were not under- or overexposed.

I arbitrarily selected pixels at radii 5°, 15°, and 25° from the Sun to measure sky color. I saw a small increase in redness as the eclipse progressed, but seconds before totality began, that trend reversed to an increase in blueness. But the latter change, as measured by the ratio of the intensity of blue pixels to the red pixels, was only about 5% at 15° from the Sun. Was that enough to notice with the naked eye? Halley may have noticed it, but I was too intent on enjoying the diamond rings and coronal views to check for any visual color change — it certainly wasn't obvious to me.

The same set of photos showed that the sky had darkened at the same rate that the Moon had covered the Sun. At mid-totality the sky was 6,000–10,000 times darker in the blue filter, depending on the angular distance from the Sun — equivalent to a drop of 9.5 to 10 magnitudes. Meanwhile, the sky darkened another 0.4 magnitude in the red filter.

Future eclipse experiments could build on this first set of observations: Astronomers might make measurements closer to the Sun, collecting more frequent data points to include any effect from limb-darkening. I would be interested in comparing your results with mine.

— Ronald Bruns

DEFLECTION DATA: DON BRUNS

The Moon Mess

A planet-scale smash created Earth's satellite. But how did it manage to make a moon so like Earth?

"There is *orange soil*! It's all over! Orange!" Harrison Schmitt's excitement crackled over Apollo 17's radio.

His companion, surrounded by the gray lunar landscape, wondered if Schmitt had been on the Moon too long. He came to take a look. "Hey, he's not going out of his wits," Eugene Cernan chimed in, seeing the material Schmitt's footsteps had uncovered and catching his excitement. "It really is."

Schmitt, a geologist and the first scientist-astronaut to set foot on our planet's natural satellite, knew he was seeing something important. The two astronauts hurried to dig a trench, snap images, and collect samples. Further analysis on Earth later revealed that the orange soil was 3.7 billion years old and had formed during a volcanic eruption.

The orange soil wasn't the only thing worth bringing back home. When the Apollo 17 command module finally splashed down in the Pacific Ocean on December 19, 1972, it carried some 110 kilograms (243 pounds) of lunar rocks and dust in its guts. In total, the Apollo teams brought back to Earth 382 kg of samples. Among them were green, yellow, and orange volcanic beads; black basalts from the dark *maria* regions; twisted breccias cemented together by meteorite impacts; and a light-toned rock called anorthosite.

Although furthering lunar science was just one of the many objectives of the Apollo program, conceived during the Cold War for political and technological reasons, it produced an unprecedented amount of knowledge about the Moon. Virtually everything we know about our natural satellite was discovered or confirmed thanks to Apollo's scientific windfall.

But one of the most basic questions remains open: How did the Moon form? For a long time scientists thought they had found the answer in the Apollo lunar samples, but more recent analyses of the very same rocks, combined with powerful computer models, have shown there is still much we don't know about the birth of Earth's companion.

Probable but Unpredictable

Before Apollo, scientists had imagined three possible scenarios for the formation of the Moon: *co-accretion, fission,* and *capture*. Co-accretion means that Earth and the Moon coalesced together as a pair from a primeval cloud of gas and dust. In the capture scenario, the Moon formed elsewhere and was yanked into an Earth-circling orbit when the two bodies came too close. In the fission model, the still-molten Earth started rotating faster and faster until it split itself in two.

However, once scientists could study actual lunar samples, those three ideas became obsolete. Chemically, the Moon looks like what you'd expect after vaporizing Earth material and letting it condense in the vacuum of space. It lacks most of the easily vaporized elements regularly found in meteorites and terrestrial rocks, including water and hydrogen, and has little iron. The oldest rocks on the Moon, the low-density anorthosites, are almost completely devoid of heavy metals and must have formed after a global event melted the entire Moon, allowing these buoyant rocks to float to the top of a magma ocean and solidify on its surface as the Moon's original, frothy crust. None of the three scenarios would produce these characteristics.

Instead, by 1974, two pairs of scientists working independently (William Hartmann and Donald Davis, Alastair Cameron and William Ward) realized that the Moon could have been created

Moon Samples

0.3 kg: Weight of all Soviet Luna mission samples

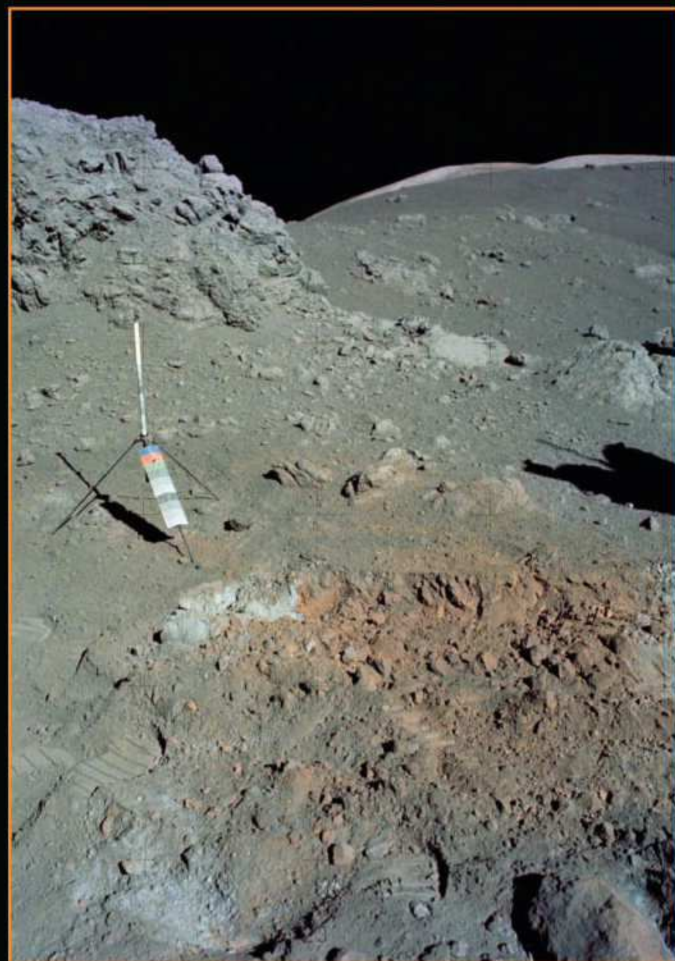
110.4 kg: Weight of Apollo 17 samples

382 kg: Weight of all Apollo samples (about 5 adult men)

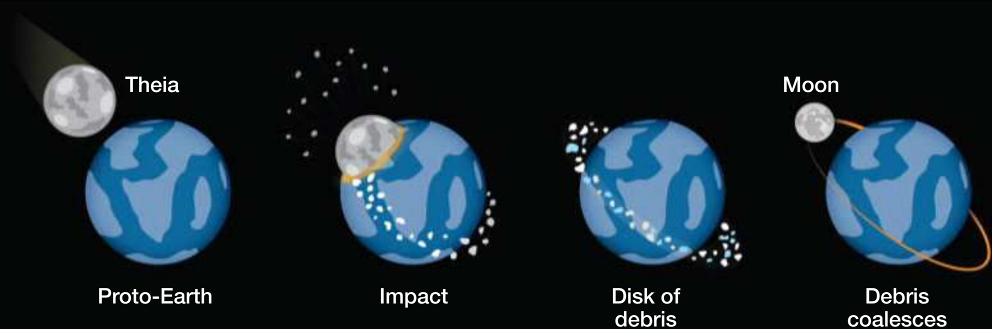
THE GREAT WALLOP
About 4½ billion years ago, a Mars-size body and the proto-Earth — both with atmospheres and, likely, surface oceans — crashed into each other. Already scarred by earlier, smaller impacts, the two bodies largely vaporized. The Moon and Earth coalesced out of the debris.

CASEY REED

ORANGE SOIL *(Clockwise, from below)* This shot shows the patch of lunar surface that surprised Harrison Schmitt at Apollo 17's Station 4, near Shorty Crater. The tripod-like gnomon and its color bars were used to assess Sun angle, scale, and color in lunar photos. *Lower left:* Astronauts Eugene Cernan (left) and Harrison "Jack" Schmitt, photographed by fellow crew member Ronald Evans during the Apollo 17 mission. *Left:* Schmitt wields a lunar rake at Station 1. Astronauts used lunar rakes to collect rocks and rock chips ranging in size from 1.3 to 2.5 centimeters (0.5 to 1 inch) across.



THE GIANT-IMPACT MODEL First proposed in the 1970s, this hypothesis posits that a Mars-size body slammed into Earth and created a debris disk that coalesced into the Moon. The details of this scenario have since proved problematic.



APOLLO 17 PHOTOS: NASA (3); IMPACT DIAGRAM: GREGG DINDERMAN / S&T

after a Mars-size body crashed into the nearly fully-formed Earth. In the scenario that has grown out of this initial work, the impactor delivered a glancing blow, powerful enough to launch huge quantities of silicate rock from both bodies into orbit. By that time, most of the iron and other heavy elements had already settled into the cores of each protoplanet, which merged inside Earth after the impact. Meanwhile, the ejected rocks formed a disk around Earth and quickly coalesced to form the Moon. Due to the high temperatures created during the collision, volatile elements, including water, would have escaped from the disk, leaving behind a dry, gas-free, and metal-poor Moon.

This *giant-impact hypothesis* successfully explains most of the peculiarities of the Moon: its geochemistry, lack of a metallic core, late formation relative to other objects in the solar system, and large mass ratio compared to its host planet — more than 50 times those of the giant planets. The scenario also accounts for the high angular momentum of the Earth-Moon system as a whole. If all the angular momentum could somehow be transferred to the Earth alone, our planet would spin around in only 5 hours.

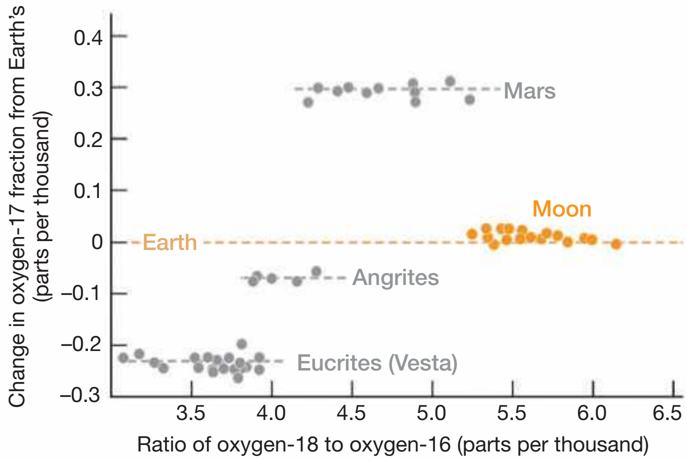
Despite its virtues, the giant-impact hypothesis didn't gain much traction among planetary scientists until the mid-1980s, when modern planet-formation models showed that titanic collisions might have been fairly common during the birth of terrestrial planets. According to these models, giant impacts mark the beginning of the end of a long process in which bits of rocky material gradually clump together, growing in size to form boulders, then planetesimals, and then planets. Such accretion is competitive, with the larger bodies absorbing the smaller ones in their feeding zones like big fish devouring all the small fry in a pond. In the final stages, the larger bodies can collide as well, crashing into each other in a series of calamitous encounters.

As this new paradigm became dominant, so did the giant-impact hypothesis for the origin of the Moon. By the 1990s, most scientists considered the question largely settled. Eventually the hypothetical impactor earned the name Theia, after the mother of the Moon in Greek mythology.

Changing Tides

At roughly the same time that the giant-impact hypothesis appeared, astronomers realized they could use the varying ratios of certain isotopes — atoms of the same element with a varying number of neutrons — to probe the origins of solar system bodies. These variations reflect the composition of the unique regions of the solar nebula each object sampled during its formation. This composition affects the proportions of heavy to light isotopes in an object as a whole, acting as a fingerprint for the object's formation history.

Scientists first used the varying ratios of oxygen's three isotopes. Initial analysis of the Apollo samples showed that, by this measure, the Moon and Earth are virtually identical, whereas other bodies in the solar system have distinctly different oxygen-isotopic ratios. The differences between Earth



▲ **OXYGEN ISOTOPES** Mars, the asteroid Vesta, and angrite meteorites all have notably different ratios of oxygen's three isotopes than terrestrial samples do. Samples of the Moon, however, plot right on top of Earth's values. The *x*-axis spread in each population is due to chemical processing within each body.

and Mars, for instance, are 100 times greater than those between Earth and its Moon. This similarity was initially taken as a point in favor for the giant-impact hypothesis: If a body as large as Theia crossed paths with Earth, scientists argued, then it must have formed in the same region of the solar system and had a similar isotopic composition.

This evidence would soon become problematic, though. Computer simulations developed in 2001 by Robin Canup (Southwest Research Institute) and Erik Asphaug (now at University of Arizona) indicated that in the "standard" giant-impact hypothesis, which involved a glancing blow, Theia's mantle contributes most of the material that ends up forming the Moon — somewhere between 70% and 90%. Concurrently, as laboratory techniques became more sophisticated, refined measurements showed with more precision that terrestrial and lunar isotopic ratios are virtually identical for most elements, including some that in principle should be different, like tungsten.

Unlike oxygen, tungsten's isotopes do not merely reflect a particular mix of the materials that formed a planet. Instead, tungsten-182 is generated when hafnium-182, a radioactive element with a relatively short half-life of 9 million years, eventually decays into it. While tungsten tends to bond with iron, hafnium has an affinity for silicates. As a result, hafnium and tungsten end up in different parts of a young planet as its interior separates into layers: Iron drags the tungsten with it as it sinks into the growing core, while hafnium remains in the mantle. If the core forms faster than all the hafnium-182 can decay, whatever hafnium-182 is left ultimately seeds the mantle with tungsten-182.

Since each planet's core likely assembles with its own pace and process, it's very unlikely that Theia and the proto-Earth could have had matching ratios of tungsten-182 to the element's other stable isotopes.

ISOTOPES: GREGG DINDERMAN / *S&T*, SOURCE KEVIN RIGHTER (NASA JSC) VIA ERIK ASPHAUG / *ANNUAL REVIEW OF EARTH AND PLANETARY SCIENCES* 2014

At the same time, dynamical models for the formation of the solar system began to show that it would be highly implausible to have two planet-size bodies with the same isotopic composition, even if they formed relatively close to each other. Planets grow by accreting the material in their orbits, but as an infant solar system evolves, these orbits also change, disturbing the solar nebula they're forming in and scattering dust and boulders around. As a result, each planet obtains a distinctive isotopic composition, similar to an unblended whiskey.

By the end of the 2000s, the feeling among planetary scientists was that the giant-impact hypothesis as originally defined was in trouble, threatened by what Jay Melosh (Purdue University) provocatively called an "isotopic crisis." The race to find a way to fix — or conceivably kill — Theia had begun.

Just Add Water

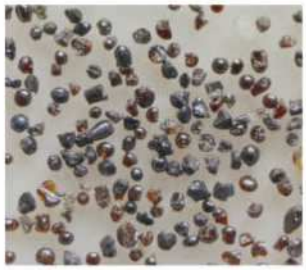
As the isotopic crisis developed, geochemist Alberto Saal (Brown University) proposed updating the water and other volatile content measurements for the Apollo samples, made in the 1970s. Saal had never worked with lunar rocks, but he knew that modern analytical tools were 10 times more precise than anything available back then. He sent a research proposal to NASA but hit a wall.

"They actually laughed," Saal says. The lunar samples were known to be bone-dry, so why check? "It took me three years for them to say yes."

Eventually, Saal's persistence earned him a few tiny volcanic glass beads to analyze, the very same ones that astronaut Harrison Schmitt had scooped up three decades earlier from the lunar surface. The magma that produced those beads had emerged from the depths of the lunar mantle, travelled up through the lunar crust, and been hurled to the airless surface of the Moon by a fire fountain–type volcano, similar to the ones found on Earth. Now they were in Saal's hands.

"As soon as we tried, we found the water," he says.

▼ **MORE LIKE THE MOON THAN EXPECTED** Seafloor basalts like those shown here from the Axial Seamount underwater volcano in the Pacific actually have a water content similar to that in lunar rocks. (Axial Seamount lies where the Juan de Fuca and Pacific plates are spreading apart.)



Water in Moon Rocks

Expected: **0**

Amount Saal's team found: **up to 1,410 ppm**

◀▲ **ALBERTO SAAL**

◀ **VOLCANIC BEADS** Sifting the Moon's orange soil yielded bits of volcanic glass, including those shown here. The particle size is about 100 microns. Studies of this sample and another from Apollo 15 revealed that lunar rocks contain water.

In the beads, the researchers found up to 46 parts per million (ppm) of water, a meager 0.0046%, but still a big departure from the scientific consensus of a perfectly dry Moon. Finding some water in the volcanic beads meant that the magma below the surface must have been even wetter. Underground magma contains dissolved water and gas. As it ascends during an eruption, its pressure decreases, allowing the gas to expand and escape from the molten rock. The released gas forces the magma to emerge even faster. "It's like opening a soda," Saal explains. "The fact that this type of volcanic bead is in the surface reveals that the magma had lots of gas."

According to the team's estimates, the magma that formed the beads probably had around 750 ppm of water, similar to the basalts erupting along Earth's mid-ocean ridges, implying that the Moon's interior could be as wet as Earth's.

These findings were backed by further analysis made by Saal, Erik Hauri (Carnegie Institution of Washington), and their colleagues of *melt inclusions*, small bubbles trapped in the volcanic beads. Like ancient, amber-preserved mosquitoes, these inclusions are bits of magma encapsulated by minerals that solidified before reaching the surface. They found up to 1,410 ppm of water, supporting earlier estimates. However, since the samples the team analyzed might not be representative of the bulk of the Moon, they conservatively claim that the lunar interior has at least a tenth the water content of Earth's interior.

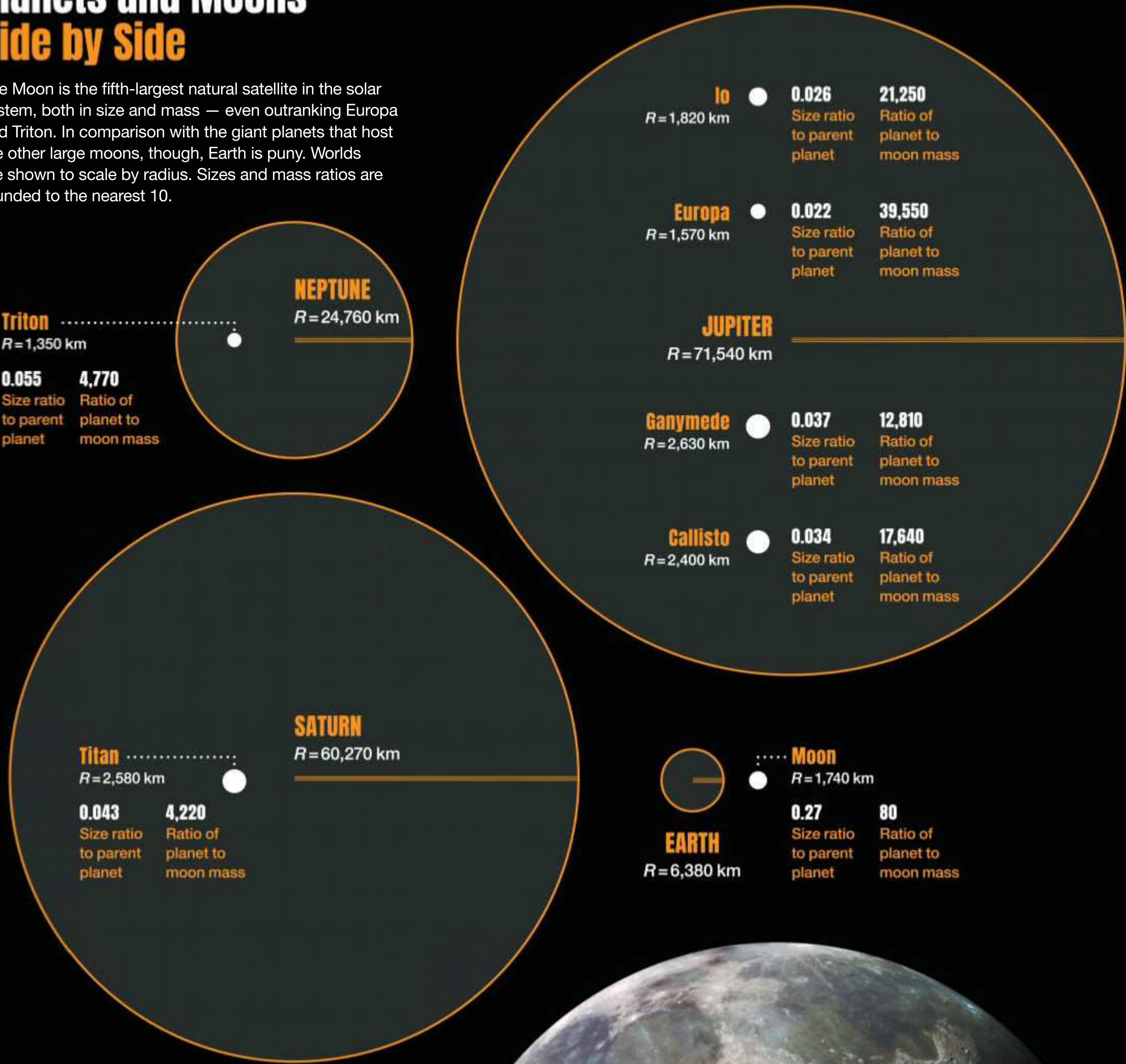
Since the Theia hypothesis was built on the premise that the Moon was totally dry, Saal thinks his findings open the door to a revision of ideas about how our natural satellite formed. "The models are flexible but the measurements are not," Saal says. "Now that we have new measurements, the models will have to change."

Fix the Scenario?

Since the giant-impact hypothesis was proposed, the power of modern laboratory analysis tools has shifted the ground below its foundations. The Moon is not considered bone-dry

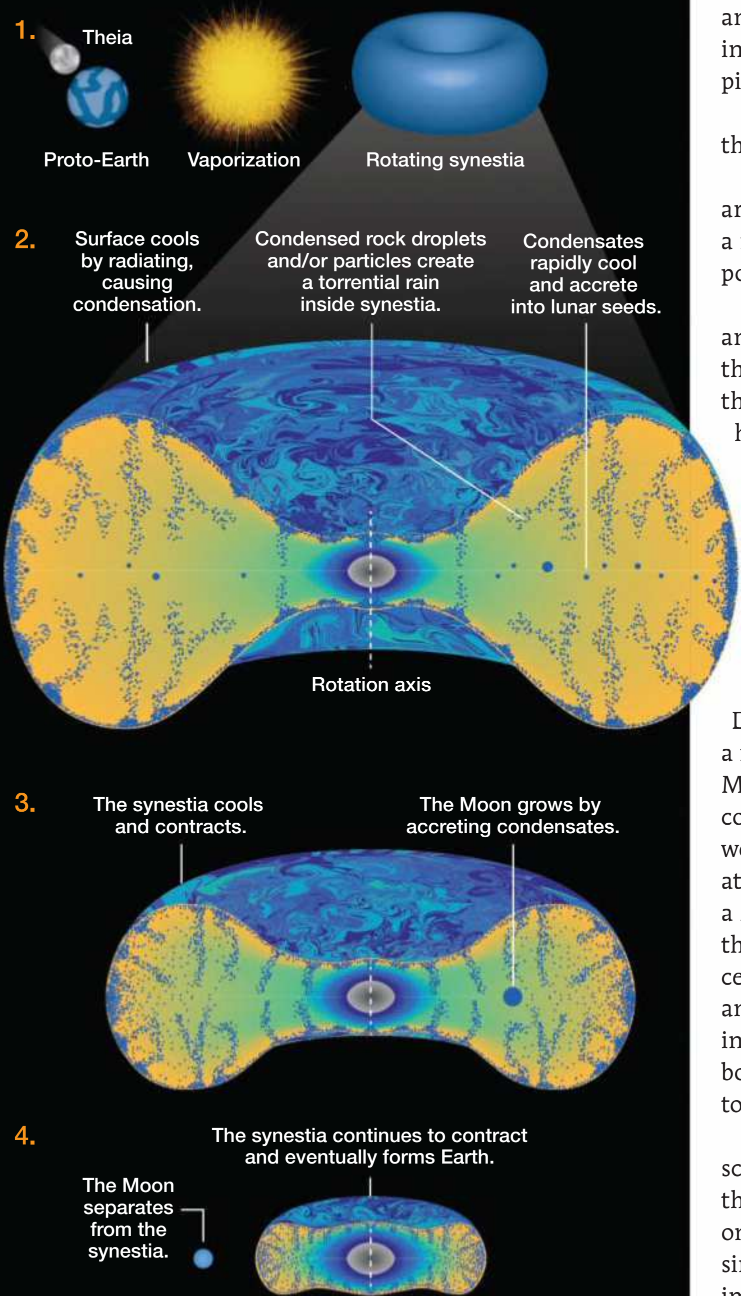
Planets and Moons Side by Side

The Moon is the fifth-largest natural satellite in the solar system, both in size and mass — even outranking Europa and Triton. In comparison with the giant planets that host the other large moons, though, Earth is puny. Worlds are shown to scale by radius. Sizes and mass ratios are rounded to the nearest 10.



THE MODERN MOON This 18-image mosaic from the Galileo spacecraft looks down on the lunar north pole. The lighter highland rocks are calcium-rich, metal-poor anorthosites, the original lunar crust. The maria formed much later, about 3.1 to 3.9 billion years ago, when lava erupted from great depths and pooled inside preexisting basins (*S&T:* Apr. 2016, p. 16).

MOON: NASA / JPL / USGS; SIZE COMPARISONS: TERRI DUBÉ / *S&T*



PLANETARY DANISH Recent simulations by Simon Lock and Sarah Stewart suggest that a high-energy collision that vaporized both the impactor and proto-Earth could explain why the Moon and Earth ended up so chemically similar. After the massive collision (**1**), the debris would have quickly formed a vast connected structure, or synestia, inside which turbulent convection would have mixed material into a fairly uniform soup. As the synestia's surface cooled, rock vapor there would condense into droplets and/or dust, falling as a torrential rain into the interior and building up into lunar seeds (**2**). Over the course of a year or so, the Moon grows from these moonlets and condensates (**3**). After several to tens of years, the synestia has cooled and shrunk enough that the Moon separates from it (**4**). The contracting synestia will eventually create Earth. The gray region is the iron core. Depending on the type of impact, most of the impactor's core merges with that of the proto-Earth, with the rest either ejected from the system, dissolved in the synestia's hot outer regions, or put into orbit as larger chunks.

anymore, many other volatiles like carbon have been found in lunar rocks, and the list of elements with matching isotopic compositions keeps growing.

Rather than killing Theia, most researchers are trying to fix the giant-impact scenario. The idea seems too good to discard.

To reconcile Theia with the new observations, scientists are trying one of two approaches. The first is to come up with a mechanism that could have equilibrated the isotopic compositions of Earth and Theia after the impact.

In 2007, Kaveh Pahlevan (now at Arizona State University) and David Stevenson (Caltech) developed a collision model that could have rendered an Earth-like Moon. They proposed that, right after the giant impact, the protolunar disk was so hot that it allowed the transfer of material from Earth into orbit through convection and turbulent mixing. However, the mixing must have been very efficient to completely mask Theia's isotopic contribution before the Moon formed and the disk disappeared. Also, extremely rapid mixing would require lots of convection, which would also cause rapid cooling and thus leave less time to mix the material well.

In 2012, Sarah Stewart (now at University of California, Davis) and Matija Ćuk (now at SETI Institute) tried to find a mechanism that would decrease Theia's contribution to the Moon. They showed that a faster, nearly head-on collision could launch more of our planet's mantle into orbit — *if* Earth were also spinning very fast (with a period of about 2½ hours) at the time of the impact. Although the extra energy produces a Moon-Earth system with much higher angular momentum than what we see today, Stewart and Ćuk calculated that certain orbital resonances could have transferred that excess angular momentum to Earth's orbital velocity, slightly enlarging its path around the Sun. This effect, combined with the bodies' tidal pulls on each other, ended up de-spinning Earth to its current 24-hour day.

This realization opened the door to more energetic impact scenarios and other exotic ideas. Among those to cross through that door was Simon Lock (Harvard University), one of Stewart's graduate students. While running computer simulations, Lock and Stewart realized that sometimes giant impacts vaporize so much material that the planet ends up looking like something completely different: a molten, bagel-shaped structure with a metal-rich bulge where it should have the hole. The bulge is the core of the planet, connected to an outer torus of silicate vapor and molten silicate droplets. Since there isn't a gap between the core and the torus orbiting around it, Lock and Stewart coined the name *synestia*, or "connected structure."

In this model, the Moon forms within the torus of the synestia. As the rock vapor cools down, it begins to condense into droplets of liquid. As these grow, they might form several moonlets that eventually merge together.

Lock's synestia could be the perfect superheated mixer in which the isotopic ratios of the impactor and the proto-Earth could equilibrate. There would be enough energy to mobilize

IMPACT CARTOON: GREGG DINDERMAN / *S&T*, SYNESTIA CUTAWAYS: SIMON LOCK a lot of material, and since the whole structure is connected everything would blend together. It's almost like accreting the Moon and Earth anew from a single source of material.

The synestia model also makes Moon-forming events more likely to occur. "The canonical model has a very narrow range of impact conditions over which it would work," Lock says. "You would need a roughly Mars-mass body traveling at near the escape velocity and hitting the proto-Earth within a couple of degrees of the correct angle." Synestias, on the other hand, can form under a wider range of circumstances.

▲ SIMON LOCK AND SARAH STEWART

Thomas Kruijer (Lawrence Livermore National Laboratory), who has recently performed high-precision measurements of tungsten isotopes in lunar rocks, agrees that a synestia could effectively mix tungsten isotopes. "Although it remains to be seen how likely this synestia scenario is, it at least would provide a possible way to explain the isotopic similarity of all elements," Kruijer says.

As another way to fix the scenario, some researchers instead question the single-hit idea. Last year, a team of Israeli researchers led by Raluca Rufu (Weizmann Institute of Science) suggested that a succession of smaller impacts could have launched enough material into orbit to form a few mini-moonlets. If they could stay in orbit long enough, they would eventually merge into the Moon. These impacts would have been fast and nearly head-on in order to mine and eject more Earth material on each hit, forming a Moon with a predominantly terrestrial makeup. Having multiple bodies crashing into Earth could further mask their isotopic signatures too, since one body's contribution would be diluted by the others.

Fix Theia?

The second way to fix the giant-impact theory is to fix Theia itself — by showing that it had the same isotopic composition as Earth all along. This position is mostly favored by geochemists who, undeterred by the current dynamical models of the solar system, suspect that if two worlds form in the same region from similar building blocks, they should share the same bulk chemistry.

The work of Nicolas Dauphas (University of Chicago) goes in that direction. Dauphas thinks that Theia and the proto-Earth assembled from the same material, a geochemical mix of stuff found in meteorites called enstatite chondrites. These meteorites have isotopic compositions very similar to those of Earth and the Moon and therefore might have formed in the same region of the protosolar disk.

"I actually think that's probably the most likely story," Stevenson says. "Not the complete story, but a major part of what was going on — that the thing that hit the Earth was actually very, very similar to Earth."

But most dynamicists don't share Dauphas's views. Planet formation is a chaotic process, explains Alessandro Morbidelli (Côte d'Azur Observatory, France), with each object forming from a slightly different mix of material. "My personal inclination is that there aren't two bodies alike in the solar system," he says, "and the fact that the Moon and Earth are so similar points toward a synestia."

A Long Way Ahead

More than 45 years after the last Apollo lunar landing, we are still missing important pieces of information in our attempts to fully unravel the origin of the Moon. Although the giant-impact hypothesis still seems the best bet, most of the ideas trying to fix its shortcomings require a set of special conditions to work. "For many of us, that necessary contrivance of having the initial conditions just right doesn't feel like a very natural solution to the problem," Melosh says. "Although you can't say it didn't happen, since we only have this one example of the Earth and Moon."

Sampling more solar system bodies — and Venus in particular — might be the only way to help scientists determine how variable the isotopic compositions were when the planets were forming. Thanks to Martian meteorites, researchers know that the Red Planet's oxygen ratios are quite different from those of Earth. That's likely because, since Mars is the outermost of the rocky planets, its formation was cut short by the giant planets ejecting material from its feeding zone. But if Venus shares Earth's isotopic compositions, Theia probably did, too. "There is a huge missing link in any story that seeks to understand what the projectile might've been, and that missing link is Venus," Stevenson says.

Meanwhile, scientists worldwide continue to try to find a complete solution. Lock is still working out the finer details of his synestia. "We've calculated what we expect for the composition of the Moon, and it matches to surprisingly good levels," he says. He has also been trying to figure out how astronomers could identify a synestia elsewhere — or clues that point to one, such as a rapidly rotating planet. Even if synestias happen often in the universe, they would be transient, short-lived events. "There is the chance we will never see one," he admits.

Despite the concerns, the giant-impact hypothesis looks secure. "There is no sensible alternative to a story where the Moon arose from a giant impact," Stevenson says. Theia will likely remain in astronomy textbooks for many years to come.

■ Former *S&T* intern **JAVIER BARBUZANO** is a bilingual (Spanish-English) science communicator. He holds a master's degree in science journalism from Boston University and writes about many topics, but astronomy and technology are his favorites. Find more about his work at **javierbarbuzano.com**.

UNIVERSITY OF CALIFORNIA, DAVIS

Aquila's Gems

LEYSAN / ISTOCK / GETTY IMAGES PLUS

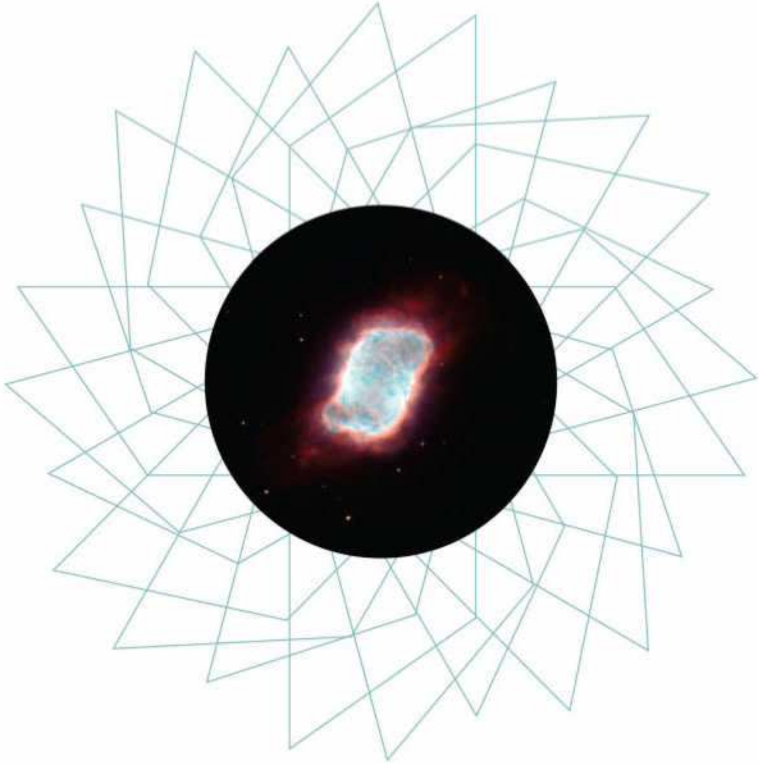
Planetary nebulae capture everybody's imagination, and the celestial Eagle offers a plethora of these gems.

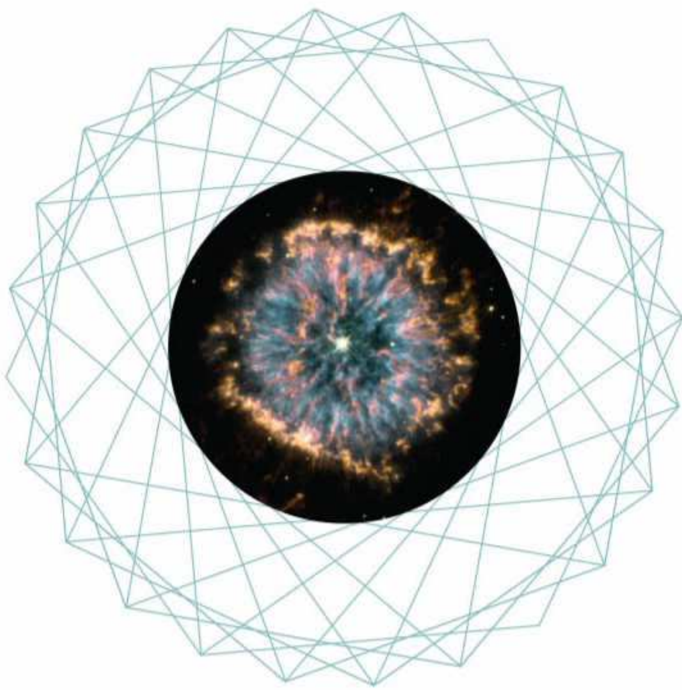
The Milky Way appears as a brilliant pillar of light stretching upward from the southern horizon on August evenings. High overhead, the summer triangle is anchored by its lucida, the bright star Altair, the alpha star of Aquila, the Eagle. Containing only three stars brighter than 3rd magnitude and having no Messier objects within its borders, Aquila may be unfamiliar to some observers, but not to admirers of planetary nebulae. Very few constellations contain as rich and diverse a population of these intriguing and colorful objects as the Eagle. There are over 140 of them within its boundaries. They make fascinating targets, and August nights are the perfect time to seek them out.

Many planetary nebulae appear green or blue, and while the color is often subtle, it can nevertheless be quite vivid.

Planetary nebulae are a late stage in the evolution of intermediate and low mass stars. They are comprised of a cloud of dust and gas, the expelled outer layers of the progenitor star, surrounding an extremely hot, very compact object. This central object is essentially an exposed stellar core caught in the act of evolving toward its end state as a white dwarf. Planetary nebulae can exhibit a wide range of morphologies, which is why they are so attractive as telescope targets. The expanding envelope that surrounds the star shines by fluorescence — it absorbs ultraviolet light from the central star and re-emits radiation at visible wavelengths. That happy circumstance is what makes some planetary nebulae such colorful objects. Many appear green or blue, and while the color is often subtle, it can nevertheless be quite vivid.

Planetary nebulae are identified by emission lines in their spectra (see page 58) — contrary to the absorption lines that characterize main sequence stars — that also reveal their highly evolved nature. The principal emission line results from doubly ionized oxygen (O III) at 500.7 nm. A large number of planetary nebulae are so small in angular size that they're distinguishable from stars only by their emission lines. Aquila contains dozens of planetary nebulae that appear stellar, or starlike, in the eyepiece. While many are visible in small apertures even under light-polluted skies, the challenge lies in picking the planetaries out from the crowded star fields where we often find them. A detailed star map is essential for locating these tiny objects, and a narrowband nebular filter is the only reliable way of positively identifying them.

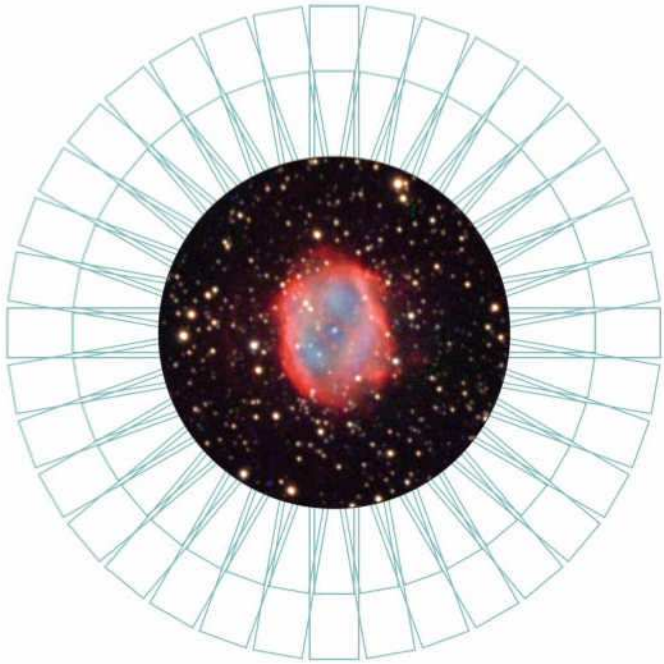




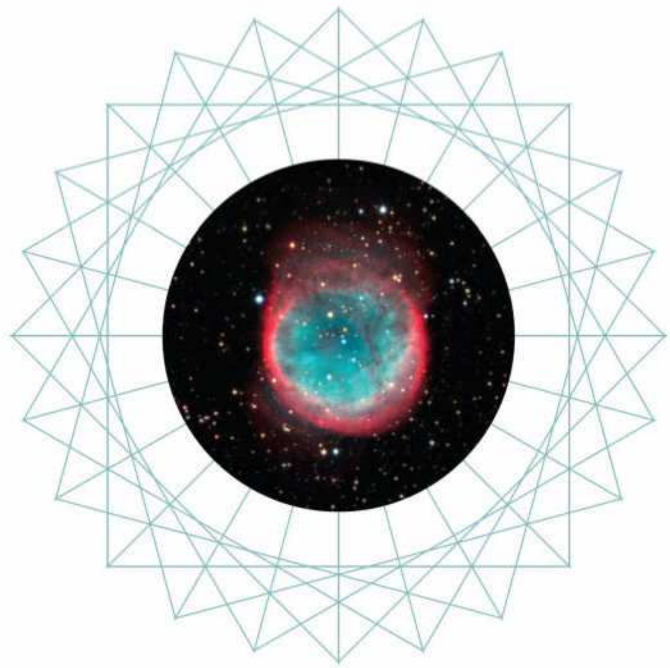
▲▲ **PHANTOM STREAK** Planetary nebulae, the last gasps of dying stars, come in a variety of different morphologies, making them very attractive observing targets. Aquila, the Eagle, is brimming with these celestial gems, such as NGC 6741. The images accompanying this article are either taken with the Hubble Space Telescope or with larger ground-based telescopes. As you take your tour through Aquila and gaze upon these ethereal objects, keep in mind their sometimes astonishing structure.

▲ **DANDELION PUFFBALL** NGC 6751, shown here in this Hubble Space Telescope image, is a prime example of why so many of these objects earn such colorful nicknames.

NGC 6741: ESA / HUBBLE / NASA; NGC 6751: NASA / ESA / THE HUBBLE HERITAGE TEAM STSCI / AURA



▲ **ANCIENT BUBBLE OF GAS** NGC 6772 is an evolved planetary nebula with a rather low surface brightness. Dark, transparent nights are recommended for trying to spot this diffuse annulus.



▲ **THE AUTHOR'S FAVORITE** Ted Forte is particularly fond of NGC 6781. Look for this gem, with its irregular annular disk and a smattering of stars superposed on the nebula, under the Eagle's western wing.

NGC 6772: ADAM BLOCK; NGC 6781: JOSEF PÖPSEL / BEATE BEHLE

By holding a filter between thumb and forefinger and repeatedly passing it between eye and eyepiece, a planetary nebula can be made to *blink*. The filter's suppression of all but the few wavelengths that constitute the principal emission of these objects makes them seem to brighten against the backdrop of stars. It takes practice to master this blinking technique, and Aquila offers several fine test subjects to tempt you to try your hand at it.

M 1-66 is located near the far western edge of the Eagle, 1.5′ west of a 10.8-magnitude star. **M 1-69** lies about 3° west-northwest of Delta (δ) Aquilae. **M 1-70** sits on the border of an area of patchy dark nebulae known as Barnard 332 and is 6.5° west-northwest of Altair. **M 1-74** is on Aquila's northern border with Sagitta. All of these tiny objects are visible in an 8-inch telescope from dark skies. A nebular filter like the O III will improve their contrast with neighboring stars and make them stand out when you employ the filter-blinking technique.

Planetary nebulae can be classified as high, intermediate, or low excitation based on the intensity of certain emission line ratios. **NGC 6741**, or the Phantom Streak Nebula, is a notably high-excitation planetary with an unusually rich spectrum located 30′ east of the nondescript open cluster NGC 6735. It's visible as a small green disk when viewed without a filter. A dim star close to its northwestern edge seems to be nearly in contact with the planetary. The object *responds* to the O III filter, by which I mean that the filter improves the contrast of the object and enhances the view.

It's remarkable to contemplate that if we are, in the words of Carl Sagan, "star stuff," it's planetary nebulae that are responsible for making that star stuff available.

The astronomer Bruce Balick described **NGC 6751** as a "dandelion puffball" and that nickname has attached itself to the object. The professional literature reveals NGC 6751 to be a highly structured, multiple-shell planetary with a bipolar outflow. Well-known observer Steve Coe proclaims it to be one of the best objects in Aquila, and many would agree. Its bright disk is usually seen as green and on nights of good seeing can exhibit a ring structure. Higher powers will reveal its faint central star. The nebula responds well to the O III filter but can be seen without it. NGC 6751 lies 1° east-southeast of 4th-magnitude 12 Aquilae and 30′ southeast of the fine carbon star V Aquilae.

NGC 6772 is a rather evolved planetary resulting in a diffuse disk of low surface brightness. I find it necessary to employ the O III filter to find this planetary, although once detected, it becomes faintly visible without the filter. On the best transparent nights, the disk appears annular and, on occasion, it displays two darker areas that are reminiscent of the "eyes" of the Owl Nebula, M97, in Ursa Major. The scientific literature on NGC 6772 describes pockets of CO emission concentrated in two clumps where the emission lines are weaker. While I've

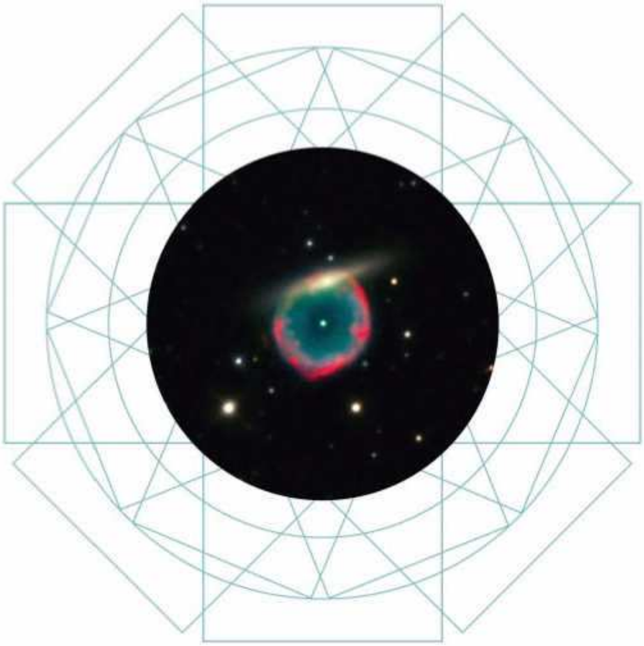
▲ **MULTIPLE SHELLS** As if suspended in space, NGC 6804, discovered by William Herschel, floats like a gauzy button. It is an example of a planetary nebula with multiple shells that are most probably due to the presence of a binary star at the core. North is up.

VOLKER WENDEL / STEFAN BINNEWIES / JOSEF PÖPSEL

not found any declared correlation between these CO clumps and a visually detectable feature, it's exciting to speculate that they're linked. NGC 6772 is located 3° northeast of Lambda (λ) Aquilae.

Situated beneath the tail of the Eagle in the southwest corner of the constellation, **IC 4846** is a starlike object that reveals a tiny disk when a filter is used. Both its small angular size and a high electron density indicate that this is a rather young planetary nebula. Morphological evaluation hints at a number of knots embedded in an elongated structure, but none of that is detectable to the eye.

Perhaps the most exciting area of research involving planetary nebulae today involves the hypothesis that the non-spherical morphology exhibited by most planetary nebulae may be the result of the interaction of binary central stars. An exceptionally hot topic is the role played by common envelope binaries. The late evolution of a binary star system often results in a rapid decrease in the orbital separation of the two stars, which results in the once separate objects being drawn so closely together that one companion is absorbed into the atmosphere of the other. The two stellar cores continue to gravitationally interact within their com-



▲ **DIAMOND RING** You will find Abell 70 in the far southeastern corner of Aquila. An O III filter will help bring out the ghostly disk of this planetary nebula.

mon envelope. The propeller-like effect of the two rapidly orbiting cores in conjunction with other forces expels the outer layers of the envelope. The expulsion usually manifests in bipolar or multipolar outflows shaped by powerful magnetic fields and nonspherical outbursts. The relationship to observed planetary nebula morphology is unmistakable — in theory. The problem is that too few planetary nebulae have been confirmed to have binary central stars. It's likely that future surveys may eliminate the discrepancy, but until then the role of binaries in the formation of planetary nebulae remains a subject for debate.

Our next target, **NGC 6778**, harbors a short-period binary central star and is one of the objects being studied to assess the role of the common envelope phase in the formation of planetary nebulae. Under detailed scrutiny, NGC 6778 is revealed to be bipolar with two jets, or collimated outflows. Those outflows show a clear connection to the dual lobes of the nebula. In the eyepiece, however, NGC 6778 doesn't reveal its bipolar structure as anything more than a slight elongation of a mostly round disk. The 16.9-magnitude central star is usually not seen, but I have suspected it on occasion. A faint outer halo is also sometimes visible. NGC 6778 is 5′ west-southwest of an 8.5-magnitude star in the middle of the Eagle's tail.

My favorite Aquila planetary is undoubtedly **NGC 6781**, located about a third of the distance between Delta (δ) and

The Eagle's Gems

Object	Alt. Name	Surface Brightness	PN Mag(v)	Central Star Mag(v)	Size	RA	Dec.
PK 32-2.1	M 1-66	8.8	13.0	—	10″	$18^h\ 58.4^m$	−01° 04′
PK 38-3.2	M 1-69	8.3	14.0	—	10″	$19^h\ 13.9^m$	+03° 38′
PK 45-2.1	M 1-70	9.3	12.7	14.6	14″	$19^h\ 24.4^m$	+09° 54′
PK 52-4.1	M 1-74	8.5	12.9	18.1	5″	$19^h\ 42.3^m$	+15° 09′
PK 33-2.1	NGC 6741	7.6	11.5	20.3	8″	$19^h\ 02.6^m$	−00° 27′
PK 29-5.1	NGC 6751	9.3	11.9	15.4	26″	$19^h\ 05.9^m$	−06° 00′
PK 33-6.1	NGC 6772	14.2	12.7	18.6	86″	$19^h\ 14.6^m$	−02° 42′
PK 27-9.1	IC 4846	4.3	11.9	15.1	11″	$19^h\ 16.5^m$	−09° 03′
PK 34-6.1	NGC 6778	11.1	12.3	16.9	37″	$19^h\ 18.4^m$	−01° 36′
PK 41-2.1	NGC 6781	12.9	11.4	16.7	114″	$19^h\ 18.4^m$	+06° 32′
PK 37-6.1	NGC 6790	3.7	10.5	11.1	10″	$19^h\ 23.0^m$	+01° 31′
PK 46-4.1	NGC 6803	4.8	11.4	15.2	10″	$19^h\ 31.3^m$	+10° 03′
PK 45-4.1	NGC 6804	12.2	12.0	14.3	66″	$19^h\ 31.6^m$	+09° 14′
PK 42-6.1	NGC 6807	6.1	12.0	16.3	8″	$19^h\ 34.6^m$	+05° 41′
PK 42-14.1	NGC 6852	9.5	12.6	17.9	28″	$20^h\ 00.6^m$	+01° 44′
PK 38-25.1	Abell 70	13.4	14.5	19.1	42″	$20^h\ 31.6^m$	−07° 06′

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.

MAKIS PALAIOLOGOU / STEFAN BINNEWIES / JOSEF PÖPSEL

Zeta (ζ) Aquilae and 28′ east of a magnitude-6.7 star. It's an irregular annular disk that appears ragged on its north rim and very much brighter and more sharply defined on the south. A number of stars superposed on the nebula add immeasurably to its charm. While it responds to nebular filters, they are not necessary to see the object. The 16.7-magnitude central star is not seen. It's likely that we see NGC 6781 pole-on and that its true shape is bipolar. A study of the molecular hydrogen in its halo shows evidence of shock excitation, suggestive of very intense polar outflows.

NGC 6790 is sometimes challenging to detect and appears stellar at low powers. High power on nights of good seeing yields a tiny visible disk that is very subtly blue. It is located on a line connecting Delta and Lambda Aquilae about a quarter of the way from Delta. NGC 6790 seems to be a relatively young object and is thought to be truly spherical. It's been suggested as the prototype of a body that's intermediate in age, density, and evolutionary stage.

If you look some 3° 40′ west of Gamma (γ) Aquilae you should find the small, bright, bluish disk of **NGC 6803**. The center of the nebula is bright and hides the 15.2-magnitude central star. It's stellar at low powers, but an O III filter helps to make the small disk visible.

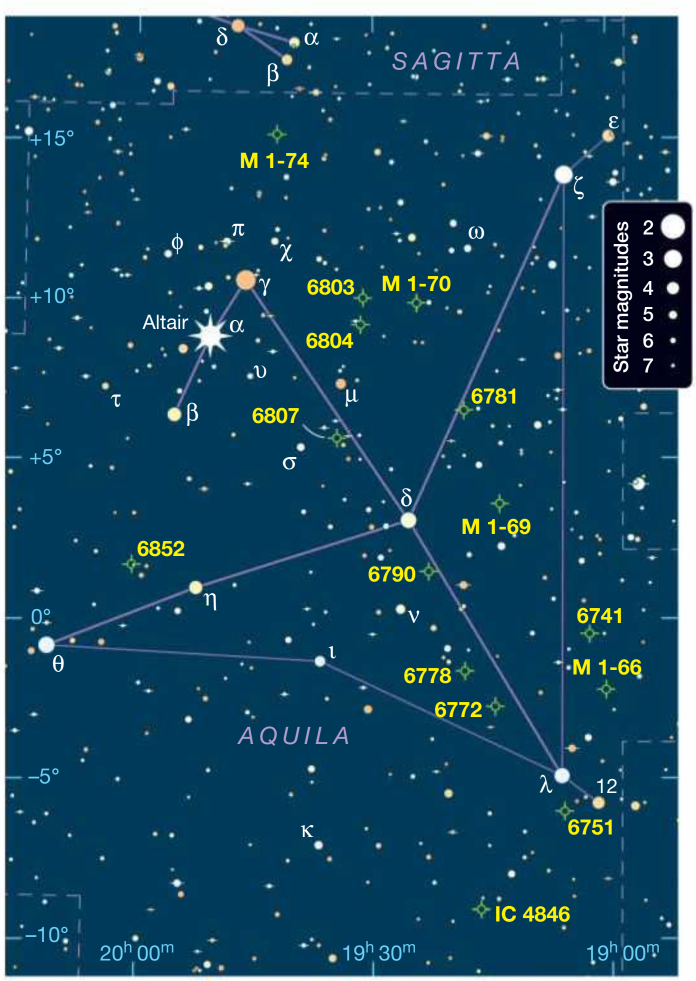
About 50′ directly south of NGC 6803 is **NGC 6804**. The 14.3-magnitude central star is seen surrounded by a fainter shell. It responds well to filters but is much prettier without. Two other stars are superposed on the disk. This nebula was discovered by Sir William Herschel, who mistook it for a cluster of stars and placed it in his Class VI (rich and compressed clusters). NGC 6804 is an example of a multiple-shell planetary nebula. It has an oval inner shell that is apparently breaking through the rounder outer structure.

NGC 6807 is easily seen with direct vision as a faint, vaguely blue star that responds to the O III filter. It is located 3.5° northeast of Delta Aquilae.

Two degrees northeast of Eta (η) Aquilae, **NGC 6852** is seen as a tenuous transparent disk when an O III filter is employed. It's 4.5′ northeast of a 7th-magnitude star, and there's a 14th-magnitude star on the southeast edge of the nebula. A fainter star lies within the nebula, but the 17.9-magnitude central star is not visible.

Abell 70 is sometimes called the Diamond Ring, a name popularized by Eric Honeycutt in his May 2002 *Sky & Telescope* article, "The Best Abell Planetary Nebulae." However, Honeycutt attributes this nickname to Jay McNeil, of McNeil's Nebula fame. Find Abell 70 in the southeast corner of the constellation, where it is the apex of a triangle that has Epsilon (ε) Aquarii and 3 Aquarii as its base. Abell 70 is a ghostly disk that benefits from an O III filter.

Abell 70 is now known to harbor a binary central star and is the subject of intense study. The binary consists of a main sequence star seen at optical wavelengths and a hot white dwarf secondary detected in the ultraviolet. The spectrum identifies the secondary as a barium star, which is an important object of interest to astronomers. It provides evidence supporting a hypothesized scenario whereby the secondary has become polluted by material from the primary. During its thermal pulse phase of evolution, carbon and heavier *s-process* (slow neutron capture process) elements are dredged up from deep within the larger star and deposited on the white dwarf through a process known as wind accretion.



▲ **SOAR WITH THE EAGLE** All the targets discussed in the text except for Abell 70 (in the far southeastern corner of Aquila) appear here.

Objects like Abell 70 and NGC 6778 illustrate the importance of planetary nebulae as laboratories for the study of stellar evolution and processes like common envelope interaction. Our current understanding of planetary nebulae as purveyors of the heavy elements that enrich the interstellar medium points to their extreme importance in the cycle of creation that makes things like planets and people possible. It's remarkable to contemplate that if we are, in the words of Carl Sagan, "star stuff," it's planetary nebulae that are in part responsible for making that star stuff available.

■ Contributing Editor **TED FORTE** observes planetary nebulae and other faint fuzzies from his home observatory near Sierra Vista, Arizona. He coordinates the Astronomical League's Planetary Nebula Observing Program.

1 **DUSK:** The month opens with a glorious quartet of planets arcing low across the sky, with Mars in the southeast, Venus in the west, and Saturn and Jupiter in between. Enjoy this spectacle all month long.

6 **MORNING:** The waning crescent Moon shines near the Hyades in Taurus.

11 **DAYTIME:** A partial solar eclipse is visible across Greenland, northern Europe, and northeast Asia.

12–13 **LATE NIGHT TO DAWN:** The Perseids peak the evening of August 12th. Head out in the pre-dawn hours on August 12th and 13th to catch the best this meteor shower has to offer. The new Moon on August 11th promises optimal viewing conditions throughout both nights — provided, of course, that the skies are clear.

14 **DUSK:** Brilliant Venus and the delicate waxing crescent Moon, around 6° apart, bracket Gamma (γ) Virginis (Porrima) as they set toward the west.

16 **DUSK:** Jupiter hovers a mere ½° above Alpha (α) Librae, while the Moon guards the pair a little more than 7° to the right or upper right.

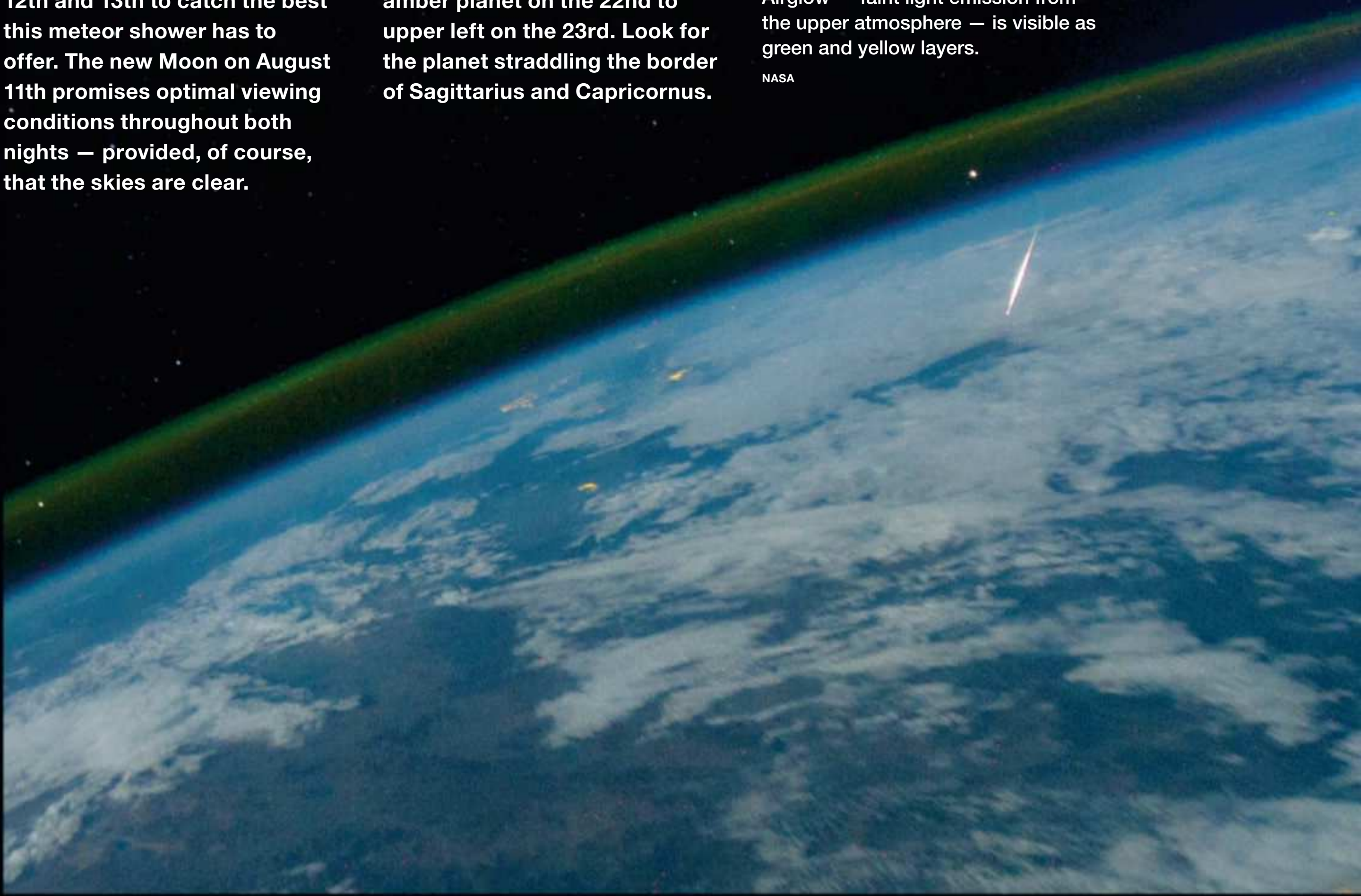
20 **EVENING:** Look for the waxing gibbous Moon 4° upper right of golden Saturn, the ringed planet still gracing Sagittarius.

22–23 **EVENING AND NIGHT:** The fattening Moon traces an arc some 8–9° above Mars as it glides from upper right of the amber planet on the 22nd to upper left on the 23rd. Look for the planet straddling the border of Sagittarius and Capricornus.

26 **DAWN:** As the full Moon sets in the west, look to the east-northeast to see Mercury rising — the tiny world reaches greatest western elongation 18° from the Sun this morning. Bring binoculars.

31 **DUSK:** Venus has crept up on Spica, and the two are separated by little more than 1° as they set toward the west.

▼ With the Moon mostly out of the way for the nights of August 12th and 13th, this is a great opportunity to view the Perseid meteor shower. Astronaut Ron Garan, flight engineer for Expedition 28 aboard the International Space Station, took this photograph of a Perseid meteor over China in 2011. Airglow — faint light emission from the upper atmosphere — is visible as green and yellow layers.
NASA



AUGUST 2018 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	31	

LAST QUARTER

August 4
18:18 UT

NEW MOON

August 11
09:58 UT

FIRST QUARTER

August 18
07:48 UT

FULL MOON

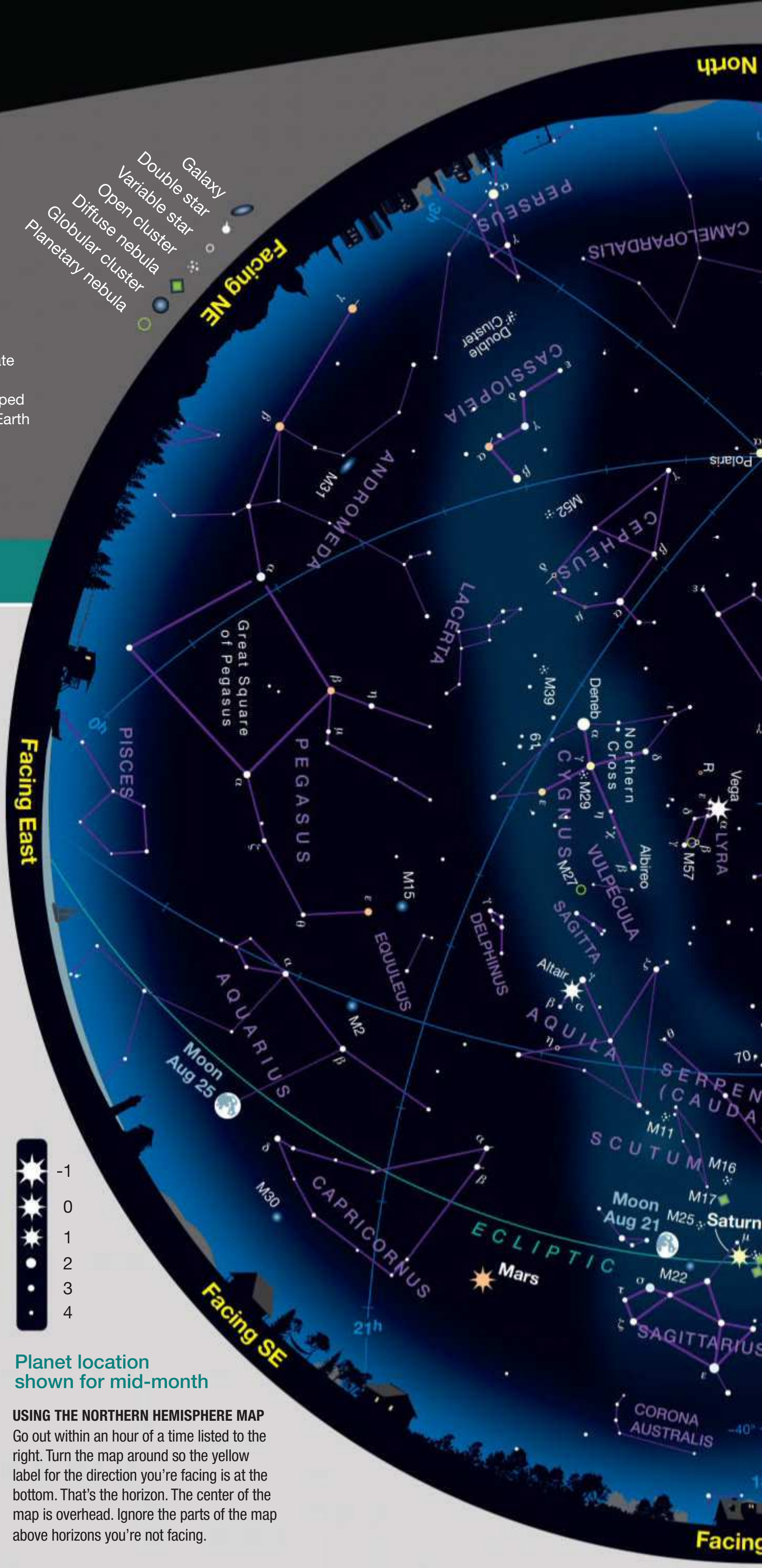
August 26
11:56 UT

DISTANCES

Perigee	August 10, 18^h UT
358,078 km	Diameter 33′ 22″
Apogee	August 23, 11^h UT
405,746 km	Diameter 29′ 27″

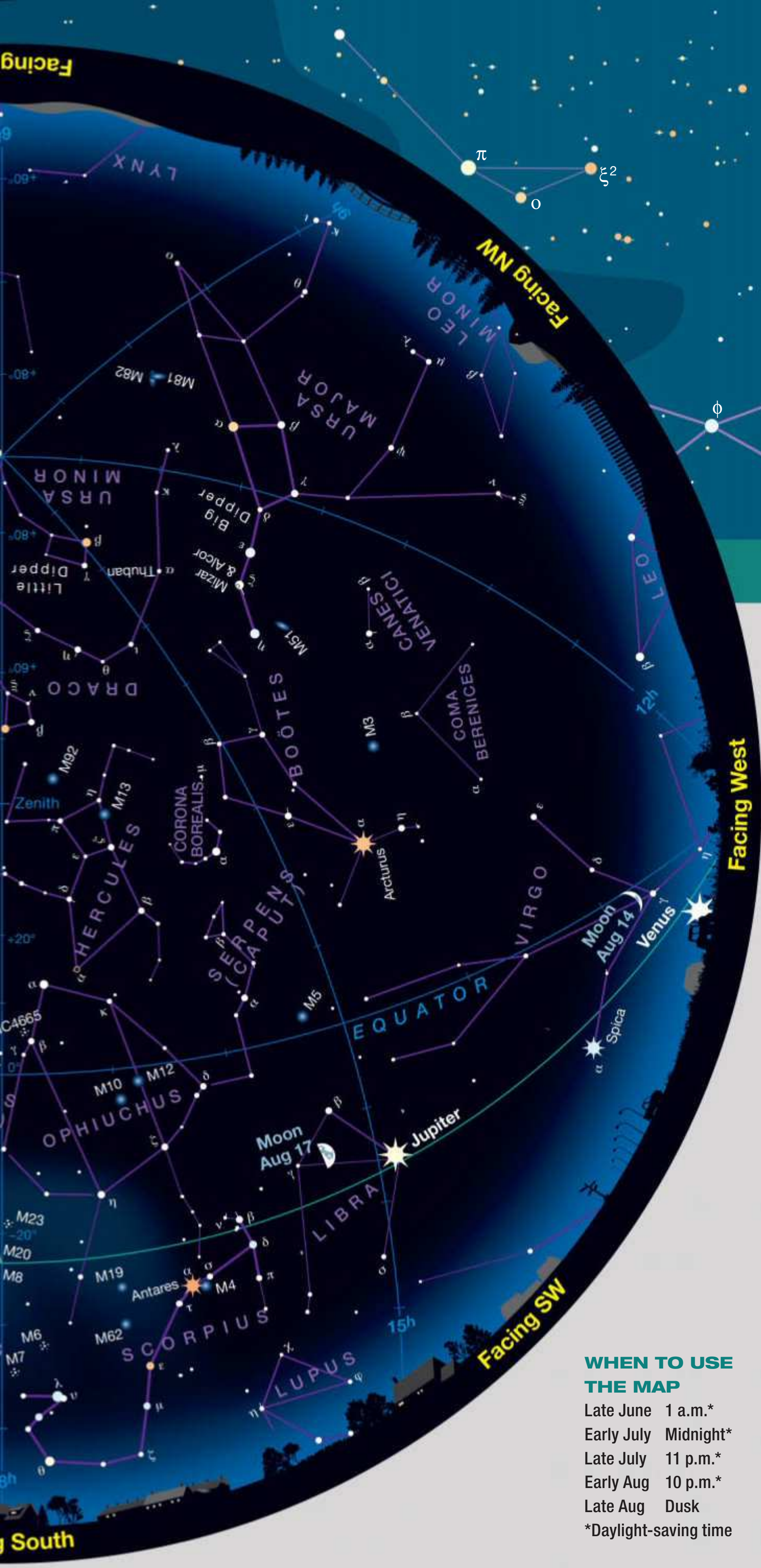
FAVORABLE LIBRATIONS

• Bunsen A Crater	August 3
• Gerard Q Inner Crater	August 5
• Jenner Crater	August 17
• Lyot Crater	August 19



Planet location shown for mid-month

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



WHEN TO USE THE MAP

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

*Daylight-saving time

Binocular Highlight by Mathew Wedel

Surprises Come in Twos

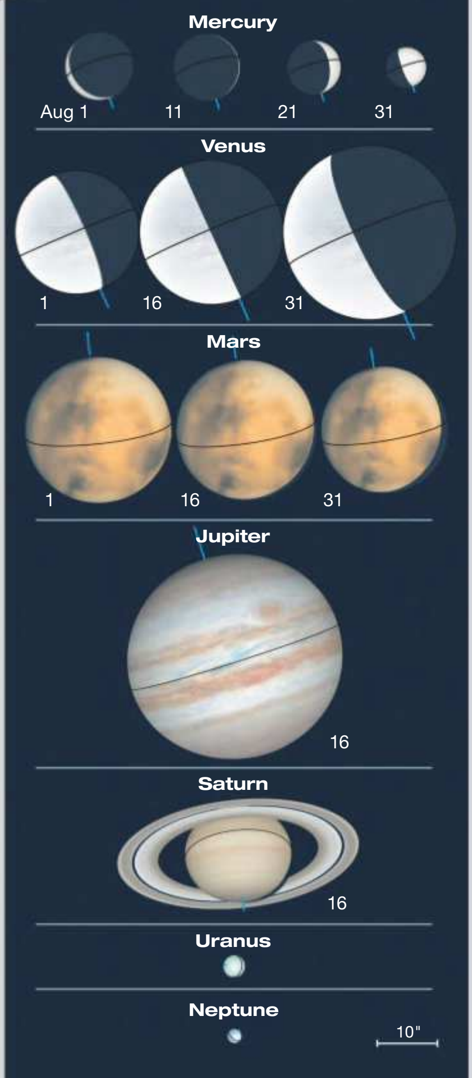
Perhaps the best argument for slowing down and really looking at celestial objects is that you often see something surprising, either in the object itself or in the same field. So it was last weekend, when I was checking on M8, the Lagoon Nebula, and M20, the Trifid Nebula, for the first time this season. I noticed what looked like a pair of open clusters in the same field, each about 1.3° east-northeast of the respective nebulae. They were so bright and obvious that my first thoughts were, “How have I not noticed these before?” and, “What the heck are they?”

The more southerly and brighter of the two was easy to identify: It was **Collinder 367**. With a diameter of 40′ and a magnitude of 6.4, it’s big and bright enough to be plotted in most atlases these days. The northern cluster wasn’t listed in any of my magnitude-6 or -7 atlases, but I found it in one of the deeper, more comprehensive sources back home. It’s **ASCC 93**, one of 109 new open clusters identified by Kharchenko and colleagues in 2005, based on the All-Sky Compiled Catalogue of 2.5 million stars that was published online in 2001. It’s smaller and dimmer than Cr 367 but still an easy catch in 7×50 binos under reasonably dark skies.

Whatever we call them, I can’t help but see four objects in a parallelogram now. In the northwest corner, M20, M21, and a group of bright stars between them all merge together into a bright glow that rivals M8, which occupies the southwest corner. To the east, Cr 367 and ASCC 93 seem like smaller, fainter echoes of their nebular neighbors. Have a look and see if they don’t jump out at you as well.

■ **MATT WEDEL** thought he’d know the sky pretty well after a decade of observing. He’s never been happier to be wrong.

PLANET VISIBILITY **Mercury:** visible at dawn after the 20th • **Venus:** visible at dusk • **Mars:** visible at dusk, highest near midnight • **Jupiter:** visible at dusk, sets late evening • **Saturn:** visible at dusk, sets after midnight

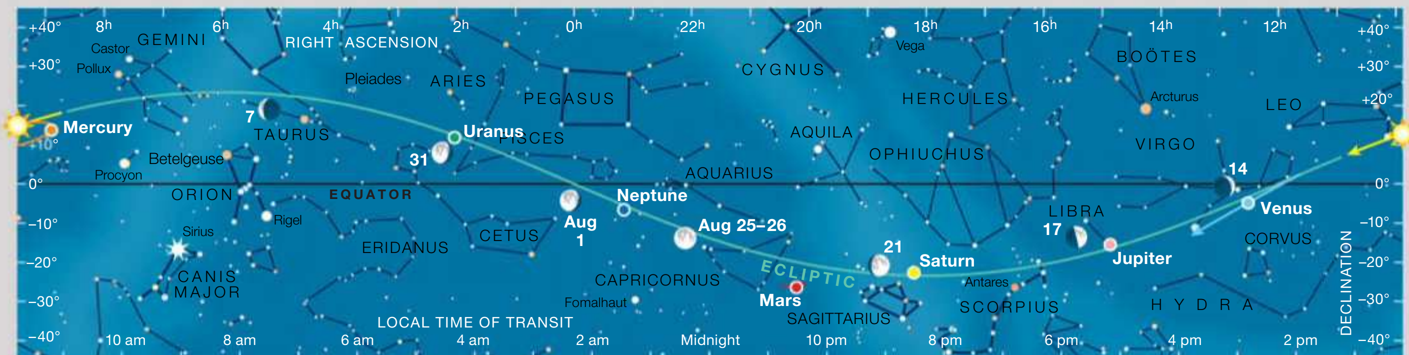


PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

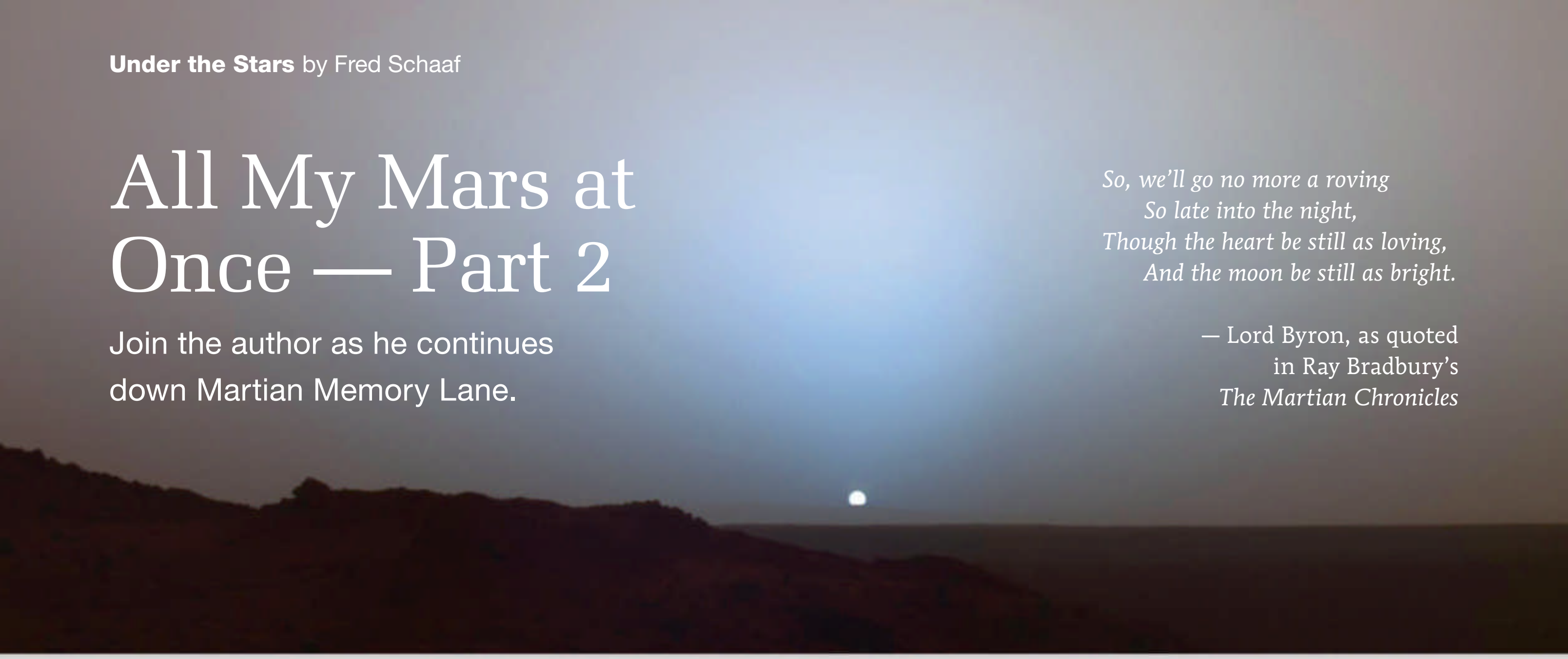
August Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$8^h\ 43.6^m$	+18° 09′	—	–26.8	31′ 31″	—	1.015
	31	$10^h\ 36.0^m$	+8° 50′	—	–26.8	31′ 41″	—	1.010
Mercury	1	$9^h\ 30.8^m$	+9° 56′	14° Ev	+2.9	11.0″	8%	0.610
	11	$9^h\ 03.4^m$	+12° 01′	6° Mo	+5.0	10.9″	2%	0.616
	21	$8^h\ 53.3^m$	+15° 16′	16° Mo	+1.1	8.7″	21%	0.769
	31	$9^h\ 29.9^m$	+15° 20′	17° Mo	–0.7	6.5″	61%	1.029
Venus	1	$11^h\ 36.4^m$	+2° 37′	45° Ev	–4.3	20.4″	57%	0.818
	11	$12^h\ 12.7^m$	–2° 18′	46° Ev	–4.4	22.6″	52%	0.739
	21	$12^h\ 46.7^m$	–7° 05′	46° Ev	–4.5	25.3″	47%	0.659
	31	$13^h\ 18.2^m$	–11° 35′	45° Ev	–4.6	28.8″	41%	0.580
Mars	1	$20^h\ 26.1^m$	–25° 58′	171° Ev	–2.8	24.3″	100%	0.385
	16	$20^h\ 11.5^m$	–26° 33′	156° Ev	–2.5	23.3″	98%	0.402
	31	$20^h\ 07.3^m$	–26° 04′	141° Ev	–2.1	21.0″	94%	0.445
Jupiter	1	$14^h\ 46.4^m$	–15° 03′	95° Ev	–2.1	37.9″	99%	5.201
	31	$14^h\ 58.3^m$	–16° 02′	69° Ev	–1.9	34.9″	99%	5.654
Saturn	1	$18^h\ 14.3^m$	–22° 36′	145° Ev	+0.2	18.0″	100%	9.218
	31	$18^h\ 10.0^m$	–22° 42′	115° Ev	+0.4	17.3″	100%	9.596
Uranus	16	$2^h\ 01.1^m$	+11° 45′	111° Mo	+5.8	3.6″	100%	19.499
Neptune	16	$23^h\ 07.9^m$	–6° 40′	157° Mo	+7.8	2.4″	100%	29.003

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



All My Mars at Once — Part 2

Join the author as he continues down Martian Memory Lane.

So, we'll go no more a roving
So late into the night,
Though the heart be still as loving,
And the moon be still as bright.

— Lord Byron, as quoted in Ray Bradbury's *The Martian Chronicles*

▲ NASA's Mars Exploration Rover Spirit captured this panorama of Mars's western sky as the Sun set behind the rim of Gusev Crater.

NASA / JPL-CALTECH / TEXAS A&M / CORNELL

Because of the ideal Mars opposition this year, I wanted to cram into a two-part column as many of my marvelous Mars memories as possible. Here's part two. What most wonderful memories of Mars do *you* have?

From John Carter to the Viking Project. How delightful are the invented names and words in Edgar Rice Burroughs's books about John Carter of Mars: thoats, calots, banths, Barsoom, and especially Tars Tarkas — a name I've always thought would be great for a very large planetary telescope. Who hasn't read, heard, or seen "The War of the Worlds" as presented by H. G. Wells, Orson Welles, or George Pal? And potent parts of Ray Bradbury's *The Martian Chronicles* include "Rocket Summer," and two poignant quotes from the poet Byron.

Speaking of fantasies, I vicariously lived a real-life one through the Viking Project internship of my college roommate, Steve Albers. He sent me everything, from insider Viking images to JPL employees' recreation club flying disks, and shared with me by far the longest phone calls of my life.

When Mars and Saturn touched. On June 4, 1978, Mars and Saturn were high in darkness and a little more than 0.1° apart, a proximity that greatly enhanced Saturn's gold and Mars's orange. The sharp area of our vision is only within a few degrees of its center, so when I gazed slightly away to take in the whole scene, the reduced sharpness made the rays of the two planets appear to touch each other. Also wonderful was my crisp, detailed view in an 8-inch telescope at 200× — Mars with its polar icecap and dark markings together in one field with Saturn and its rings and brighter moons.

When Mars and Jupiter conquered the full Moon. Conjunctions of Mars and Jupiter occur at intervals of slightly longer than two years, when Mars is relatively dim and small, because the planets are never more than about 90° from the Sun. Never? No, once every 143 years the two planets meet when they are near opposition, at their brightest and biggest. This last happened on Leap Night (the night of February 29–March 1) in 1980. That night I was near Binghamton, New York, and the temperature plunged to –23°F. Brightest Jupiter and brightest Mars stood together right beside the precisely full Moon — and the two planets formed the only night-sky sight I've ever witnessed that exceeded even the impact and power of a full Moon.

The loveliest trio: yellow Jupiter, orange Mars, and blue-white Regulus. That once-in-143 years there was actually a special series of three Mars-Jupiter conjunctions. On May 3, 1980, the last of the conjunctions occurred high in the evening with magnitude –2.2 Jupiter, magnitude +0.2 Mars, and magnitude 1.3 Regulus within a circle little more than 1.5° in diameter. The heart of Leo overflowed with the radiance of a triple "star" of proximity-enhanced gold, orange, and blue-white.

Two wonders of a daytime Mars. From my home, the Moon just missed the Red Planet the summer Mars was nearing its famed perihelic opposition of 2003, the closest in over 59,000 years. Up the ladder with my 10-inch f/7 Newtonian, seemingly levitating over the lunar surface, I was astonished by the color contrast of Martian orange with lunar yellow-white — but even more by the latter's contrast with the *chillingly* white polar icecap of Mars. As the Sun rose and the sky turned blue, the icecap remained intense and contrasted beautifully with that blue.

Many years earlier, not too many minutes after sunrise, I observed Mars with the unaided eye, and its orange was prominent against the deep blue sky. But even more special was the fact that I was observing Venus and Jupiter with the unaided eye in daylight at the same time. A repeat of this feat, but this time before sunset, might be tried again late in August 2018.

■ Contributing Editor **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.

And Then There Were Five

Four bright planets grace the skies, and tiny Mercury appears at the end of the month.

A quartet of planets bridges the sky from southwest to southeast at nightfall this month. Venus is first in the night's parade, setting at the end of astronomical twilight. Jupiter glows far upper left of Venus while Saturn shines in the south. Saturn is followed by the fourth bright planet, Mars, which reaches its highest in the middle of the night or late evening. Finally, after Mars sets, morning twilight comes and, in the second half of August, brings with it a good apparition of Mercury.

DUSK

Venus achieves greatest eastern elongation, 46° from the Sun, on August 17th. But for observers at mid-northern latitudes the angle of Venus's separation from the Sun is very shallow with respect to the sunset horizon at this time of year. So Venus is fairly low and getting lower during the month, its sunset altitude decreasing from about 20° to 15° in August. Its magnitude improves from –4.3 to a stunning –4.6, its angular diameter in telescopes grows from 20″ to 29″, and its phase thins from 57% to 40% illuminated. How many days before greatest elongation will Venus appear exactly half-lit in your telescope?

Venus closes in on Spica all month. On the final day of August the planet burns a little more than 1° below the star — but the pair are only about 10° high 30 minutes after sunset.

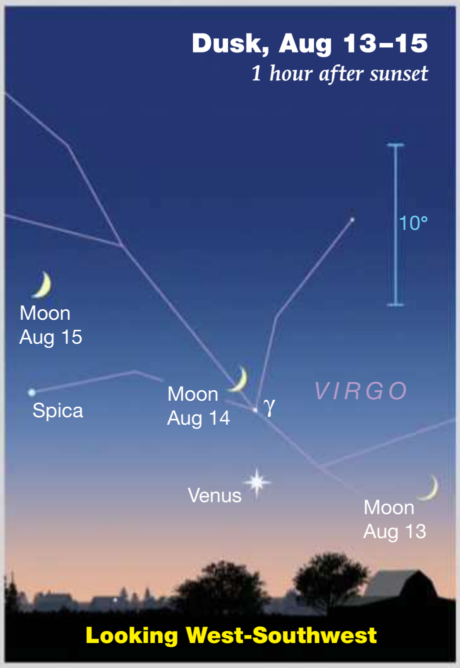
Most of the gaps between bright stars and planets at nightfall are similar around August 21st. The exception is Venus to Spica at less than 10°, but then we have 22° from Spica to Jupiter, 25° from Jupiter to Antares, 23° from Antares to Saturn, and finally 27° from Saturn to Mars.

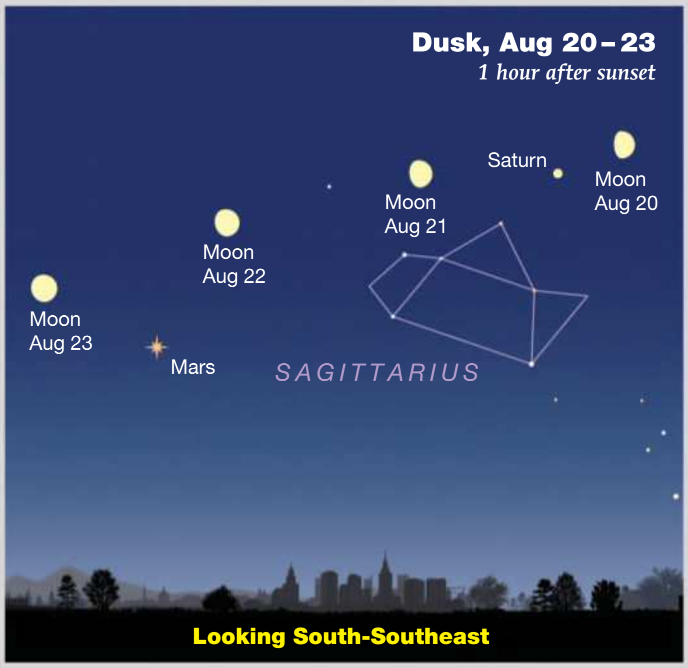
DUSK TO PRE-DAWN

Jupiter shines in the southwest at dusk. It fades from –2.1 to –1.9 during August, and its diameter decreases from about 38″ to 35″. The stately world reaches east quadrature, 90° east of the Sun, on August 6th, permitting improved views of eclipses of the Galilean satellites (see page 51 for a listing of specific events). Also note that Jupiter passes only about ½° north of the wide double star Alpha (α) Librae (Zubenelgenubi) around mid-month. Jupiter starts setting before 10:30 p.m. by the final days of August.

Saturn slows its retrograde (westward) motion in Sagittarius all month,

▶ 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.

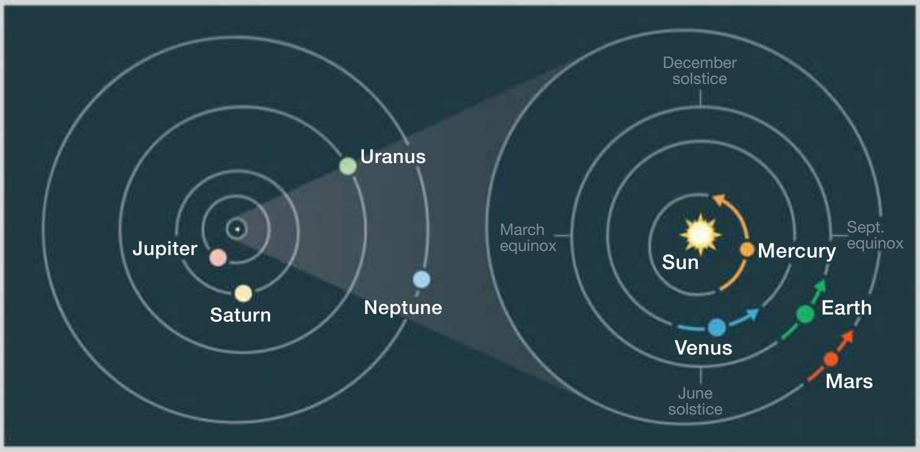




falling just short of reaching M8 (the Lagoon Nebula) and M20 (the Trifid Nebula). The ringed world is at its not-very-high highest around 10:30 p.m. as August starts and around 8:30 p.m. as the month ends. Saturn's brightness fades from magnitude +0.2 to +0.4, and its equatorial diameter decreases slightly from 18″ to 17″ — but its rings remain magnificently prominent, tilted at more than 26°.

Mars was at opposition on July 27th and its closest to Earth in 15 years on July 31st. The Red Planet remains brighter and bigger than it has been since 2003 for the entire month of August. Rising just after sunset as August begins, Mars crosses the meridian in the south after 12:30 a.m. in early August but before 10:30 p.m. as the month ends.

Mars starts August still burning at its peak magnitude of –2.8 and by the final days of the month glows at –2.2, still brighter than Jupiter. Telescopes reveal its globe to be more than 24″ wide on August 1st and 21″ wide on August 31st. For specific details on making telescopic observations of Mars and determining which side of the planet is facing you at a given time, see **https://is.gd/marsprofiler** and the July issue, page 22.



ORBITS OF THE PLANETS

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

The biggest problem for viewers around latitude 40° north or farther north is the extreme southerly declination of Mars this month. In addition to being near the southernmost part of the zodiac, it's also 6° south of the ecliptic. The tiger-colored planet moves from southern Capricornus back into Sagittarius, but halts its retrograde motion on August 28th and then resumes direct motion (eastward against the background stars).

Neptune and **Uranus** rise in the evening this month and are highest a few hours before dawn (Neptune) or before sunrise (Uranus). Finder charts for these two distant worlds appear at **https://is.gd/urnep**.

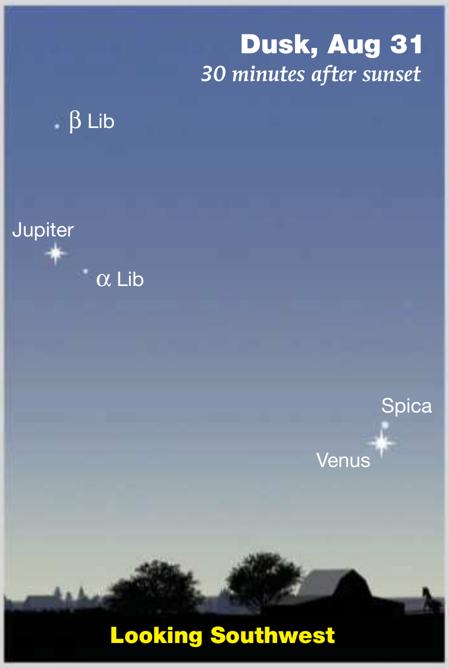
DAWN

Mercury leaps up from inferior conjunction on August 9th and becomes visible after the 20th; binoculars will help. By the 26th, the date Mercury reaches greatest western elongation 18° from the Sun, the planet is brighter than zero magnitude and rises just before 5 a.m., right after the start of astronomical twilight.

SUN AND MOON

The Sun is partially eclipsed by the Moon on August 11th across Greenland, northern Europe, most of Russia, and northeast Asia.

The Moon is a waning crescent entering the Hyades at dawn low in the east on August 6th. The waxing crescent Moon is around 10° right of Venus at dusk on August 13th and 7° above Venus on August 14th. The waxing gibbous Moon shines less than 4° right of Saturn at nightfall on August 20th. The fattening Moon is around 9° upper right of Mars at nightfall on August 22nd and then 8° upper left of Mars the next night.



■ **FRED SCHAAF** teaches astronomy at Rowan University and Rowan College in Gloucester County, both in southern New Jersey.

Peak Perseids

Plan for optimal conditions for the year's most popular meteor shower.

"Stars fell like weaving in the south, unceasingly through the night." So a city gazetteer printed in Shanxi, China, described the sky above Fenyang on August 10, 1862. Calculating backward, scholars have determined that the "weaving stars" witnessed by the townspeople were in fact Perseid meteors, falling at a time when the shower's radiant, the point from which the meteors appear to emanate, lay low in the sky.

The Perseids are associated with the short-period Halley-type comet 109P/Swift-Tuttle, which was independently discovered by American astronomers Lewis Swift and Horace Tuttle as it approached perihelion in July 1862. When Earth crosses Swift-Tuttle's orbit, bits of dust and rocks left behind by the comet hit the planet's atmosphere, creating the light show we know as the Perseid meteor shower. In years when Swift-Tuttle reaches perihelion, the number of visible meteors significantly increases, which explains the dramatic display of August 1862. Since the comet has a 133-year orbital period and last visited the inner solar system in 1992, we've got another 107 years to go before that possibility arises again. Occasional bump-ups in the number of detected meteors do occur when

This composite image is made of several exposures shot at Sunset Crater, Arizona, over nearly 2 hours on the morning of August 12, 2016. The image shows 48 Perseids — including two spectacular fireballs — and 5 sporadics (meteors not associated with the Perseids, identified by the trails not in alignment with the majority).

JEREMY PEREZ

Earth passes close to dust trails left behind during even earlier visits. However, the next such major outburst isn't predicted until 2028. Even so, the "ordinary" Perseids make for a strong shower and an impressive spectacle. Under ideal, dark skies, viewers may see more than 50 meteors in an hour.

The extant Chinese records for the 1862 event all come from northern China, suggesting unfavorable weather in the south that year. Here and now in 2018, we hope for good weather for the summer's greatest shower, because viewing conditions should otherwise be perfect. The shower's predicted peak falls on the evening of August 12th, soon after new Moon (9:58 UT August 11th). Weather and light pollution (and possibly mosqui-

▲ The Perseid meteors appear to stream away from the shower's radiant point near the border of Perseus and Cassiopeia.

toes) should be the only impediments to a good show. The best viewing will certainly be early on the mornings of August 12th and 13th, but don't wait for the predicted peak to go outside. Perseids begin streaking across the sky in mid-July, when the radiant is still in Cassiopeia, and the odd shower meteor will continue to be visible until around August 24th.

The easiest way to view a meteor shower is to kick back with a lawn chair and a sleeping bag. All you really need to do to see the show is look up, stay warm, and stay awake. Find the darkest sky you can, away from street lights. For most viewers in the Northern Hemisphere, shower meteors can appear any time after evening twilight ends, since the radiant in Perseus is circumpolar (i.e., up all night). So start looking as soon as evening twilight ends. These early evening space streaks will be long, showy "Earthgrazers" that skim Earth's upper atmosphere. As the radiant moves higher in the northeast throughout the evening, the meteors will become more frequent and appear all over the sky. The later you observe, the more meteors you'll see, and the best hours fall between midnight and dawn.

The most suitable equipment for watching a meteor shower are desire and dark skies, but if you'd like to document your observations more formally, the International Meteor Organization (IMO) recommends that visual observers track sky activity for at least 1 hour, with reports broken into short intervals of no longer than 15 minutes. For more detailed instructions regarding recording and reporting, visit the IMO Visual Observations page (**https://is.gd/IMOvisual**). Earth may encounter a Perseid filament — a relatively young accumulation of meteroids — on August 12th around 20^h UT. There's also a possibility of our planet meeting an old Swift-Tuttle dust trail on August 13th around $1^h\ 27^m$ UT. Accurate observation records may help detect activity connected to filament and meteoroid clump.

Occultation by Asteroid

EARLY ON THE MORNING of August 3rd, the 14.7-magnitude asteroid 1461 Jean-Jacques hides a 9th-magnitude star in Piscis Austrinus. Named for the son of its discoverer, Jean-Jacques is an M-type asteroid, so called because it and other members of its class have a high metallic content (C-type asteroids are carbonaceous, S-type silaceous). The occulted object, HD 207290, is a white-yellow main sequence star of spectral class *F7*. The shape of Jean-Jacques may be unusual, so the International Occultation Timing Association (IOTA) encourages scientific observations to help to clarify the asteroid's form. For more on planning your observations and setting up your equipment, visit the IOTA website (**occultations.org**). Free software and an observer's handbook are available for download at the site.

The predicted path of visibility angles across North America from Baja California Sur through El Paso and Sioux City to Duluth. The dip in brightness is expected to occur within a minute or two of 9:19 UT (4:20 a.m. CDT) for Duluth and 9:21 UT (2:20 a.m. MST) for Ciudad Obregón, Sonora, Mexico. HD 207290 will be about 36° high for Baja Sur, but not much higher than 10° for Minnesota.

A week or so before the event, more precise predictions, a path map, and finder charts will be available from Steve Preston's minor-planet occultation website (**asteroidoccultation.com**). For advice on timing and reporting observations, see **asteroidoccultation.com/observations**. Occultation enthusiasts may also join an active online discussion group at **groups.yahoo.com/neo/groups/IOTAoccultations**.

21P/Giacobini-Zinner Returns

▲ **FREQUENT FLYER** Comet 21P/Giacobini-Zinner was captured by the Kitt Peak 0.9-meter telescope on October 31, 1998. North is up with east to the left.

N. A. SHARP / NOAO / AURA / NSF

BY THE TIME THIS ISSUE hits the newsstands, we'll have some idea as to how impressive the 2018 return of Comet 21P/Giacobini-Zinner will be. French astronomer Michel Giacobini discovered this "unexpected comet" from Nice Observatory on December 20, 1900. In October 1913, German astronomer Ernst Zinner, observing from Remeis Observatory in Bamberg, picked it up on its second return since discovery and determined its period to be 6.6 years, rather than the 6.8 years calculated by Giacobini.

Predictions for Giacobini-Zinner have it coming into visual range in late June and brightening rapidly through July. The best-case observing scenario is a naked-eye comet by the end of August. Giacobini-Zinner is closest to the Earth — 0.39 a.u. — in September, so if it becomes brighter than a binocular object in August, we can expect it to remain so in the following month.

Imagers will have plenty of opportunities to capture Giacobini-Zinner against pleasant backdrops. A few highlights: On the night of July 4th, the comet is about 4° from the open cluster M39 in Cygnus. On July 21st, it passes less than 1° from the planetary nebula NGC 7354 in Cepheus. Look for it about 4° from the open cluster NGC 1502 (the Jolly Roger Cluster) on the night of August 22nd. On the night of September 3–4, it's about 1° from Capella.

Giacobini-Zinner moves rapidly south during September, becoming a morning object near the beginning of the month. On the morning of September 12th find it low in the east, about 1° from the open cluster M37. If you're positioned to track it until the end of the month, look for it about ½° from the open cluster NGC 2254 on September 26th and less than 2° from the Rosette Nebula the next morning.

Action at Jupiter

JUPITER, STILL IN LIBRA, appears low in the south at dusk all month. Near the middle of August about 3½ hours separates sunset and Jupiter-set, but that gap grows smaller as the evenings pass.

Jupiter reaches east quadrature (90° east of the Sun) on August 6th. This is a good time to shadow watch as Jupiter's moons dance around the planet. Any telescope shows the four Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify them. All of the August interactions between Jupiter, its major moons, and their shadows are tabulated on page 51 as well.

And here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Daylight Time is UT minus 4 hours.)

July 1, 0:13, 10:09, 20:05; **2,** 6:00, 15:56; **3,** 1:52, 11:47, 21:43; **4,** 7:39, 17:35; **5,** 3:30, 13:26, 23:22; **6,** 9:17, 19:13; **7,** 5:09, 15:05; **8,** 1:00, 10:56, 20:52; **9,** 6:47, 16:43; **10,** 2:39, 12:35, 22:30; **11,** 8:26, 18:22; **12,** 4:18, 14:13; **13,** 0:09, 10:05, 20:00; **14,** 5:56, 15:52; **15,** 1:48, 11:43, 21:39; **16,** 7:35, 17:31; **17,** 3:26, 13:22, 23:18; **18,** 9:14, 19:09; **19,** 5:05, 15:01; **20,** 0:57, 10:52, 20:48; **21,** 6:44, 16:40; **22,** 2:35, 12:31, 22:27; **23,** 8:23, 18:18; **24,** 4:14, 14:10; **25,** 0:06, 10:01, 19:57; **26,** 5:53, 15:49; **27,** 1:44, 11:40, 21:36; **28,** 7:32, 17:27; **29,** 3:23, 13:19, 23:15; **30,** 9:11, 19:06; **31,** 5:02, 14:58.

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

These times assume that the spot will be centered at System II longitude 292°. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 292° and 1⅔ minutes later for each degree more than 292°.

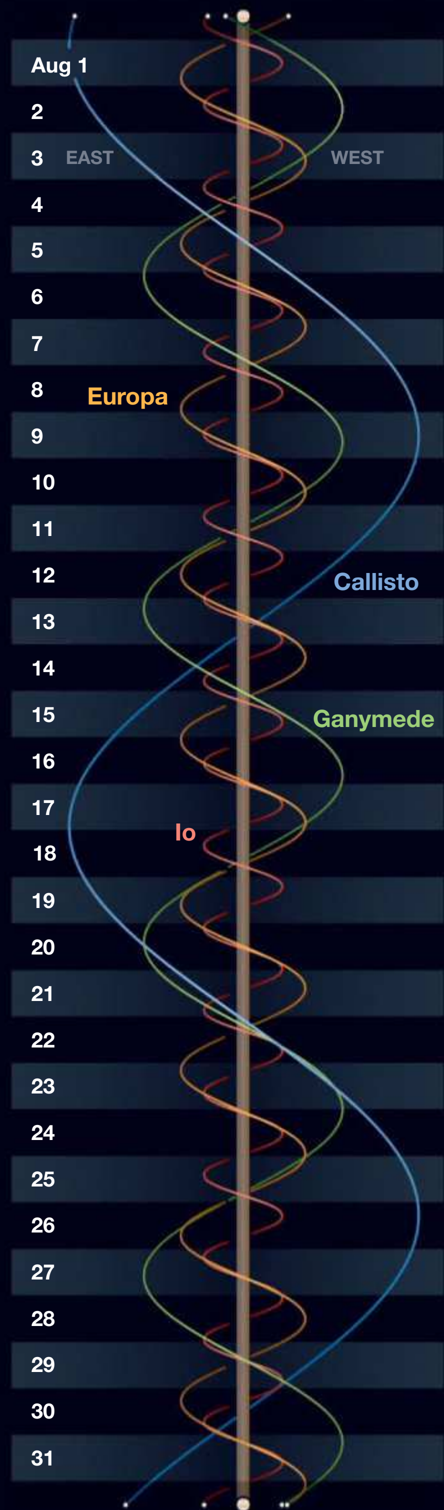
Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. A light blue or green filter slightly increases the visibility of Jupiter's reddish and brownish markings.

Phenomena of Jupiter's Moons, August 2018

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

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 Crater that Cried Wolf

An enigmatic crater in Mare Nubium refuses to give up its true nature.

Before the 1960s, many lunar observers believed that lunar craters were actually volcanoes. This notion arose partially because the physics of impact cratering was poorly known. Also, most observers were not geologists and didn't appreciate that volcanic craters often occur at the summits of tall mountains, unlike flat-lying lunar craters. In the last 50 years the evidence has become overwhelming that nearly all craters on the Moon formed by impact. There are exceptions: The rimless crater **Hyginus** is of volcanic origin, as are the summit pits on domes, but almost no other crater is. Maybe that's about to change.

In 1998, NASA's Lunar Prospector spacecraft discovered anomalous abundances of thorium on the lunar surface that could be associated with volcanic landforms. Thorium is rare in lunar mare basalts and highlands rocks, but spectral measurements show that it occurs in silica-rich volcanic rocks. A new generation of infrared and microwave sensors on the Lunar Reconnaissance Orbiter (LRO) and China's Chang'e 2 orbiter make the case more likely that thorium's presence marks silicic volcanic rocks. The Moon's most abundant volcanic materials — the maria — are basaltic: dark-hued lavas rich in iron and magnesium but low in silica. Over the years geochemists have realized that a number of hilly landforms such as the Gruithuisen domes, Mons Hansteen, Lassell Massif, and the Compton-Belkovich Volcanic Complex aren't basaltic in composition. These new sensors indicate that the materials are instead volcanic rocks richer in silica and poorer in the minerals that make the maria appear dark. None of these are craters.

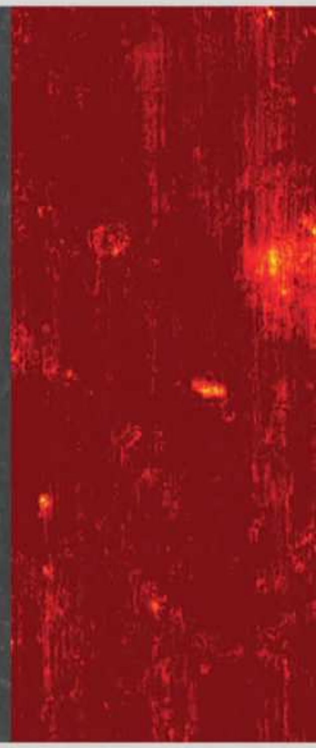
Recently Benjamin Greenhagen and colleagues at John Hopkins' Applied Physics Laboratory used LRO's Diviner radiometer to investigate the thorium anomaly at **Wolf** crater in southern **Mare Nubium**. Chances are you've observed Wolf — it's 25 km (16 miles) across — but didn't spend much time on it due to its irregular, eroded appearance. However, this feature has cap-

WOLF CRATER: NASA / LUNAR RECONNAISSANCE ORBITER; MID-INFRARED IMAGE: NASA / GSFC / UCLA / APL

▶ Few lunar craters are known to be volcanic in nature. One questionable feature is Wolf, a ruined crater found in southern Mare Nubium that shows signs of both volcanic and impact origin.

▶▶ Mid-infrared observations using the Diviner instrument aboard NASA's Lunar Reconnaissance Orbiter suggest that silica-rich material (colored blue and possibly volcanic in nature) lies along the top of Wolf's rim.

▶▶▶ Using the *Standard Christiansen Feature Value* overlay feature on the ACT-REACT-QuickMap website reveals silica-rich material on several crater rims within Mare Nubium.



tured the interest of lunar geologists, because the Diviner spectral maps show that the inner face of the crater's rim stands out as being highly silicic. Wolf looks to be the first known crater made of silicic lavas — and it might actually be a circular volcano.

Greenhagen offers two possible explanations for this. Wolf could be an impact crater that excavated into an older region of silica-rich terrain sticking up above the Nubium mare lavas. If you look closely, you can see that mare lavas flowed through gaps in Wolf's walls and flooded its floor. This implies that the impact that created Wolf occurred before those lavas.

The second hypothesis is that Wolf is not an impact crater at all, but instead is some sort of volcanic landform — possibly a caldera — whose eruptions and subsequent collapse left an elevated rim consisting primarily of silicic lavas. In either case, Wolf's floor sits about 100 meters below the surrounding lava plains, suggesting that it subsided after lavas flowed into it and solidified.

Greenhagen and his colleagues do not prefer one interpretation over the other, but I suggest that other relevant

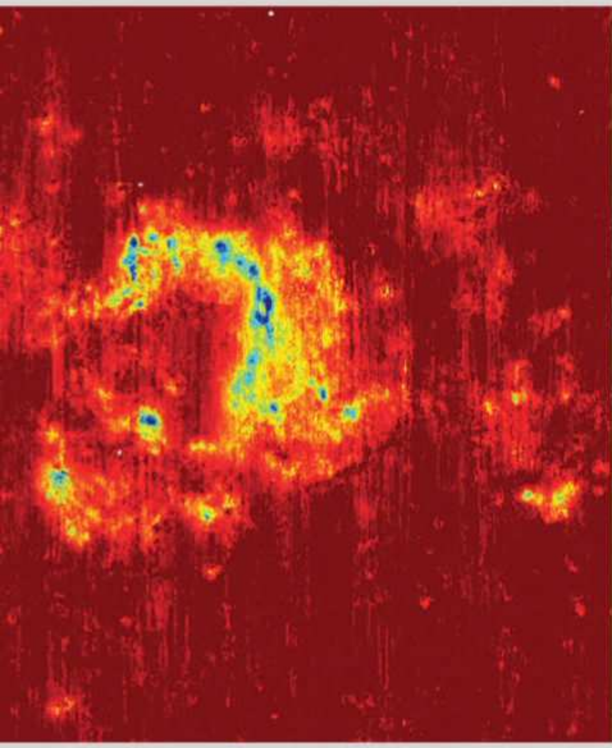
▲ Images taken under oblique solar illumination reveal Wolf (lower right) to be the southernmost feature in a chain of ruined craters.

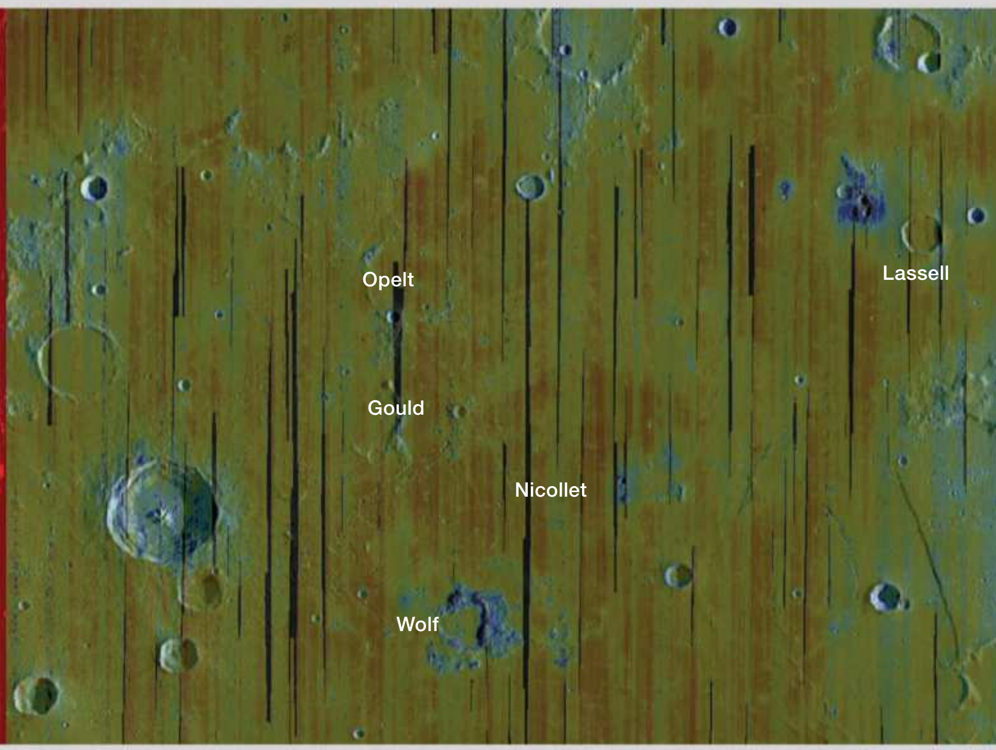
observations arise from looking more carefully at the surrounding region. Nearly nine years ago, British amateur Simon Kidd captured an image of Wolf and the mare region to the north that shows it to be the most visible of a line of five or six degraded craters. Within that string, **Opelt** is the farthest north, **Gould** is near the middle, and Wolf is at the southern end. Opelt and Gould have only arcs of elevated rims on their western sides, with mostly mare ridges defining their eastern rims. This alignment of craters points back to the western side of the Imbrium Basin — so could these be a string of large secondary craters like the ones radiating from the Orientale Basin on the lunar farside? If so, then this can be seen as proof that Wolf is an impact crater.

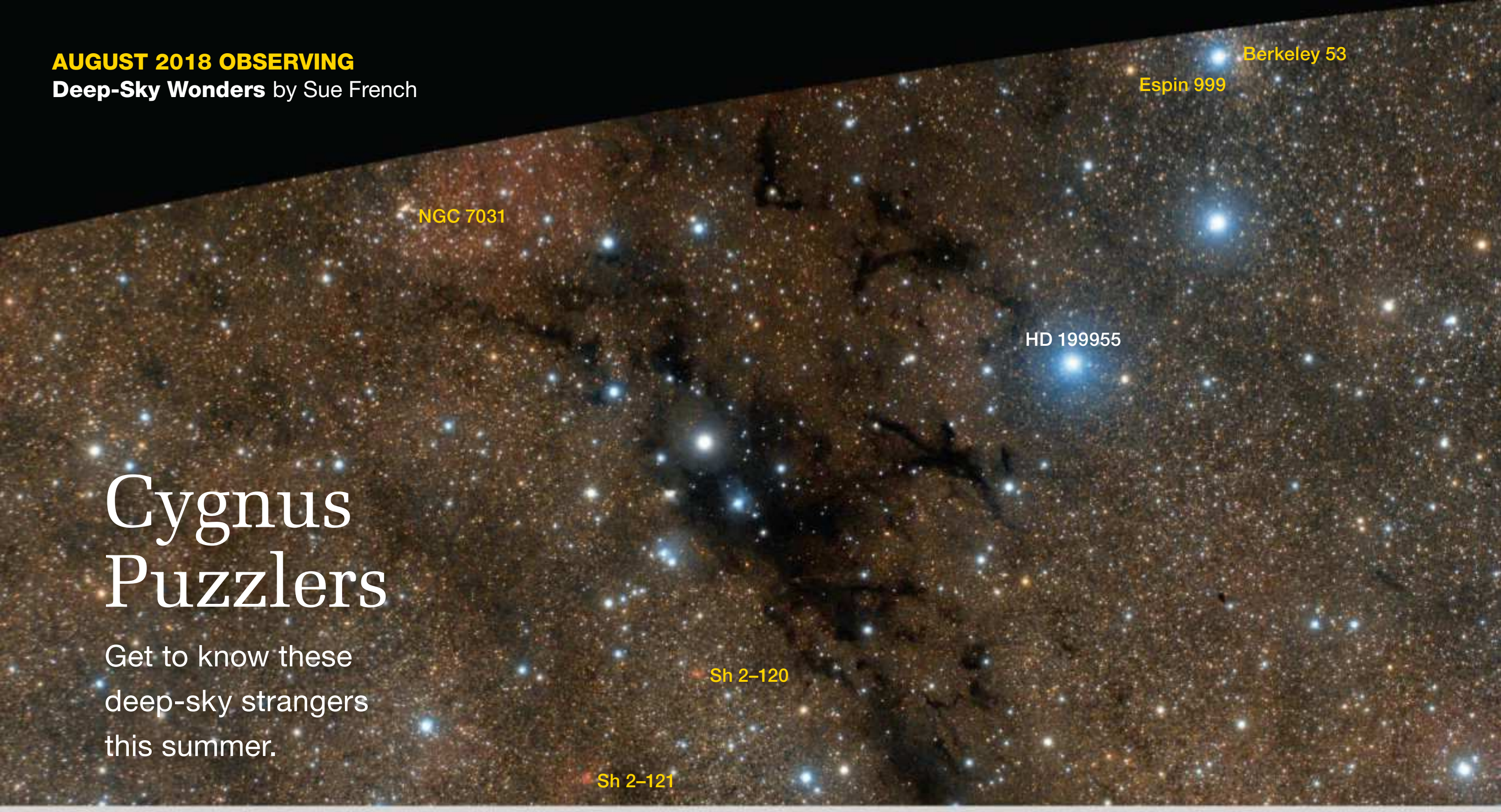
A second regional observation is that a spectral characteristic known as the *Standard Christiansen Feature Value* in the LRO QuickMap (**https://is.gd/Wolf_map**) shows that the western rims of Opelt and Gould, as well as the hills north of nearby **Nicollet**, all have hints of the silica-rich rocks seen at Wolf. Additionally, the well-studied silicic volcanic complex west of **Lassell** is only 325 km northeast of Wolf. This suggests that a layer of varying silica concentrations might lie under at least part of Mare Nubium's dark lavas. If this speculation is true, then it also indicates that Wolf formed by impact. Perhaps there are no large volcanic craters on the Moon after all.

■ Contributing Editor **CHUCK WOOD** has studied the Moon for more than five decades as both an amateur astronomer and professional scientist.

SOLAR ILLUMINATION: SIMON KIDD; MAP OVERLAY: NASA / LUNAR RECONNAISSANCE ORBITER







Cygnus Puzzlers

Get to know these deep-sky strangers this summer.

▲The diffuse emission nebulae Sh 2-120 and Sh 2-121 are subtle glows ensconced in the dust clouds at the periphery of the Le Gentil 3 dark nebula complex in northeastern Cygnus. NGC 7031, described by Steve Gottlieb as "not very rich" and "fairly scattered," shows about two dozen stars in larger scopes.

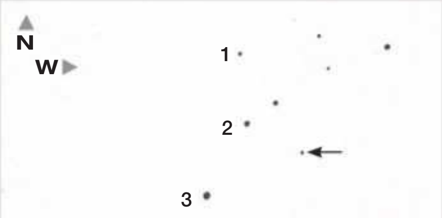
The plentiful deep sky holds many wonders you've never heard of, or perhaps could never quite figure out. Some aren't what they seem, are difficult to pinpoint, or have an indefinite status. Let's scoop up a handful of these curious little stumpers and see what we can make of them.

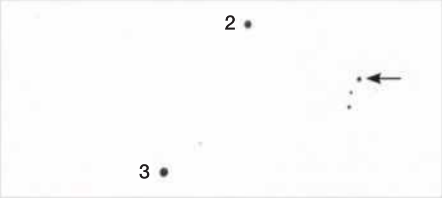
We'll begin with the tiny planetary nebula **NGC 6833**. Since it isn't signposted by any bright stars, those without computerized telescopes will need to star-hop, with the aid of a good atlas, from the closest star they can see. With a diameter of only 1″, the nebula is quite difficult to distinguish from the stars. A 10.6′-long star pattern near the planetary can help you pick out the nebula, shown on my sketch as seen with a 130-mm refractor. Its brightest stars are 9th-magnitude. Using a magnification of 117× and an O III filter, the identity of the planetary becomes apparent. The stars dim, and NGC 6833 becomes brighter than the stars labeled 1 and 2. On a night of very good seeing, my 10-inch reflector makes a better job of it. Even at 88× NGC 6833 gives itself away by its bluish color, and at 187× it looks suspiciously edged rather than showing a sharp point like the stars.

The nebula finally suggests a Lilliputian disk at 299×. It's the brightest and northernmost object in a 40″-long arc it makes with two dim stars. The arc is shown in my second drawing with respect to 9th- and 10th-magnitude stars (labeled 3 and 2 respectively) 3.8′ apart and east of the nebula.

According to a 2011 study published in the *Astronomical Journal* by Raghvendra Sahai and colleagues, given a distance of 15,500 light-years, we are now seeing NGC 6833 at a time when it had been expanding for little more than 700 years, one reason it appears so petite.

A horse of a different color, the elderly open cluster **Berkeley 53** is about 1 billion years old. It sits 2.3° east-northeast of 51 Cygni and clasps the 6.6-magnitude star HD 199578 within its eastern boundary. Aiming my 15-inch reflector at the area, there's an interesting oval ring of fairly bright stars with HD 199578 marking its eastern end — but that's not the cluster. Look instead for a faint glow cozied up to the bright star. At 247× its haze spans roughly 5′. It contains some obvious foreground stars, the brightest one orange, and at least 15 very faint to exceptionally faint stars, perhaps a few of which might reach the feeble





▲*Top:* This sketch shows the field around the planetary nebula NGC 6833 as viewed through a 130-mm refractor at 117×. An O III filter will help you pull the nebula, marked here with an arrow, out of the stars. *Bottom:* Greater aperture and more magnification make NGC 6833 more apparent. Look for it at the top of a 40″-long arc west of the 10th-magnitude stars marked 2 and 3 here.

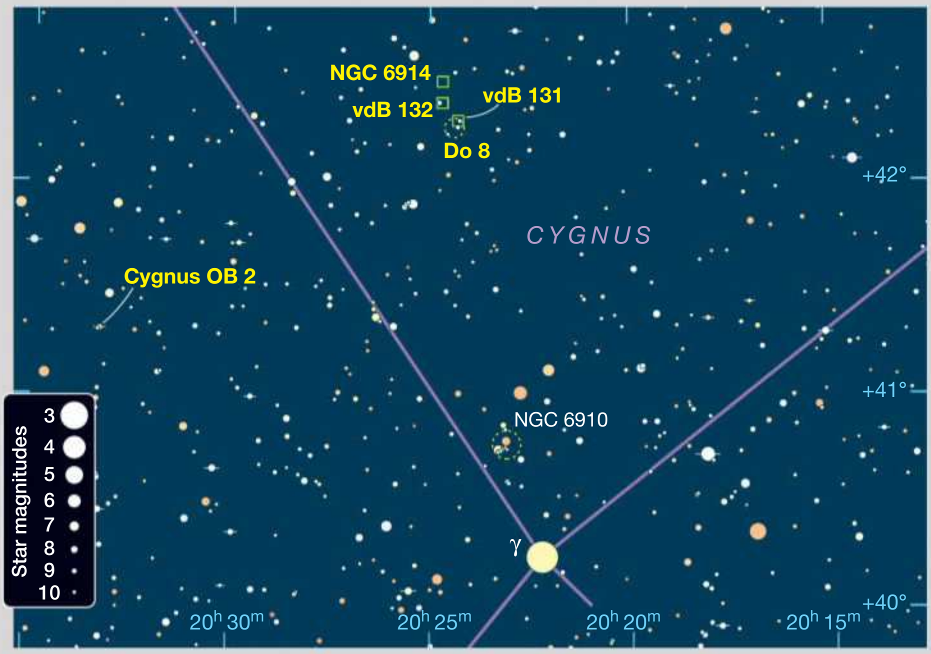
SKETCHES: SUE FRENCH; CYGNUS: RAUL VILLAVERDE

16th magnitude of the group's brightest stars. As indicated by Roger N. Clark (*S&T:* Apr. 1994, p. 106), an experienced observer under a very dark sky can detect stars of magnitude 16.6 through a 15-inch scope about 50% of the time. Can you see any of the shy stars that belong to this cluster, or will you have to content yourself with catching its phantom glow?

While studying Berkeley 53, I noticed a lovely pair of red stars 11.3′ east of HD 199578. This is **Espin 999** (ES 999), whose 9.8-magnitude primary guards a 10.7-magnitude companion 3.2″ to the west.

Sweeping 1.8° east and a bit south from Berkeley 53 takes us to **NGC 7031**. As an open cluster, the size and position of NGC 7031 differ from source to source. William Herschel discovered the group in 1788, and his son, John Herschel, also observed it. Summarizing their catalog descriptions gives us a scattered, 6′ group that's not rich and contains triple stars. William's position differs slightly from that of John's, and NGC/IC researcher Harold Corwin proposes a center of $21^h\ 07^m\ 12^s$ +50° 52.5′, which has become fairly widely accepted. Examining this area with my 130-mm refractor at 117× yields about 15 stars, 10th-magnitude and fainter. *Sky & Telescope* Contributing Editor Steve Gottlieb captures two dozen stars down to magnitude 15 in his 17.5-inch scope at 220×.

With so many emission nebulae in the sky, the little guys don't get much attention. Two such are **Sharpless 2-121** and **Sharpless 2-120**, located 1.2° south-southwest of NGC 7031. They're challenging even for experienced observers with fairly large telescopes. Through my 15-inch scope at 192×, Sh 2-121 is a faint 1′ glow with a dim star at its north-northwestern edge. Just 19′ northwest, Sh 2-120 is smaller, even more ghostly, and best seen with averted vision. These little powder puffs are more popular with astrophotographers than visual observers. Wide-field images are stunning, showcasing the bits of fluff nestled in a Milky Way star field laced with impressive dark nebulae.



East of NGC 7031 by 2.3°, **NGC 7058** is a coarse group of about 25 stars in my 10-inch reflector at 187×. They spread across 6½′ × 4½′, most of the bright ones outlining a V with curved sides. Perched on the group's west-northwestern edge, the brightest star is 8.1-magnitude HD 203609

(SAO 33352). NGC 7058 stands out fairly well but doesn't look much like an open cluster. The SIMBAD Astronomical Database (**simbad.u-strasbg.fr**) lists it as a moving group — a collection of stars that travel in roughly the same direction through space but aren't gravitationally bound.

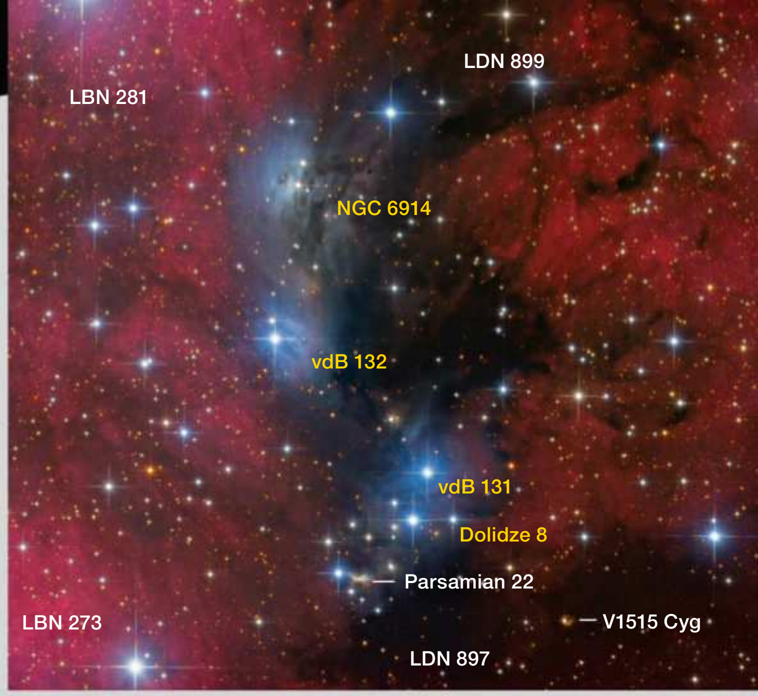
Small reflection nebulae draw even less attention than their emission cousins, as they're often more difficult to spot. Bright enough to bear an NGC designation, **NGC 6914** rests in the hollow of the swan's northern wing. My 130-mm scope at 48× reveals faint nebulosity trailing east and south from a star pair (magnitudes 11.3 and 11.9) on its western side. A second star pair (magnitudes 9.3 and 11.3) 6′ to the south dons a splotch of nebulosity spreading west and south, **van den Bergh 132**. Each nebula spans less than 2′. Just 8′ south-southwest from vdB 132, a collection of six stars, magnitude 9 to 12, belong to the open cluster **Dolidze 8**. Boosting the magnification to 102× brings out five more stars, giving us a loose collection scattered across 5.4′. Through the 10-inch scope at 68×, the bright star pinning the northwestern edge of Dolidze 8 wears a cocoon of gossamer haze, **van den Bergh 131**.

Scanning the internet, you'll often find the light of these reflection nebulae ascribed to the hot, young stars of the Cygnus OB 2 association. However, Cyg OB 2 is generally credited with a radius of ½° to 1°, and its center lies 2° southeast of NGC 6914. Current estimates place Cygnus OB 2 between 4,000 and 5,000 light-years away from us.

The heart of the Cygnus OB 2 association holds a "trapezium" of spectral-class O stars known as **Cyg OB 2 #8**, which includes two of the association's brightest stars. I observed the trapezium while out with my 15-inch reflector at 90×, but since its faintest star is magnitude 11.0, a considerably smaller telescope would do. The scope shows a beautiful and irregular, ½° group of more than 100 stars, many of them Milky Way field stars. Despite its descriptive name, the trapezium consists of four stars arranged in the shape of a 38″-long pizza slice. Three stars in an arc outline the pizza's crust, the trapezium's brightest star in the middle. To the east, the tip of the slice is marked by the group's second-brightest star. All but the faintest star are bright enough to show some color — yellow, because we see these blue-white stars significantly reddened by intervening dust in the plane of our galaxy. The group's brightest star is actually a spectroscopic binary composed of two O-type stars, weighing in at 44 and 37 solar masses and orbiting each other in 22 days.

Those of you with Go To scopes may be able to pinpoint this binary with its Hipparcos or Smithsonian Astrophysical Observatory number (HIP 101425, SAO 49781). Give it a try.

■ Contributing Editor **SUE FRENCH** loves to solve celestial stumpers.



▲ Snugged under the northern wing of the Swan, the blue reflection nebula NGC 6914 trails from a star pair at the southeastern edge of LDN 899. Move southward to vdB 132, vdB 131, and the open cluster Dolidze 8. This image was captured through a 12-inch reflector with a total exposure time of 23 hours, 24 minutes.

BERNHARD HUBL

Strangers in Cygnus

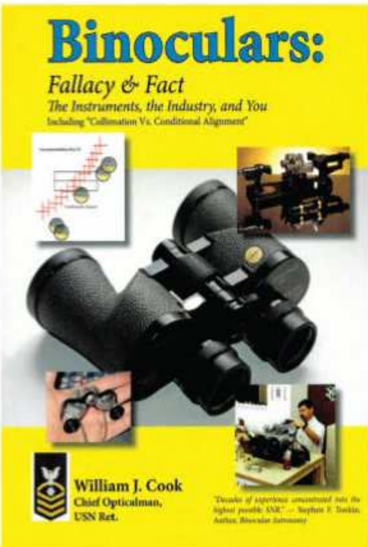
Object	Type	Mag(v)	Size/Sep	RA	Dec.
NGC 6833	Planetary nebula	12.1	1″– 2″	$19^h\ 49.8^m$	+48° 58′
Berkeley 53	Open cluster	—	6.0′	$20^h\ 56.0^m$	+51° 05′
Espin 999	Double star	9.8, 10.7	3.2″	$20^h\ 57.4^m$	+51° 03′
NGC 7031	Open cluster	9.0	6.0′	$21^h\ 07.2^m$	+50° 53′
Sh 2-121	Emission nebula	—	~1′	$21^h\ 05.3^m$	+49° 40′
Sh 2-120	Emission nebula	—	~1′	$21^h\ 03.7^m$	+49° 52′
NGC 7058	Moving group	7.2	7.0′	$21^h\ 21.9^m$	+50° 49′
NGC 6914	Reflection nebula	—	6.3′ × 4.9′	$20^h\ 24.8^m$	+42° 29′
vdB 132	Reflection nebula	—	5.0′ × 3.2′	$20^h\ 24.7^m$	+42° 23′
Dolidze 8	Open cluster	8.4	5.4′	$20^h\ 24.4^m$	+42° 16′
vdB 131	Reflection nebula	—	4.6′ × 3.4′	$20^h\ 24.3^m$	+42° 18′
Cyg OB 2 #8	Multiple star	9.0, 10.6, 9.9, 11.0	9.4″, 38.0″, 18.2″	$20^h\ 33.3^m$	+41° 19′

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.

Idiosyncratic but Authoritative

Binoculars: Fallacy & Fact

William J. Cook
CreateSpace Independent Publishing Platform, 2017
196 pages, ISBN 978-1548932190
$24.95, paperback.



BINOCULARS: FALLACY & FACT isn't like other binocular books. It seems to have been directly downloaded from the brain of the author, William J. "Bill" Cook, Chief Opticalman, U.S. Navy (retired). It's idiosyncratic and informal, but also authoritative on many technical aspects of binoculars, and indispensable in describing techniques that aren't otherwise in print.

The book is self-published, and it shows. Physically it's fine, with an attractive soft cover, good paper and print quality, and over 100 black-and-white photos and diagrams. The self-publication becomes more evident in the organization and writing.

The book is structured as a series of 47 short chapters or "vignettes". The first 23 vignettes are a broad and deep treatment of how binoculars are designed, built, sold, and serviced. The vignettes on prism types, optical coatings, waterproofing, and cleaning optics are particularly good. Vignettes 24–26 relate the history and mythology of optics made in the United States, Germany, and Japan, and vignettes 27–29 address magazines, the internet, and advertising as sources of (mis)information about binoculars. The heart of the book is Vignette 30, on collimation versus conditional alignment. The final 17 vignettes cover a broad spectrum of topics, from Japanese optical manufacturers' codes to handholding large binoculars. The glossary at the end of the book is compact and helpful.

In addition to the technical content, which is clearly presented, interesting, and useful, the book is full of digressions. Some of these illustrate common misunderstandings, but others are essentially a catalog of slights the author has endured from publishers, people on internet forums, and recalcitrant customers. At points the book doesn't seem clearly thought through. For example, the assessment and cleaning of anti-reflection coatings are extensively discussed on pages 33–38, but the different types of coatings aren't defined until page 145. One figure caption directs the reader to trace red and green light paths in a black-and-white diagram. The table of contents includes no page numbers, and the last two listings don't align with their topics. Finally, the book has quite a few typos.

In fairness, the author tells you about most of these problems directly, explaining in the foreword and epilogue why he made the choices he did here. Bill Cook has, for better or worse, produced precisely the book he set out to write.

Should you get this book? If you're interested in the real guts of binoculars, how prisms, focusers, coatings, and the rest work together, don't hesitate. Even if you're a more casual binocular user, you'll find much of value here. I found myself flagging pages that described the most handy techniques, such as the step-by-step procedures for testing off-axis sharpness or quickly assessing anti-reflection coatings, and a couple of lines from the book made it into my file of favorite quotes. The conversational tone worked for me, despite the quirks.

> If you're interested in the real guts of binoculars, how prisms, focusers, coatings, and the rest work together, don't hestitate to get this book. Even if you're a more casual binocular user, you'll find much of value here.

The book is at its best when Cook is at his most technical, delving into the inner workings of binoculars with clarity, and at its worst when he's at his most self-indulgent, polishing old grudges. I wish the book had been more tightly edited, in part because I think it would reach a wider audience, and in part because it is so darned useful that I can't afford to not have a copy. That probably tells you all you need to know.

■ Contributing Editor **MATT WEDEL** wonders why there are so many books about telescopes but so few about binoculars.

 by Howard Banich

The RIDDLE of the Nebulae

Using your own equipment you can experience the historic observation that changed astronomy.

It was all William Herschel's doing. In the 1780s he began examining objects from Messier's catalog and wondered about their nature. Many of the objects Messier described as a "nebula without a star" appeared as clusters of stars in Herschel's larger and more powerful telescopes, and he formulated the idea that perhaps all nebulae were "stratums of immensely distant fixed stars" that a sufficiently large telescope would be able to resolve.

Perhaps you've noticed this yourself: Some clusters appear nebulous through a small telescope but are resolved into stars by a larger one. Or they appear nebulous at low power but resolve into stars at higher magnifications. This got Herschel thinking, and he came up with the notion that the universe started with widely distributed stars that slowly drew closer together due to gravitational attraction. They eventually fragmented into clusters, with the densest becoming globular clusters. These in turn became planetary nebulae, which he considered "very aged [globular clusters], drawing on towards a period of change or dissolution." This proved completely wrong, but at the time there was no way to test his ideas.

However, he also thought that perhaps "nebulosity of the milky kind" did exist. To his eye, the shape of M42 seemed to have changed slightly over time, which, along with his inability to resolve it into stars, suggested it was true nebulosity. His observation of NGC 1514 in 1790 convinced him that at least some of the unresolvable nebulae were made of an "interstellar aether" that through the eons condenses into stars and star clusters.

In the 1830s, astronomers William Whewell and John Pringle expanded on Herschel's ideas. They also proposed that real nebulosity exists, and under the influence of gravity it contracts into spinning clouds that eventually coalesce into stars. Clusters of stars appear because stars are born in large groups. This relatively modern idea gave the universe a more dynamic life cycle, but it was still only conjecture. But some astronomers still thought that all nebulosity would eventually be resolved into stars, and the debate about the true nature of the nebulae persisted for another 30 years.

Eternal or Evolving Universe?

William Parsons, 3rd Earl of Rosse, wanted to settle the debate. He decided to build a telescope large enough to resolve the matter, because his 36-inch telescope, built in 1840, wasn't powerful enough. Determining if nebulae were

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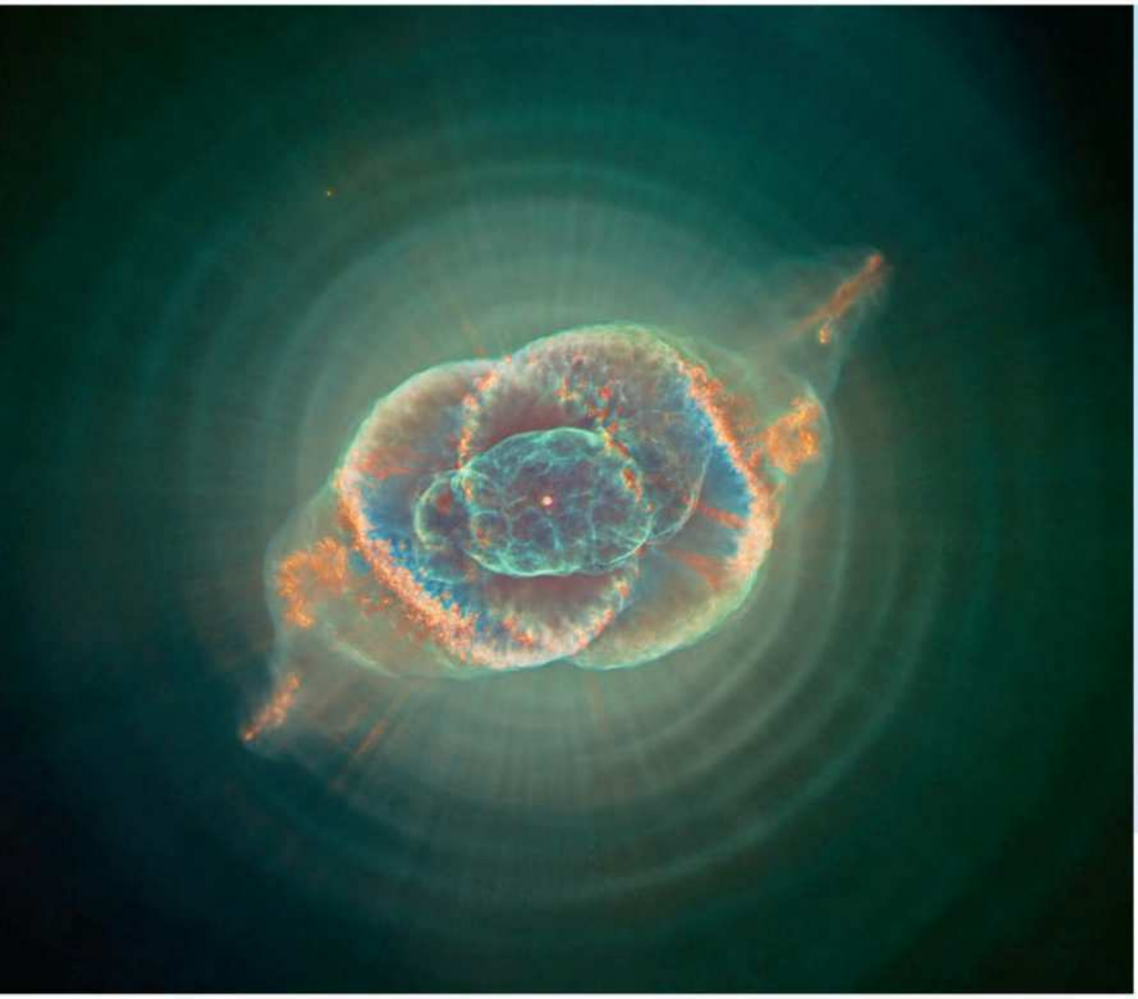

◀ **COSMIC CAT'S EYE** The planetary nebula NGC 6543, popularly known as the Cat's Eye Nebula, lies about 3,000 light-years away in the direction of Draco. This image was processed from data downloaded from the Hubble Heritage Archive. Instead of the traditional Hubble palette, a contrast-boosting alternative was used to improve the visibility of details. Light of wavelength 373 nm (O III) is processed as magenta, 502 nm (O III) as blue, 505 nm (O III) as green, 656 nm (hydrogen-alpha) as orange, and 658 nm (N II) as red.

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composed of stars or some kind of cosmic vapor was his primary motivation for building his 72-inch reflector, which was completed in 1845.

One of Lord Rosse's more consistent guest observers was the Reverend John Thomas Romney Robinson, an Ulster Episcopalian minister who was also director of the Armagh Observatory. An outspoken opponent of Darwin's theory of evolution, he believed the universe did not evolve and that all nebulae were composed of eternal, unchanging stars. That's a strong bias, and Robinson thought he could resolve all the nebulae he observed with the 72-inch, even though companion observers often could not. Perhaps they had a strong bias that true nebulosity did exist, but this points to the essential problem of visual observations — pre-conceived notions can certainly influence what any individual sees. If astronomers couldn't agree on what they saw though the same telescope on the same night, how could the true nature of the nebulae ever be established?

"The riddle of the nebulae was solved. The answer, which had come to us in the light itself, read: Not an aggregation of stars, but a luminous gas."

Even so, most astronomers of the time were still optimistic that eventually the right observer with the right telescope would succeed. And in a way they didn't anticipate, they were right.

Meanwhile, Spectroscopy

Well before the riddle of the nebulae debate heated up, Isaac Newton wrote about the dispersion of light with a glass prism. He wasn't the first to notice that a prism created a rainbow of color, but he was the first to examine the fundamental nature of light. His 1704 study *Opticks; or, A Treatise of the Reflexions, Refractions, Inflexions and Colours of Light* laid the groundwork for the investigations into the nature of light that eventually led to Joseph von Fraunhofer's innovation in 1821 to replace the prism with a diffraction grating. He also examined Venus, the Moon, and several bright stars with his spectroscope attached to a telescope and hypothesized that the dark and bright lines he saw in their spectra somehow indicated their chemical composition.

By 1849 Léon Foucault, of pendulum and telescope-mirror testing fame, demonstrated that both the bright and dark lines seen in spectra were unique to the material being examined by a spectroscope. Physicist Gustav Kirchhoff and chemist Robert Bunsen took the next step when they published their work on positively identifying chemical elements by their spectra in 1860. This was a spectacular breakthrough — for the first time a spectrum could be analyzed to determine the chemical makeup of a substance.

Enter William Huggins & William Allen Miller

Two years later, William Huggins, a little-known amateur astronomer from London, attended a lecture about spectroscopy by his neighbor, Dr. William Allen Miller. A renowned chemist, Miller began his talk by discussing Fraunhofer's work before getting to his main topic — the latest discoveries using the spectra of colored flames for chemical analysis. He also discussed Kirchhoff's map of the Sun's spectrum.

Huggins was electrified and after the lecture worked to convince Miller to join him to "apply Kirchhoff's methods to the stars." Miller was already working on the positive identification of materials based on the lines produced in their spectra, and it must have been irresistible to extend these studies beyond Earth. Miller had impressive credentials: Chair of Chemistry at King's College in London, twice president of the Chemical Society, and treasurer of the Royal Society. In addition to mentoring Huggins in spectral analysis, he would give their astronomical spectroscopy work instant credibility.

They soon began working together using Huggins's 8-inch Alvan Clark refractor equipped with a visual spectrograph in his home observatory, and within a year they gave a preliminary report to the Royal Society. By 1864 they were able to make the astounding declaration that "stars, while differing the one from the other in the kinds of materials of which they consist, are all constructed upon the same plan as our sun, and are composed of matter identical, at least in part, with the materials of our system."

Astronomy took a gigantic step forward, and Huggins made his name. The age of visual astronomy would soon be replaced by spectrographs, cameras, and astrophysics. But what about the nebulae?

NGC 6543, the Cat's Eye Nebula

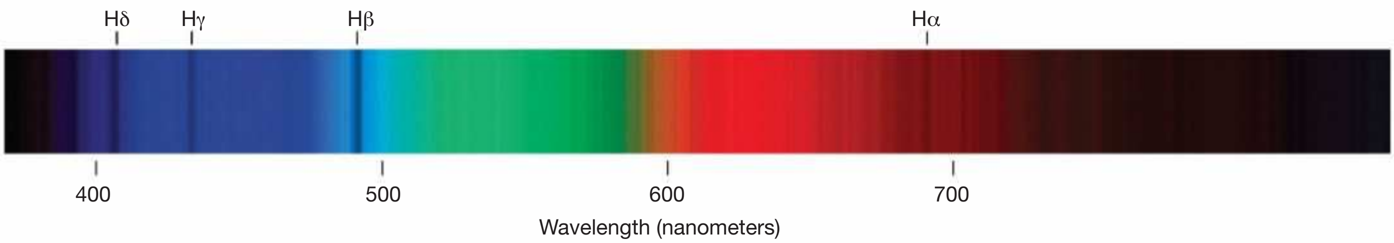
Having shown, with Miller, that stars are chemically related to the Sun, Huggins next wanted "to ascertain whether this similarity of plan observable among the stars, and uniting them with our own sun into one great group, extended to the distinct and remarkable class of bodies known as nebulae." He expected they would differ from stars more in their temperature and density than in what they were made of, and through lab experiments with Miller knew the emission line spectrum of a glowing gas was very different from a star's continuous spectrum. He was ready for his first nebulous target in late August 1864, and he chose NGC 6543, the Cat's Eye Nebula.

Bright, colorful, and placed high in the August sky, it was a well-chosen object — and with his first observation Huggins solved the long-standing riddle of the nebulae:

"On the evening of August 29, 1864, I directed the telescope . . . to a planetary nebula in Draco [NGC 6543]. The reader may now be able to picture to himself to some extent the feeling of excited suspense, mingled with a degree of awe,

COLOR BACKGROUND: RALF HIEMISCH / GETTY IMAGES; HUGGINS: POPULAR SCIENCE MONTHLY (1910) / PUBLIC DOMAIN; MILLER: SCIENCE & SOCIETY PICTURE LIBRARY / GETTY IMAGES

▶ **CHEMICAL COLLABORATION** William Huggins *(left)* and William Allen Miller worked with prisms to separate and scatter starlight. "Within this unraveled starlight," wrote Huggins, "exists a strange cryptography. Some of the rays may be blotted out, others may be enhanced in brilliancy. These differences, countless in variety, form a code of signals, in which is conveyed to us, when once we have made out the cipher in which it is written, information of the chemical nature of the celestial gases by which the different light rays have been blotted out, or by which they have been enhanced." Huggins applied the knowledge they gathered on stellar spectra to another class of celestial object, planetary nebulae.

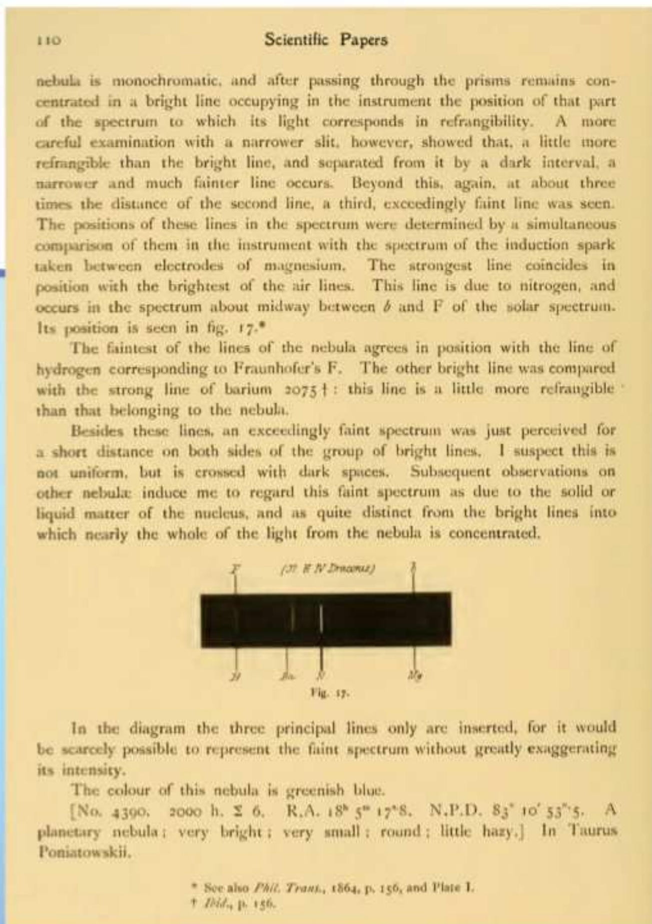


▲ **STELLAR SPREAD** The spectrum of Vega showing its most obvious absorption bands. The colors look even brighter through the author's spectroscope.

with which, after a few moments of hesitation, I put my eye to the spectroscope. Was I not about to look into a secret place of creation?

"I looked into the spectroscope. No such spectrum as I expected! A single bright line only! At first I suspected some displacement of the prism, and that I was looking at a reflection of the illuminated slit from one of its faces. This thought was scarcely more than momentary; then the true interpretation flashed upon me. The light of the nebula was monochromatic, and so, unlike any other light I had yet subjected to prismatic examination, could not be extended out to form a complete spectrum. . . . A little closer looking showed two other bright lines on the side towards the blue, all three lines being separated by intervals relatively dark.

▼ **RECORDED LIGHT** William Huggins sketched the emission lines he detected in NGC 6543 with his 8-inch Clark refractor and visual spectroscope. He determined that the brightest line coincided with nitrogen and the faintest with hydrogen. "37. H IV Draconis" is William Herschel's designation for NGC 6543.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nebula is monochromatic, and after passing through the prisms remains concentrated in a bright line occupying in the instrument the position of that part of the spectrum to which its light corresponds in refrangibility. A more careful examination with a narrower slit, however, showed that, a little more refrangible than the bright line, and separated from it by a dark interval, a narrower and much fainter line occurs. Beyond this, again, at about three times the distance of the second line, a third, exceedingly faint line was seen. The positions of these lines in the spectrum were determined by a simultaneous comparison of them in the instrument with the spectrum of the induction spark taken between electrodes of magnesium. The strongest line coincides in position with the brightest of the air lines. This line is due to nitrogen, and occurs in the spectrum about midway between *b* and F of the solar spectrum. Its position is seen in fig. 17.*

The faintest of the lines of the nebula agrees in position with the line of hydrogen corresponding to Fraunhofer's F. The other bright line was compared with the strong line of barium 2075†: this line is a little more refrangible than that belonging to the nebula.

Besides these lines, an exceedingly faint spectrum was just perceived for a short distance on both sides of the group of bright lines. I suspect this is not uniform, but is crossed with dark spaces. Subsequent observations on other nebulæ induce me to regard this faint spectrum as due to the solid or liquid matter of the nucleus, and as quite distinct from the bright lines into which nearly the whole of the light from the nebula is concentrated.

Fig. 17.

In the diagram the three principal lines only are inserted, for it would be scarcely possible to represent the faint spectrum without greatly exaggerating its intensity.

The colour of this nebula is greenish blue.

[No. 4390. 2000 h. Σ 6. R.A. 18h 5m 17s·8. N.P.D. 83° 10′ 53″·5. A planetary nebula; very bright; very small; round; little hazy.] In Taurus Poniatowskii.

* See also *Phil. Trans.*, 1864, p. 156, and Plate I.
† *Ibid.*, p. 156.

"The riddle of the nebulae was solved. The answer, which had come to us in the light itself, read: Not an aggregation of stars, but a luminous gas."

Everything had come together for this second breakthrough. His ongoing laboratory work with Miller, his observations of terrestrial, solar, and stellar spectra, and now a bright spectrum from a planetary nebula had given Huggins the means to recognize what the emission line spectrum of NGC 6543 and other planetary nebulae meant. About planetary nebulae in general he wrote:

"This is a memorable observation not only for duplicating Huggins's observation, but that I can (do it) so easily and with such an inexpensive spectrograph . . ."

". . . we must probably regard these objects, or at least their photo-surfaces, as enormous masses of luminous gas or vapor." Only "matter in the gaseous state" emits "light consisting of certain definite refrangibilities only." (In this instance "refrangibilities only" means light refracted into discrete emission lines.)

Bingo.

153 Years Later

I can't help but get caught up in the excitement of Huggins's account, and in 2017 I recreated his observation of NGC 6543. To do so, I purchased a relatively inexpensive, low-resolution diffraction grating spectroscope that attaches to a 1.25-inch eyepiece like a filter and had a look for myself.

I started by examining the spectra of Vega (spectral class *A*0V) and Altair (*A*7V) to become familiar with continuous stellar spectra. They appear nearly identical as bright, beautiful rainbow streaks with several dark absorption bands.

SPECTRUM: GREGG DINDERMAN (*S&T*); SCIENTIFIC PAPER: *THE SCIENTIFIC PAPERS OF SIR WILLIAM HUGGINS*, K.C.B., O.M. (1909) / PUBLIC DOMAIN

▲ **EMISSION IN ACTION** In this sketch of NGC 6543's emission line spectrum as seen through the author's 28-inch f/4 reflecting telescope, the darkest vertical line corresponds to the O III lines at 495.9 nm and 500.7 nm. The fainter line to the left is Hβ 486.1; it marks the visual end of the green-blue section of the spectrum. The broad gray zone at the right is likely centered on the red Hα 656.3 line. Even the brightest emission line was not bright enough to show color, although if it were visible it would be the same turquoise as seen in the author's full-color sketch of NGC 6543 on the facing page.

Then I was ready for NGC 6543. I felt a little of the suspense and awe that Huggins described, and even hesitated a moment before putting my eye to the eyepiece just to savor the moment. My notes from the evening of July 30, 2017:

"Not just one line but two! It took a minute to figure out which was the primary spectrum, and which was the nebula because the image of the primary is so much brighter! Seeing a second line is unexpected, but the appearance of the spectrum is so different than a stellar spectrum that I can't help but think of Huggins's exclamation that he knew at first glance that this spectrum proves that at least some nebulae are gaseous. This is especially remarkable because there's a continuous stellar spectrum right next to 6543's lines.

"This is a memorable observation not only for duplicating Huggins's observation, but that I can (do it) so easily and with such an inexpensive spectrograph . . . 15-mm Plössl / 5 spacers, 21.34 SQM. A last look showed a bit more spectrum, a faint patch on the opposite (red) side of the bright line from 6543!"

Recreating Huggins's observation was thrilling not only for commemorating his landmark discovery but also because I saw the vast difference between NGC 6543's emission-line spectrum and a continuous stellar spectrum. It was obvious why he understood its significance so quickly.

Of course, NGC 6543's bright turquoise color and internal structure are a joy to observe with a regular eyepiece, particularly when the seeing is steady. I've had several excellent views of its inner helix-like shape and outer halos at various times, and of all the planetary nebulae I've observed its color stands up best to high magnification. In retrospect, it makes perfect sense that it shows a line spectrum.

I re-observed the Cat's Eye Nebula and its spectrum at the 2017 Oregon Star Party. One evening I devoted an hour explaining the significance of spectroscopy to astronomy and science in general to my family, and how Huggins used it to solve the riddle of the nebulae. Just as I had for myself a few weeks before, I showed them Vega with its bright and colorful spectrum and easily seen dark absorption bands. Its bright colors are also a nice change of pace compared to the shades of grey most objects show without the spectroscope.

Everyone in the group quickly understood that the absorption bands are signa-

◀ **MODERN EQUIPMENT** The diffraction grating *(lower left)* screws onto a 1.25-inch eyepiece like a filter. The lens *(top right)* fits over the eyepiece and widens the resulting spectrum, making absorption and emission lines easier to see.

In a Nutshell

Barbara J. Becker, author of *Unravelling Starlight: William and Margaret Huggins and the Rise of the New Astronomy* sized up the thinking of many visual astronomers about solving the riddle of the nebulae in August 1864:

". . . they believed that if and when the great breakthrough were to come, it would be thanks to expert use of a fine telescope. It was an unquestioned conviction that both guided and constrained all their thinking about the celestial challenges they faced. Having lived so long inside this deceptively comfortable box, those actively working on the nebular riddle expected the answer would arrive out of imaginable improvements to methods and instruments with which they were familiar. Thus, until August of that year, they continued to row through the fog in a boat firmly tied to the pier."

Miller and Huggins were the first to figure out how to cast off the lines and trim the spectroscopic sails. It took only a modestly sized telescope and the use of a visual spectrograph to decipher the cryptic Cat's Eye Nebula.

HOWARD BANICH (3)

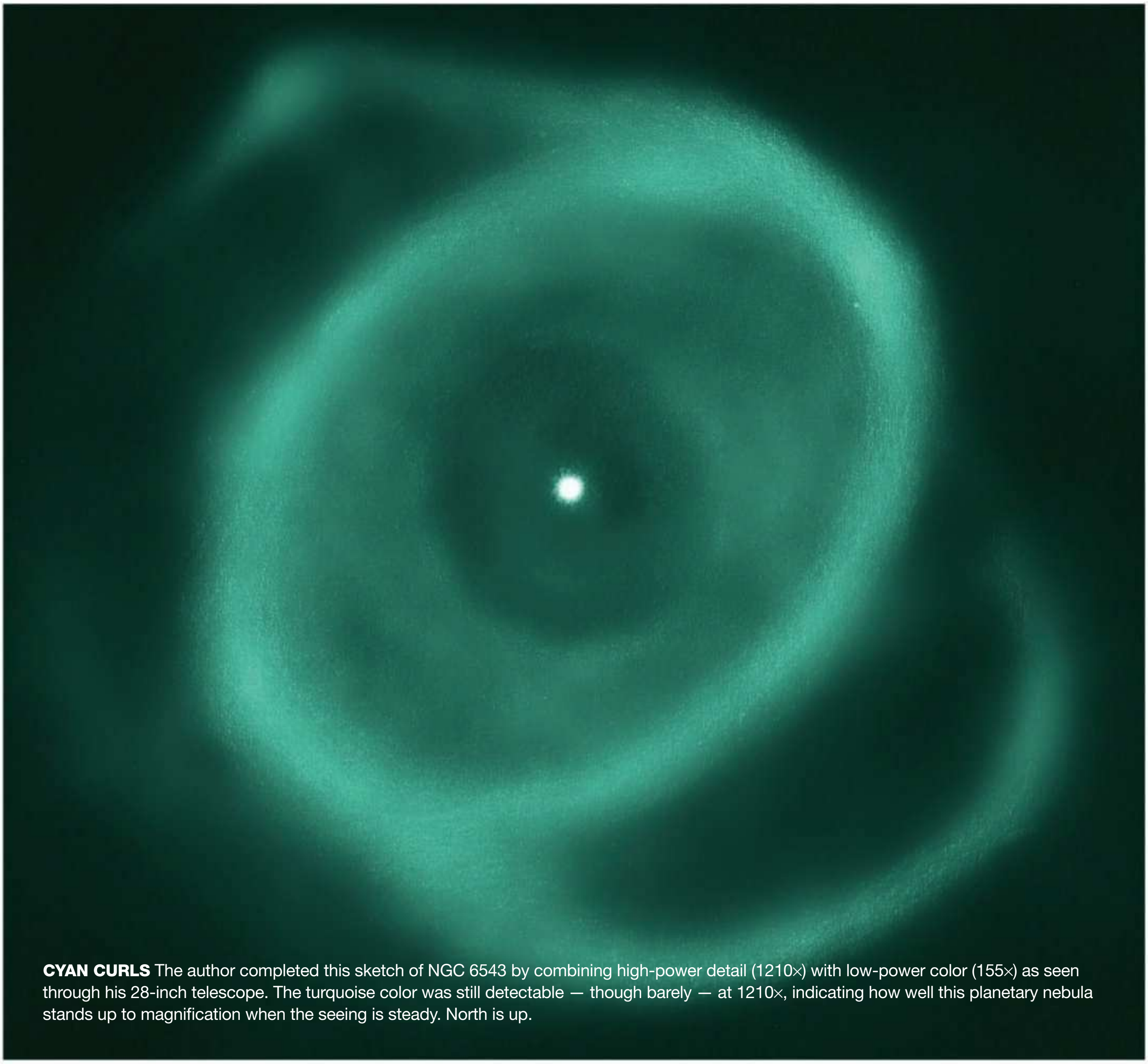
tures of the elements that make up Vega, and that analyzing spectra is how astronomers discoverd what the universe is made of. Sensational stuff!

Then on to NGC 6543 and its two emission lines. I explained how those lines confirmed NGC 6543 was a nebula, and they understood that too, now even more excited. Along the way, some random observers wandered by and joined the fun, so our little family gathering turned into something of an event. It was pretty darn cool.

Although the views I've described were made with my 28-inch reflecting telescope, my 8-inch f/4 scope shows these spectra nearly as well, which isn't surprising considering Huggins used an 8-inch telescope for his work. A huge aperture isn't needed to see the most obvious spectral features of the brightest stars and planetary nebulae.

To say I've been surprised at how genuinely enriching observing spectra can be is an understatement, and not just because of its historical roots. It's a deeper way to actually see, and appreciate, the fundamental nature of stars and nebulae and how different they are from each other. Huggins's and Miller's work is arguably the most meaningful astronomical breakthrough of the 19th century, and if you can afford the cost of a modest eyepiece you can see it for yourself.

■ Contributing Editor **HOWARD BANICH** can be reached at **hbanich@gmail.com**.



CYAN CURLS The author completed this sketch of NGC 6543 by combining high-power detail (1210×) with low-power color (155×) as seen through his 28-inch telescope. The turquoise color was still detectable — though barely — at 1210×, indicating how well this planetary nebula stands up to magnification when the seeing is steady. North is up.

I'm extremely fortunate that in my line of work I get to travel to many places where dark skies are within my reach. One of those locations is the beautiful island of Maui. During the past few years I've had the opportunity to attend a conference on the Hawaiian island crowned by the 10,023-foot (3,055-meter) volcano Haleakalā and home to the first observatory established on the island chain. On my first visit, I enjoyed the sights, while last year my goal was to capture some deep-sky images from this dark mountaintop in the middle of the Pacific Ocean.

Mid-Pacific Paradise

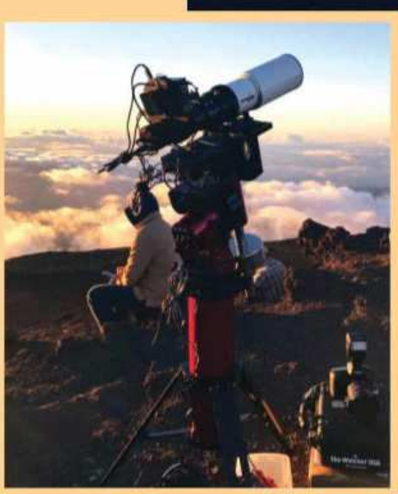
Maui is a relatively large island, with a population less than that of most small cities. Light pollution, while present, isn't as bad as in most rural locations in the continental U.S. east of the Mississippi River, nor even on the nearby island of O'ahu. The largest source of wasted light is Kahului, located on the northwest isthmus that connects the older Mauna Kahalawai volcano (sometimes referred to as the West Maui Mountains) with the younger, larger Haleakalā. In fact, you can see the Milky Way from just about anywhere on the island, including the parking lot of the hotel where I stayed!

But if you're looking for truly dark skies, the summit of Haleakalā is the place to go. This massive shield volcano ("house of the Sun" in Hawaiian) is the tallest point in the southeastern section of the island. Surrounded by the 33,265-acre Haleakalā National Park, the mountain is well away from the busy tourist centers to its northwest and west, and is just as dark as neighboring Mauna Kea.

Haleakalā National Park is open 24 hours a day, year-round, and with a mountain summit often above the cloud deck, it is a veritable astrophotographer's dream. With its peak at more than 10,000 feet, the mountain stands above one-third of Earth's troposphere, making it conducive to extremely dry and transparent conditions.

The summit is home to Haleakalā Observatory, a facility managed by the University of Hawai'i Institute for Astronomy, which operates some instruments on the site and leases others to partners. Among the many domes at Haleakalā are the Faulkes Observatory; the Mees Solar Observatory; the Pan-STARRS observatories housing two 1.8-meter Ritchey-Chrétien telescopes responsible for many recent near-Earth asteroid and comet discoveries; and several others operated by the U.S. Air Force.

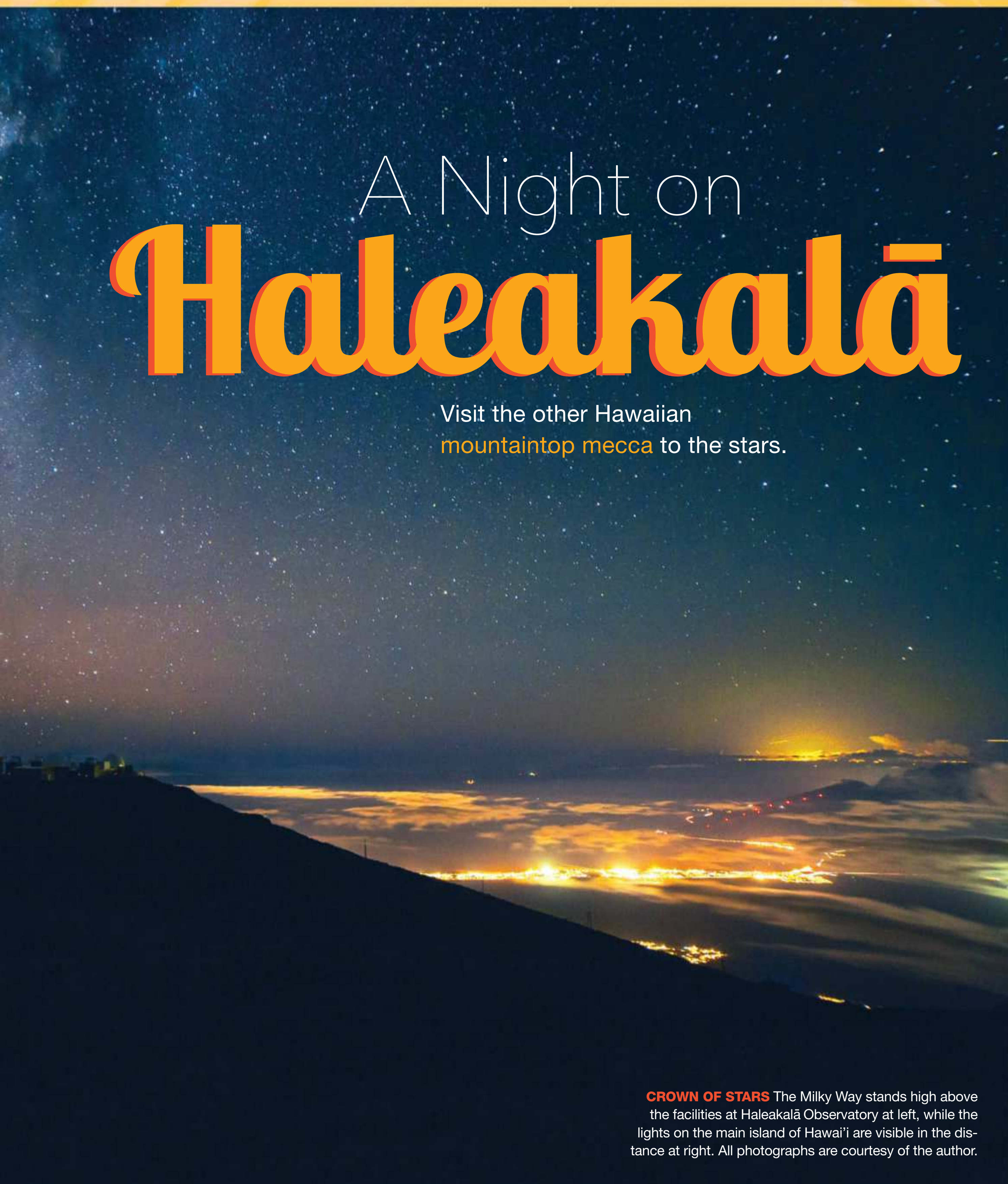
There's a public area outside the observatory grounds that affords a fantastic location for observing and astrophotography. Slightly



SUMMIT RIG In addition to a DSLR camera to shoot nightscapes, the author brought along a Sky-Watcher Esprit 80-mm ED Triplet APO refractor, a Starlight Xpress Trius-694 monochrome CCD camera, and a Raspberry Pi mini-computer controlled by his iPad. Everything rode atop a Software Bisque Paramount MyT.

A Night on Haleakalā

Visit the other Hawaiian mountaintop mecca to the stars.



CROWN OF STARS The Milky Way stands high above the facilities at Haleakalā Observatory at left, while the lights on the main island of Hawai'i are visible in the distance at right. All photographs are courtesy of the author.

LEAF TEXTURE: ANDREA_HILL / GETTY IMAGES

HALEAKALĀ DOMES Haleakalā High Altitude Observatory Site is the oldest astronomical facility on the island archipelago. It includes the 3.67-meter Advanced Electro-Optical System telescope at left, the 1.8-meter Pan-STARRS telescopes, and the U.S. Air Force Maui Space Surveillance Site facilities at right.

below the summit, at 9,740 feet, is the Haleakalā Visitor Center, with a large parking lot. While the visitor center facilities are closed at night, there are walking paths that offer spectacular views of the summit crater during daylight hours. On both of my visits the park was quite busy.

A little farther up from the main visitor center is a smaller parking lot near the true summit of the mountain. Here you'll find yourself high above the cloud deck on terrain that looks and feels like an alien landscape. The vista will take your breath away. Facing southeast on a clear day you can see the Big Island of Hawai'i, and those with keen eyesight (or binoculars) can make out the largest observatory domes on the summit of Mauna Kea. I could just see the glint of the buildings without optical aid, but with a 200-mm lens the site was plainly visible through the viewfinder of my camera.

A word of caution: The climate at the summit of Haleakalā is *very* different than it is at sea level. It is often 50°F colder — or more — compared to the tropical beaches below, so plan to dress appropriately! I should have known better and was pretty uncomfortable later at night in my short-sleeved shirt and light jacket.

Gearing Up

For my Haleakalā imaging adventure, I brought along a Software Bisque Paramount MyT and a Sky-Watcher Esprit 80-mm f/5 ED Triplet APO refractor equipped with a Starlight Xpress Trius-694 monochrome CCD camera. While I shipped the mount for the conference I was attending representing Software Bisque (**bisque.com**), I managed to squeeze the telescope, camera, mini-computer, and a few additional accessories into my carry-on luggage for the long flight from Orlando to Maui.

◀ **DOMESTIC POWER** Airlines limit the size of batteries that are allowed on flights, so a good alternative was to purchase a deep-cycle marine battery and DC-to-AC inverter.

The only wrinkle I encountered with getting my equipment to the island was my custom power supply. It turns out that there is a strict limit to the size of batteries that UPS will allow you to ship air freight. After a long conversation with the folks at the UPS Store, I quickly formulated "Plan B." The alternative was to purchase a good DC-to-AC inverter, bring along the wall-wart power adapters for both the mount and camera, and also pick up a deep-cycle marine battery at the local Walmart on Maui. This ended up costing me just shy of \$100, but in short order I had the battery charging up in my room on the day before my big excursion. In fact, this solution turned out to be quite a bit cheaper than it would have been to ship my batteries in the first place. The only downside was having to dispose of the battery before returning to the mainland (I did manage to find someone who could use it).

So with everything ready, I headed out to the summit in the early afternoon. The drive up the mountain itself is on a short, winding road that takes roughly 30 minutes once you enter the park. The road is narrow and there are many unguarded switchbacks, so be sure to remain alert, especially if arriving after sundown.

Darkness Descends

I arrived at the topmost parking lot in late afternoon with plenty of time to set up, and it was a good thing, too. The thin air at 10,000 feet will take the wind out of your sails a little bit, so be prepared to take extra time setting up. As I finished assembling my gear, the Sun was setting, and I noticed two other things as well. It was getting noticeably colder by the minute, and the parking lot was becoming extremely crowded. Where were all these people coming from?

It turns out this highest parking lot on Haleakalā, with the observatory domes silhouetted against the fading sunlight, is the best spot to watch the Sun as it dips below the western horizon. Looking down from the ridge here in the west, you can see the Pacific Ocean and the micro-metropolis of

LEAF TEXTURE: ANDREA_HILL / GETTY IMAGES

Wailea. The lower car park at the Visitor Center is the place to watch the sunrise above the summit crater, which is not technically a crater, nor volcanic in origin — it's thought to have formed when the headwalls of two erosional valleys merged. Visitors need a permit to enter the park after 3 a.m., in order to keep the crowd size manageable in the wee hours of the morning. Sunset was amazing, though! I must have taken 100 images of the Sun sinking below the horizon and setting the clouds on fire — it was just vivid!

A park ranger came along as my companion Giovanni was holding a drone to use its camera to record video footage, in order to make sure he was not planning to fly it. The ranger looked up and down my mount and telescope quite intently, and I had a moment of panic. "This is mine . . . is it okay?" I asked. "This is awesome is what it is," he replied, and I breathed a sigh of relief. The skies were crystal clear, and this was going to be a glorious night on top of the world.

Within minutes of sunset, the crowds evaporated, and I got down to business. Running the MyT mount was easy using the small Linux-driven computer (Raspberry Pi) and an iPad for the interface, and the battery lasted until I called it quits.

I've previously raved about the primordial skies at Dry Tortugas (*S&T:* Feb. 2017, p. 32), but nothing compares to the transparency I experienced at 10,000 feet that night. The Milky Way is absolutely luminous under such clear skies, and the zodiacal light is as obvious as a klieg light. Some of my telescopic targets, such as M31, were obvious as nonstellar objects and seemed much closer than normal. Perhaps it was the thin air, but I truly felt as if I were standing on another planet or an asteroid in the depths of outer space.

Although I had brought a telescope and planned on shooting several deep-sky targets, I was frequently distracted by the many opportunities for nightscape photography and Milky Way shots in this picturesque location. In the end, I spent as much or more time shooting with my DSLR than I did through the telescope. The high-altitude transparency was so good that I skipped setting up my camera tracker and took short-exposure nightscape images with my Canon EOS 5D Mark III at a moderately high ISO of 3200 and fast 24-mm

▲ **CRATER VIEW** Although not actually a caldera, the huge crater at the summit of Haleakalā is an otherworldly volcanic landscape that often fills up with clouds.

GOLDEN SUNSET The highest parking lot fills up each clear night as people come to witness the island's spectacular sunsets.

▲ **NEAR AND FAR** Another nightscape photographer takes aim at the Milky Way, while the author's 80-mm refractor gathers exposures of deep-sky targets.

▲▲ **ISLAND GALAXY** Shooting deep-sky images from a truly dark location produces extremely deep results in a relatively short time. This dazzling image of Messier 31, the Andromeda Galaxy, consists of only 20 minutes of luminance exposures captured on Haleakalā, while the color information was captured from the author's home observatory.

▲ **QUICK COLOR** The extremely transparent skies allowed for enough signal to create this colorful image of NGC 7822 in Cepheus.

lens. I could have stayed all night shooting nightscapes, if not for the cold and other obligations in the morning.

As the night progressed, a creeping tiredness, along with the lack of oxygen that comes with the thin mountaintop air, caused me to make a few mistakes with the imaging rig, so I never was able to record a truly deep image of my chosen targets through color filters. The cold temperature was more than I had planned for, so several times I was forced to take refuge in the car without actually starting an image sequence. Fortunately, I still managed to record several moderately deep monochrome images that took advantage of the transparency, which I then colorized later with data from my home observatory.

While the summit is remote, it wasn't until after about 1 a.m. that I was truly alone in the lot. Earlier in the evening, a family observing the sunset was convinced that, despite my protests, I was a real scientist because I just knew far too much about the night sky, and of course I had all that fancy equipment. Later on, the ranger came by to visit, and another nightscape photographer chatted with me while I took breaks to warm up in my rental car.

Haleakalā is a sacred site to the native Hawaiians, and although I've left the superstitions of childhood behind, I couldn't help but be moved by the place in a deep part of my soul. I did not speak with my ancestors, but if the spirit of my lost son wandered anywhere on this Earth, it would surely be in a place like this. I dwelt on that with quiet reverence while I was there.

I plan to return to Haleakalā again this year, and I'm determined to stay all night and catch the sunrise while recording time-lapse images. How can you be so close to something so amazing and not take advantage of it?

■ **RICHARD S. WRIGHT, JR.** travels to many dark-sky locations in his role as a software engineer for Software Bisque.

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▼ OBSERVING FILTERS

Tele Vue Optics teams up with filter manufacturer Astronomik to revamp its series of nebula filters for deep-sky observing. The Tele Vue Bandmate Type 2 Filters are offered in three select passbands: H β, O III, and the Nebustar, a unique ultra-high contrast (UHC) filter that peaks at both H β and O III wavelengths. Unlike other UHC filter designs, the Nebustar passband blocks redder wavelengths, producing sharper, more natural-looking stars while enhancing sought-after nebulosity. All three models are offered in 1¼-inch (starting at $100) and 2-inch format ($200 and up). Each filter is manufactured in Germany by Astronomik and optically tested by Tele Vue and includes a 10-year warranty against manufacturing defects.

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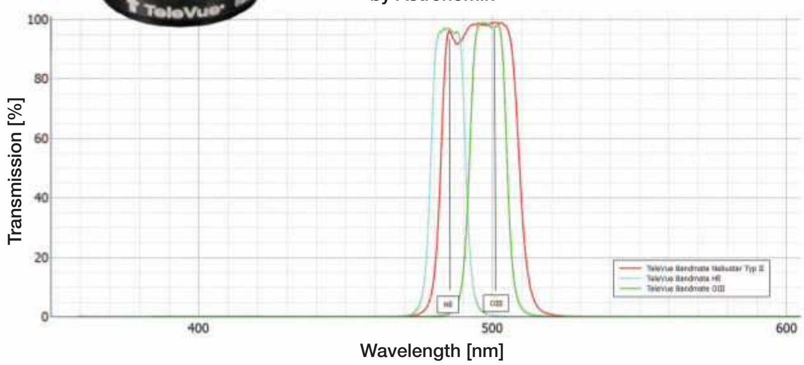

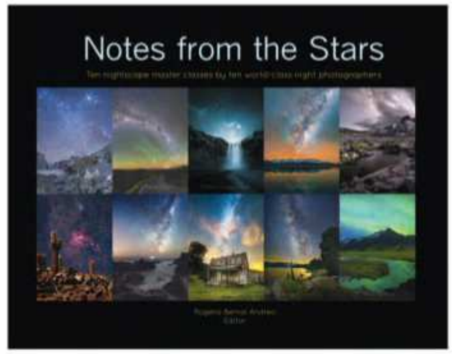

▲ NIGHTSCAPE TUTORIALS

Author and elite astrophotographer Rogelio Bernal Andreo releases his latest book *Notes from the Stars: Ten nightscape master classes by ten world-class night photographers* ($50). This self-published book presents 10 chapters each individually authored by some of the biggest names in nightscape photography, including Babak Tafreshi, Wally Pacholka, and Yuri Beletsky. Each expert shares his personal techniques in his particular area of expertise — such as doing time-lapse photography, photographing meteor showers, or assembling gigapixel panoramas — to help readers get the most out of their own nightscape photography. This hardcover publication is 11 by 17 inches and contains more than 100 pages with full-color illustrations.

Deep Sky Colors
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◀ WIDE-FIELD EP

Stellarvue announces an expansion of its Optimus line of 100° eyepieces. The new 13.5-mm Optimus 1¼-inch eyepiece ($349) fills the void between 9 and 20 mm offerings, adding additional versatility to the series. The ocular is sealed to prevent moisture between glass elements, and it features broadband multi-coatings on all surfaces to virtually eliminate internal reflections. The 13.5-mm Optimus includes extra-durable rubber eye guards and a precision-machined 1¼-to-2-inch focuser adapter.

Stellarvue
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An Optimized Dob

Wringing the last ounce of performance out of a scope.

◀ Steve Hosein has fine-tuned his telescope into a high-contrast, high-quality instrument.

IN HIS YOUTH, Steve Hosein spent many evenings lying back on the teeter-totters in a neighborhood park looking at the stars. In later years, he saw the sky from a Moroccan desert, the Peruvian Andes, and at sea near Tasmania. He was used to dark sky and crisp stars even before he began using a telescope, so it's no surprise that high contrast and quality were paramount concerns when he acquired a set of mirrors and began to build a scope of his own.

But other than using excellent optics, what can a person do to improve the view through a standard Dobsonian telescope? Turns out, there's quite a bit.

Cooling the primary mirror is the first and most obvious thing. A mirror that's warmer than the air around it will warp, and air currents will form in the light path, leading to even more distortion. Yet in an enclosed tube, primary mirrors spend most of the night cooling down, seldom achieving ambient temperature until early morning. People use fans to blow air against the back of the mirror, and sometimes fans in front to sweep away the boundary layer, but there's still no place for the warm air to go except up the tube, causing turbulence the entire way.

So Steve drilled a bunch of 1¾-inch-diameter holes in the tube near the primary mirror. He has two rows in front of the primary, one even with the front face, and one behind. Those holes allow air to circulate around the primary mirror and exit the tube without running all the way forward, cooling the mirror quickly and effectively.

But holes in the side of the tube allow light from the sides to shine in, reducing contrast in the image if any of that light makes it to the eyepiece. So Steve built a shroud for the holes. It's a lightweight shield made from thin plastic that wraps around the holes after the mirror has cooled, effectively blocking any unwanted light.

There's still plenty of light entering the front of the tube, though, and the only part of that you want is the light from your target object. Anything else can brighten the tube walls and reflect around until it enters the eyepiece, reducing contrast. Refractors use baffles along the length of the tube to minimize this, but reflectors can't do that because any baffles below the secondary can reflect light back up into the eyepiece. However, Steve realized that the portion of the tube from the secondary upward could still be baffled, significantly reducing light incursion. So he built a set of closely spaced baffles that do just that. He used sheet aluminum cut with a Dremel tool and epoxied 10 rings together into a framework he could slide into the tube.

He painted the baffles and the inside of the tube with an ultra-flat black paint called "scenic black" formulated for the film industry. The result is an ultra-dark interior.

The traditional four-vaned secondary spider is another source of stray light, this time in the form of diffraction. Reasoning that fewer, thinner vanes would reduce this diffraction, Steve made a three-vane wire spider using 0.008-inch-diameter guitar strings. The wire attachment points are carefully placed one right over the other so their cross section from the primary mirror's perspective is minimal. They're held with guitar tuning pegs on the outside

▲ Ventilation holes allow air to flow around the primary mirror, cooling it quickly. A shroud covers the holes to reduce stray light during observation, and a moveable counterweight allows precise balancing of the telescope.

GARTH TAYLOR (3)

▲ Baffles from the front to the focuser reduce stray light, and the thin wire secondary mirror spider minimizes diffraction spikes.

of the tube, which allows Steve to collimate the secondary by tightening and loosening the wires.

This was Steve's first telescope building project, and he admits that it was a learning process as much as a building project. He says, "Perhaps the most notable thing I learned was the degree to which you have to make trade-offs as you design. So many parameters depend on each other or affect one another."

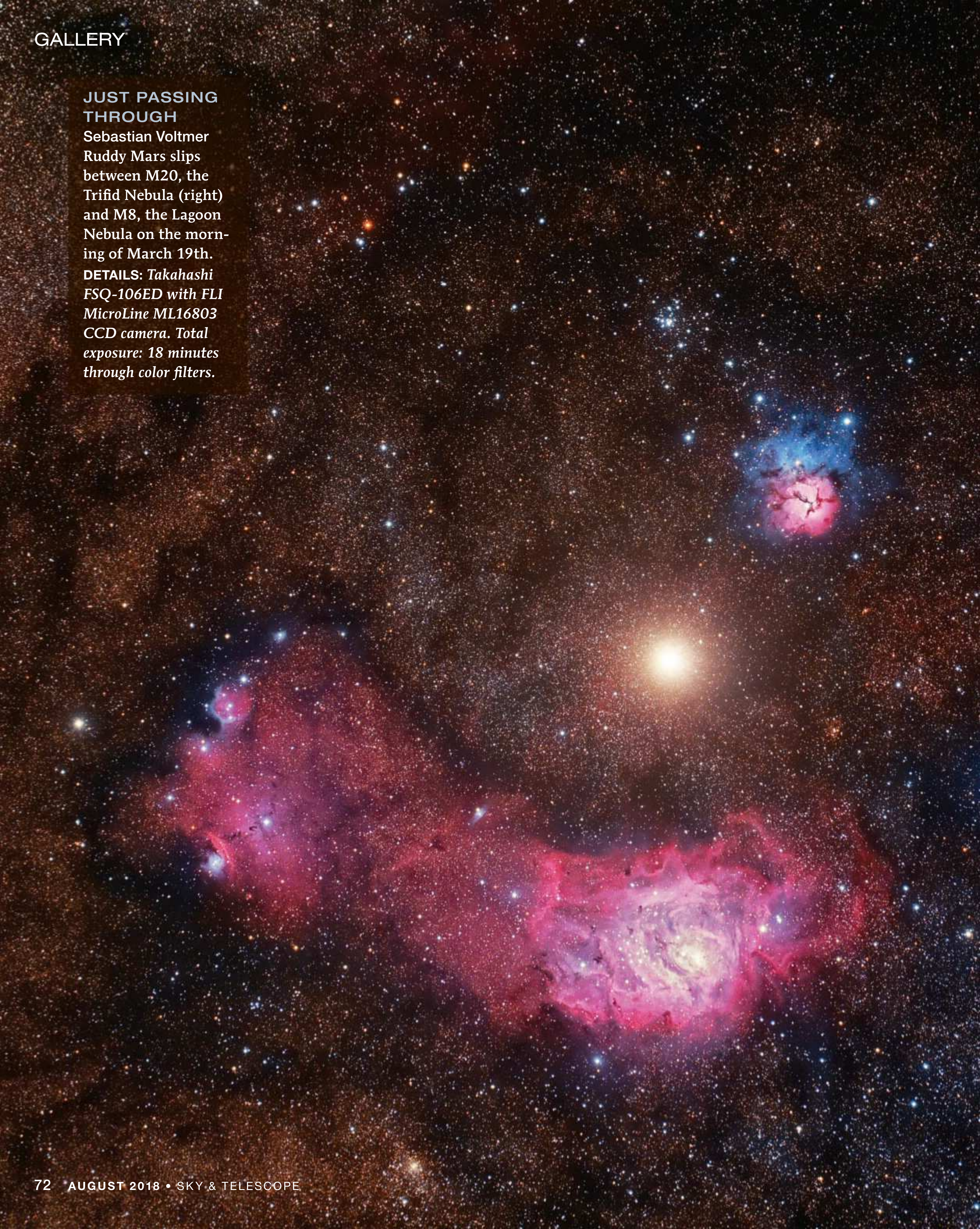
But the proof is in the puddin' as they say. After all this optimizing, how does the scope behave? Steve reports, "Observing from a 6-story rooftop in highly light-polluted downtown Vancouver, with the scope directed at Jupiter over a brightly lit skylight only 10 feet away, I was amazed at how well the scope performed."

For more information, visit Steve's website at **https://is.gd/dobsonian**.

Contributing Editor **JERRY OLTION** has drilled countless holes in telescope tubes, most of them being improvements.

SHARE YOUR INNOVATION

Do you have a telescope or observing accessory that *S&T* readers would enjoy knowing about? Email your projects to Jerry Oltion at j.oltion@gmail.com.



JUST PASSING THROUGH

Sebastian Voltmer

Ruddy Mars slips between M20, the Trifid Nebula (right) and M8, the Lagoon Nebula on the morning of March 19th.

DETAILS: *Takahashi FSQ-106ED with FLI MicroLine ML16803 CCD camera. Total exposure: 18 minutes through color filters.*

△△ GALACTIC ARCH

Barry Burgess

The Milky Way from Cassiopeia (left) through Scorpius (right) stands high above a dark landscape in Indian Fields, Nova Scotia, shortly before twilight last April 24th.

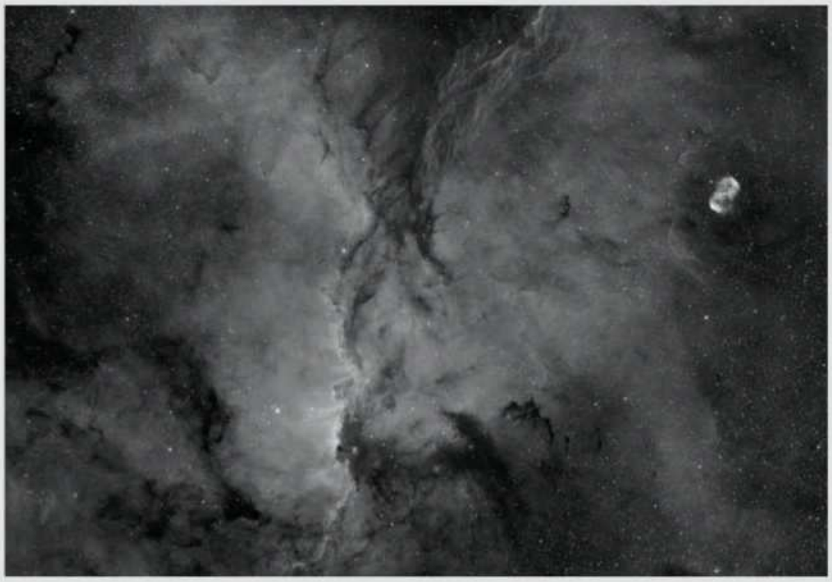
DETAILS: *Canon EOS 6D DSLR camera with Sigma 14-mm f/1.8 lens. Multiple-image panorama assembled from seven frames, each exposed for 30 seconds at f/2.5, ISO 3200.*

△ ULTRA-THIN MOON

Chris Schur

Capturing this exceedingly young crescent Moon took months of planning, but everything fell into place for Arizona imager Chris Schur on the evening of May 26, 2017, when he recorded the 19.2-hour-old crescent.

DETAILS: *Orion 10-inch f/3.9 Newtonian astrograph with Imaging Source DMK 51AU02.AS video camera. Total exposure: 1⁄500 second.*



△△ SPRING SPIRAL
Christopher Gomez

Among the many interesting galaxies in the nearby Virgo Cluster is the starburst galaxy Messier 61, which displays loose spiral arms speckled with many pinkish ionized hydrogen (H II) regions.

DETAILS: *TPO 8-inch f/8 Ritchey-Chrétien telescope with QSI 690wsg-8 CCD camera. Total exposure: 13 hours through Astrodon Gen II color filters.*

△ FIGHTING DRAGONS
Patrick Winkler

A dark column of gas and dust bisects the large emission nebula NGC 6188 in Ara. At upper right is NGC 6164, a bipolar emission nebula formed by the hot O-type star HD 148937 at its center.

DETAILS: *Astro Systeme Austria ASA N300 Astrograph with FLI MicroLine ML16200 CCD camera. Total exposure: 12 hours through a Hα filter.*

GLOWING ATMOSPHERE

Johnny Horne

An intense, red-and-green display of airglow competes with the colorless glow of the zodiacal light last October from Cape Lookout National Seashore, North Carolina.

DETAILS: *Nikon D750 DSLR with 14-to-24-mm zoom lens at 19 mm and f/2.8. Total exposure: 30 seconds at ISO 1600.*

STAR CLUSTERS YOUNG AND OLD
Jaspal Chadha
Young, blue stars dominate nearby open cluster M35 (bottom), whereas the more distant cluster NGC 2158 (upper right) comprises mostly older, yellower stars.
DETAILS: *Takahashi FSQ-130 astrograph with QSI 690wsg-8 CCD camera. Total exposure: 25 minutes through LRGB filters.*

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The editors of *S&T* worked with planetary specialists at the USGS to produce a custom base map showing details as small as 2 miles across. The mosaic comes from the Viking orbiters, with added shading details from Mars Global Surveyor.

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Catching the Eclipse Chills

Last August 21st, the author measured the dramatic temperature drop — 45 years after he first did so.

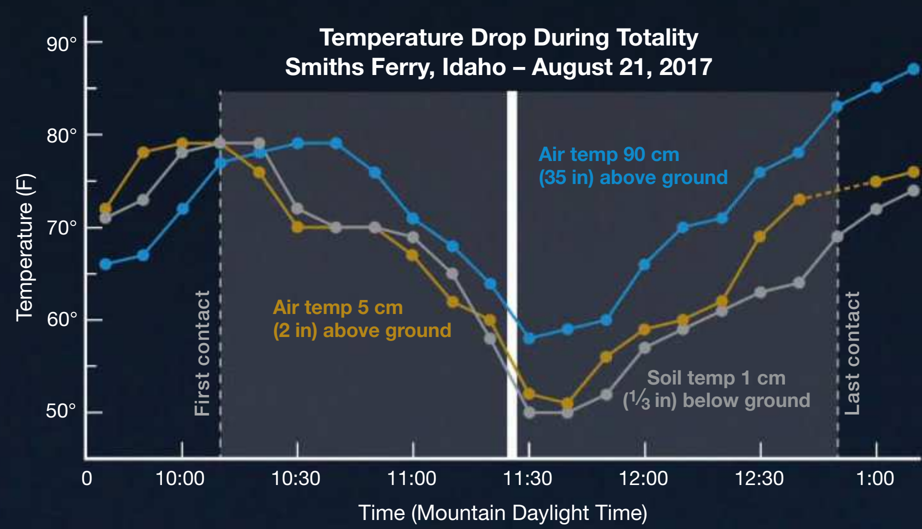
IN 1972, A FEW WEEKS AFTER earning my B.A. in physics from the State University of New York, Geneseo, my parents packed up the trailer at my urging. Off we went to Prince Edward Island, Canada, to view the July 10, 1972, total eclipse of the Sun. My inspiring astronomy professor at Geneseo, David Meisel (who still works there today!), had suggested I take along some thermometers and capture the temperature changes when the Moon covered our star. Shortly after the eclipse, I sent my data to *Sky & Telescope*, which published my graph (*S&T*: Sept. 1972, p. 146).

Last summer, almost half a century later, I set out to experience the 2017 Great American Eclipse to soak in the beauty — and once again take temperature readings.

To have excellent odds for clear skies, my wife, younger daughter, and I traveled from our homes in North Carolina to Smiths Ferry, Idaho, a hamlet about 50 miles north of Boise. We found a lovely spot along the banks of the Payette River, and our GPS revealed that we were only a few hundred feet from the centerline. The fair skies on the morning of August 21st were evident from the moment of sunrise. I set up thermometers at three different positions, each shaded by an index card.

First contact occurred at 10:11 a.m. MDT, and the 2-minute, 11-second totality began at 11:26:35 a.m. The eclipse event ended at 12:50 p.m.

I recorded temperature readings on all three thermometers at 10-minute intervals, beginning at 9:40 a.m. and ending at 1:10 p.m. The graph above displays the striking dip in temperature as the Moon blocked the Sun's photons from our riverside vantage point.



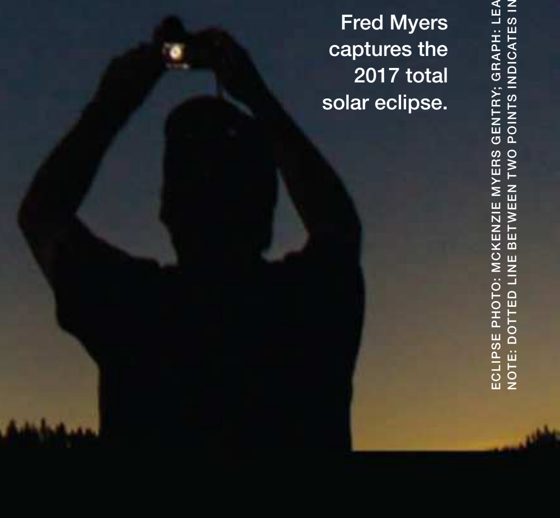
For us observers, the most perceptible temperature, naturally, was the one we recorded a few feet above ground. In a 50-minute span, the air temperature at that level dropped by 21°F, from 79°F to 58°F. It was a significant enough dip that many people instinctively donned sweaters and jackets as the wonder of the eclipse unfolded above them.

The two thermometers close to the ground's surface snagged even more precipitous temperature plunges — nearly 30°F. As solar rays became impeded, the uppermost soil likely radiated energy and adjusted to the cooler soil below.

Note how the temperature curves on the graph are not symmetrical about the time of totality. Minimum temperatures occurred a few minutes after totality ended. As with those of us slightly chilled during the drop, after the end of totality it took a few minutes of increasing sunlight for the air and ground to warm up again.

I'm fortunate to have been able to view the splendor of a total solar eclipse twice in my lifetime. Both events will always remain among the highlights of my life. All people owe it to themselves to experience the awe, beauty, and magnificence of totality at least once — if not twice!

■ FRED MYERS, a science-education consultant, taught high school physics and astronomy for almost four decades. Among other national and state accolades, he received the Presidential Award for Excellence in Science Teaching.



Fred Myers captures the 2017 total solar eclipse.

ECLIPSE PHOTO: MCKENZIE MYERS GENTRY; GRAPH: LEAH TISCIONE/ S&T; SOURCE: FRED MYERS.
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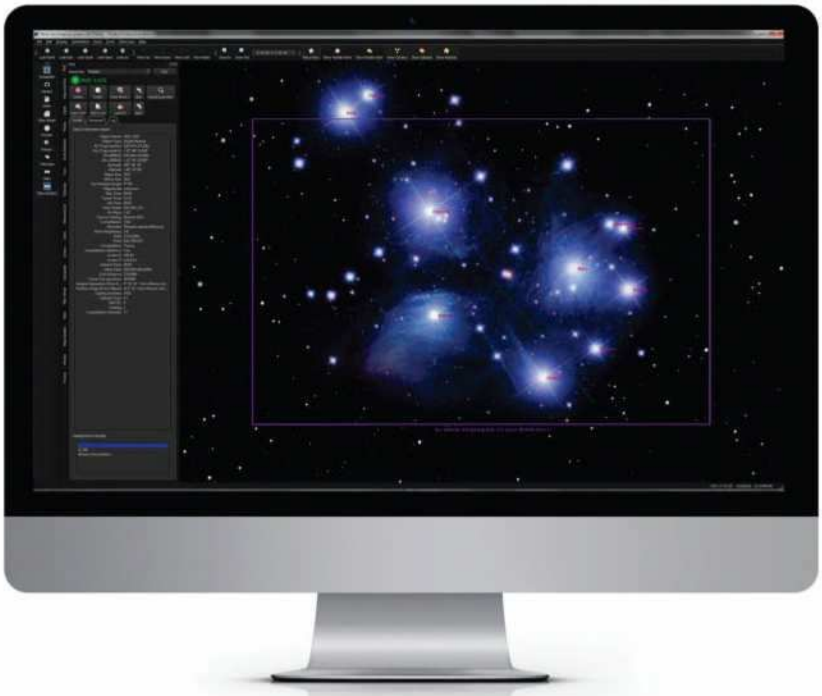

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