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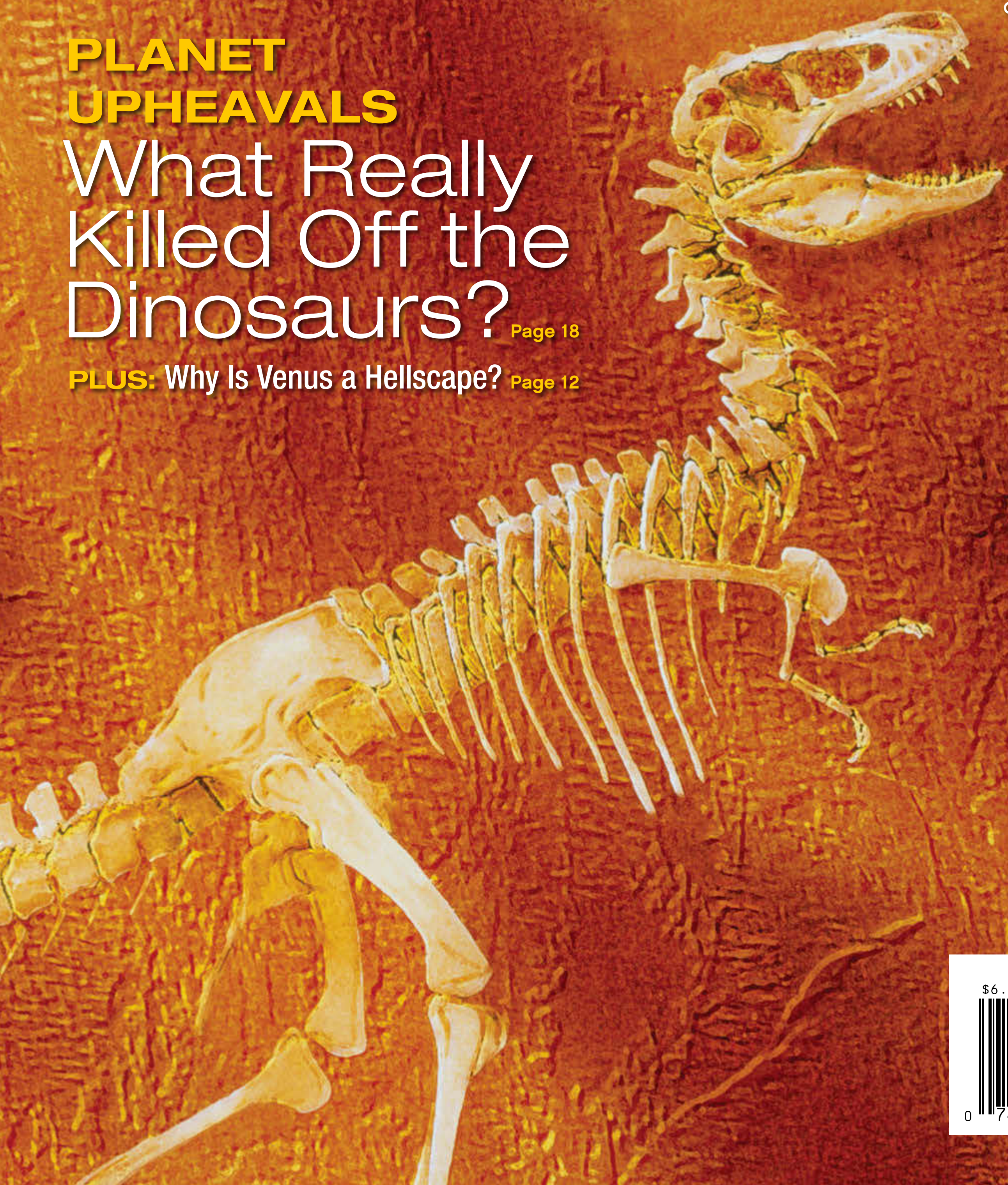
SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

OCTOBER 2021



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SKY&TELESCOPE
THE ESSENTIAL GUIDE TO ASTRONOMY

October 2021 VOL. 142, NO. 4

BOB KING

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ON THE COVER

Computer-enhanced image of a fossilized *T. rex* skeleton

PHOTO: MEHAU KULYK / SCIENCE SOURCE

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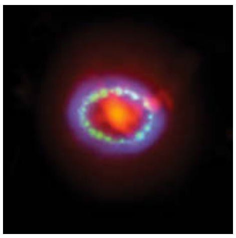
Perish the Thought

EXTINCTION IS NOT SOMETHING we commonly think of when we direct our attention to the night sky. I'm not talking about that of *light* — the atmospheric extinction that paints gorgeous sunsets, for instance — but of *life*. Why would we? For all we know, species extinction may be, like life itself, unique to down here.

Many of us suspect there's life beyond Earth, though, and if that's true, it only follows that its snuffing-out happens elsewhere, too. One merely has to visualize supernovae to convince oneself of that notion. If shockwaves from the 1987A supernova in the Large Magellanic Cloud reached nearby planetary systems, they might well have instantly extinguished any and all life there.

Here on Earth, mass extinctions in particular can be regenerative events. As Shannon Hall reminds us in her cover story on page 18, the end of the non-avian dinosaurs at the close of the Cretaceous Period 66 million years ago cleared the way for the Age of Mammals. That opportunity eventually led to the evolution of us, *Homo sapiens*, the only species that can contemplate its own demise. Just *how* that long-ago extirpation occurred is the subject of Hall's piece — the fabled asteroid might not have been the half of it, it turns out.



▲ Remnant of Supernova 1987A as seen in light of several different wavelengths

ALMA (ESO / NAOJ / NRAO) / A. ANGELICH. VISIBLE-LIGHT IMAGE: NASA / ESA HUBBLE SPACE TELESCOPE. X-RAY IMAGE: NASA CHANDRA X-RAY OBSERVATORY

Mass extinction *might* even have struck elsewhere in our own solar system. Venus today has surface temperatures hot enough to melt lead, and it's hard to imagine any mortal beings thriving there now, except possibly high in the atmosphere (*S&T:* Jan. 2021, p. 10). But if, as some scientists conjecture, our sister world had water oceans billions of years ago, could it have once sustained organisms that died out after a runaway greenhouse effect scalded the entire surface? Earth hosted life as early as 3.5 billion years ago; why not Venus?

As Paul Byrne points out in his article on page 12, it's possible that the second planet from the Sun has always been as hellish as it is now, but if not, extraterrestrial extinction might have transpired right next door to us, as it were. Three new missions to Venus will seek to determine if that broiling orb had a more habitable environment in its distant past (see page 17).

To ponder the most massive extinction of all, have a look at Nicole Nazzaro's review of *The End of Everything (Astrophysically Speaking)* on page 67. Written by astrophysicist Katie Mack, the book, as its title reveals, considers the annihilation of *everything* — the universe and all it contains.

With all this in mind, I guess it's fair to say that extinction could be something we think about every time we stargaze. Just don't let it ruin your evening.

Peter

Editor in Chief

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The Essential Guide to Astronomy

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▲ The eclipsed Sun sets into the Pacific Ocean on January 4, 1992.

Two Annular Eclipses

Joe Rao's "June's Sunrise Annular Eclipse" (*S&T:* June 2021, p. 34) reminded me of 1992's sunset annular eclipse. An article in *Sky & Telescope* (*S&T:* Jan. 1992, p. 78) about how spectacular it would be from southern California spurred me to view it. My son and I observed it from a strawberry field overlooking the Pacific Ocean. The day before was rainy, but the day of the eclipse dawned bright and sunny with a clear blue sky from morning through afternoon, including most of the way through the partial phase. Then, out of nowhere, clouds began forming out over the ocean, hiding the Sun. The band of clouds was so long that moving north or south did not produce a clear view. But just before annularity occurred, the clouds thinned briefly. We did not witness the complete ring, as the clouds thickened again shortly after, but what we saw made the trip worth it.

Maurice Snook • Athens, Georgia

Memories of Comet Halley

Like Joe Rao, I, too, doubt that I will make it for the next return of Halley's Comet (*S&T:* July 2021, p. 58). For more than 20 years at Pensacola State College, I had my students use a program called *Sky Map XP* to calculate its return in 2061 as part of a lab assignment. Their predictions were much in line with the chart on page 64 of that issue. My older son, Michael Eric Wooten, was four years old when he took his first photo of the comet on December 30, 1985, as it moved through the head of Aquarius. If he lives to be just 80, he may be one of the few people to photograph Halley's Comet during two successive returns. Thanks for calling attention to this event. It is indeed something to live for!

▲ Michael Wooten took this image of Halley's Comet in 1985 when he was four years old.

On a sad note, my wife, Merry Edenton-Wooten, whose STEM Spyglasses were featured in Jerry Oltion's Astronomer's Workbench column (*S&T:* July 2020, p. 74), will not make it to 2061. She died of Alzheimer's disease on March 27, 2021.

She was the Executive Secretary of the Astronomical League from 1986–92, the critical years when it transitioned to computers. Merry won the G. R. Wright Service Award in 1989, and I won the Astronomical League Award in 2010, making us the only couple to win the League's two highest awards. She also operated Draco Productions, selling copier-lens telescope kits and Baader solar filters, until her health failed in 2019.

Wayne Wooten
Pensacola, Florida

I thoroughly enjoyed Joe Rao's article on the historical apparitions of Comet Halley. It has been 40 years since my colleague Tao Kiang and I traced the motion of this comet backward in time using a mainframe computer and all the available positional data — including those from the ancient Chinese astronomers. In April 1986, my daughter, Sarah, and I viewed the comet from an aircraft, and since Sarah was only 12 years old at the time, she hopes to be a Comet Halley two-timer in 2061.

Don Yeomans
Rochester, New York

I just read Joe Rao's fascinating article on Halley's Comet. Strangely enough, this week I was writing a chapter of my next book and mentioned my memories of seeing Halley from Las Campanas Observatory in Chile as a young PhD student.

After the disappointment of Comet Kohoutek (C/1973 E1) when I was 10 years old, seeing the edge of Halley's tail rise, long before its coma and nucleus, over the Andes was awe-inspiring! I spent some time at the telescope observing it with a polarimeter and later published a paper based on the data. But seeing it with my eyes was certainly one of the most intense moments of my life!

Laurent Drissen
Québec City, Québec

Stellar Fireworks

I went out with my 4-inch (102-mm) refractor on July 4th to do a little stargazing while all the fireworks were going off. (They are legal in West Virginia.) Well, I was panning through Cygnus looking at open clusters when I happened across the Patriotic Trio. It's

ECLIPSED SUN: MAURICE SNOOK; HALLEY'S COMET: WAYNE WOOTEN three stars close together: the first is red, the second is white, and the third is blue. They looked nice at 92× in my telescope. I went inside and looked them up on the Online Planetarium. It listed them as V695 (red), HD 192579 (white), and 30 Cygnus (blue). They are a few eyepiece views above Deneb. With the rockets' red glare and the bombs bursting in the air, I got a little patriotic under the stars.

Ed Bailey
Daniels, West Virginia

The Formation of Globular Clusters

Galaxies and planetary systems are all flattened into disks. So why are globular clusters (*S&T:* July 2021, p. 14) spherical rather than flat? Does a globular cluster have zero total angular momentum?

David R. Skillman
Greenbelt, Maryland

Diederik Kruijssen replies: *This is a great question, and it touches on the differences between the formation processes of galaxies, star clusters, and planetary systems.*

Indeed, the collapse of a gaseous medium forms a disk, and galaxies and planetary systems inherit their flattened shapes from these disks. Star clusters don't have this shape, because their main mode of formation isn't monolithic collapse but hierarchical collapse. That is, massive clusters arise through the coalescence of much smaller ones, with just a few stars, that gravitationally interact with one another on short timescales. Through these interactions, the orbital directions of all the stars in the globular cluster become randomized. The most massive globular clusters actually are slightly flattened and show weak net rotation. This means that the stars orbit randomly but don't completely cancel out each other's angular momentum. However, over time, their gravitational interactions continue to randomize the orientations of their orbits. So even if there was some residual rotation and flattening initially, the dynamics of the cluster erase it over time. The time needed for this randomization increases with the cluster's mass, which is why the most massive globular clusters have not completely randomized the motion of their stars yet. Eventually, on timescales far longer than the age of the Universe, galaxies will become spherical too, through the same gravitational interactions that continue to randomize the orbits of stars in globular clusters.

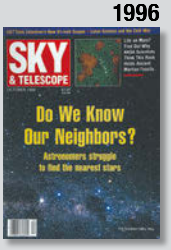
SUBMISSIONS: Write to *Sky & Telescope*, One Alewife Center, Suite 300B, Cambridge, MA 02140, USA or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1946

1971

1996



October 1946

Artificial Meteoroids "[P]ossibly as early as October 20th one of the V-2 rockets being fired at the U. S. Army Ordnance Proving Ground may carry a man-made meteorite. Dr. Fritz Zwicky, [of Caltech] and astronomer at Mount Palomar, has designed the meteorite and the system which will launch it from the nose of the rocket when a height over 100 miles is reached. It is not definite whether the meteorite will become a satellite of the earth, fly off into space, or fall back to the ground to be consumed by the atmosphere. It will weigh less than a pound and astronomical telescopes will be used to follow its path in space."

Ever the maverick, Zwicky felt that astronomers should be active experimenters, not just passive observers. The 1946 launch yielded no results, but another he arranged in 1957 fired a particle into interplanetary space as its trajectory was recorded by Schmidt cameras on the ground.

October 1971

Ganymede Oddity "The first infrared results to be obtained with [Mauna Kea Observatory's] new 88-inch reflector concern an eclipse of Jupiter's largest satellite, Ganymede, on March 17, 1971. The satellite took a little more than two hours to pass through the planet's shadow. . . .

"As observed at wavelengths near 20 microns, the satellite did *not* disappear. After a quick initial fading, its infrared flux nearly leveled off . . . This was the first time that meaningful temperature determinations for any satellite other than the earth's moon had been continued throughout an eclipse. . . .

"For Ganymede's surface material, the numerical value of the thermal inertia obtained from the eclipse observations is only about half that found for the moon. This means that the surface material of Ganymede must be an exceedingly poor conductor of heat."

We now know the thermal inertias of many small solar-system bodies, including some beyond Neptune. Their surface types and porosities vary widely, but oddly enough, their thermal inertias tend to go down with increasing distance from the Sun.

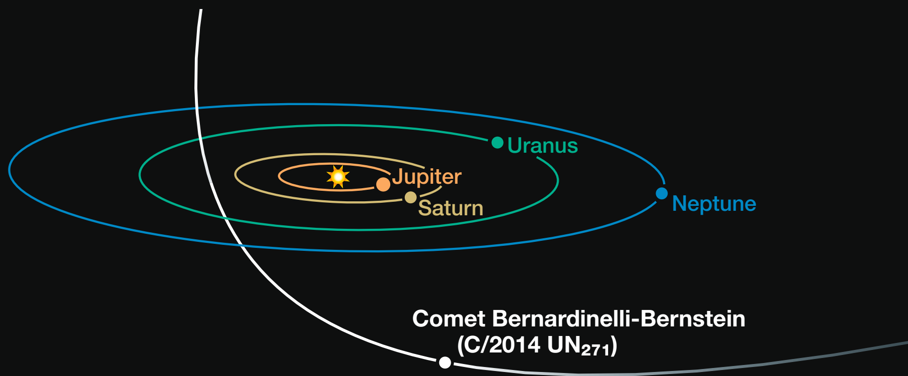
October 1996

Youthful Neighbor "Star clusters are among a galaxy's most easily detectable components, making them a valuable diagnostic tool for determining their host's age, chemical composition, and history. With this in mind, Ata Sarajedini, Douglas Geisler (National Optical Astronomy Observatories), and Paul Harding (University of Arizona) turned the Hubble Space Telescope's piercing gaze toward globular star clusters in the Milky Way's neighbor, M33 in Triangulum. . . .

"In seven of these clusters helium-burning stars . . . appear redder than their analogs in the Milky Way's globulars. This implies that M33's globulars are several billion years younger than those in our own galaxy [and that] the two neighboring galaxies have followed surprisingly different evolutionary paths."

SOLAR SYSTEM

Giant Comet from the Oort Cloud



▲ The trajectory of Comet Bernardinelli-Bernstein (C/2014 UN_{271}) will take it out to about 55,000 a.u. in the Oort Cloud.

THE LARGEST COMET ever recorded coming from the Oort Cloud has astronomers' attention. At 20 times Earth's distance from the Sun (20 astronomical units, just beyond Uranus's orbit), it's already venting gas, sporting a coma 15 arcseconds wide.

The find soon garnered an official designation from the Minor Planet Center: Comet Bernardinelli-Bernstein (C/2014 UN_{271}). Pedro Bernardinelli and Gary Bernstein (both at University of Pennsylvania) discovered the object in 32 Dark Energy Survey observations (*S&T:* Sept. 2021, p. 10) collected between 2014 and 2018.

The orbit immediately drew attention because it showed the comet coming in perpendicular to the plane of the solar system from deep in the Oort Cloud, a group of icy planetesimals surrounding the Sun at distances of about 2,000 to 100,000 a.u. At 20th magnitude, the object is roughly 160 kilometers (100 miles) across, making it the biggest object from the Oort Cloud that we've seen so far. Its size beats the modern record-holder, Comet Hale-Bopp (C/1995 O1), which was about 60 km across. Calculations currently predict that the comet will reach perihelion at 10.96 a.u. (not quite reaching Saturn's orbit) on January 23, 2031. It will most likely not reach naked-eye visibility.

Aphelion, or the orbit's farthest point from the Sun, is more uncertain because of the gravitational nudges the comet receives as it passes through the solar system. Bill Gray (Project Pluto) calculates that the previous orbit took 2.8 million years, while the next one will take about 4.6 million years.

"It's picking up a little bit of energy during this pass through the solar system," Gray notes. However, he adds, the comet will turn around in the Oort Cloud at around 55,000 a.u. — it's not an interstellar object.

Targeted observations will help constrain the comet's orbit as well as other key characteristics, including its rotation, composition, and potential satellites.

■ JEFF HECHT

GRAVITATIONAL WAVES

First Black Hole–Neutron Star Mergers

ASTRONOMERS HAVE DETECTED the first two convincing examples of black holes merging with neutron stars. Members of the LIGO, Virgo, and KAGRA collaborations (hereafter LVK) report the discoveries in the July 1st *Astrophysical Journal Letters.*

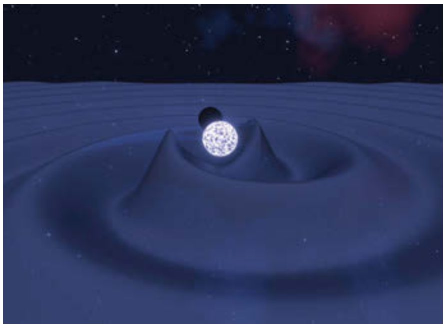
Scientists detected the two events during the second half of LIGO's third observing run, the full analysis of which is still forthcoming. The pair of gravitational-wave signals, dubbed GW200105 and GW200115, rippled through the detectors only 10 days apart, on January 5, 2020, and January 15, 2020, respectively.

Each merger involved a fairly small black hole (less than 10 Suns in heft) paired with an object between 1½ and 2 solar masses — right in the expected range for neutron stars. Observers didn't see any glow from the collisions, but that would have been unlikely anyway: Both black holes are large enough that they probably gobbled the neutron stars whole instead of ripping them into bite-size pieces.

Researchers have reported a potential black hole–neutron star smashup before (*S&T:* Aug. 2019, p. 8), but that could just be gunk in the data. And last summer, they also announced a puzzling collision involving either the most massive neutron star or the smallest black hole known (*S&T:* Oct. 2020, p. 8), though at least some astronomers are leaning toward the latter. Thus, in terms of confidence level, the two new events mark a first for gravitational-wave studies.

■ CAMILLE CARLISLE

Read more about the pairs' origin stories at https://is.gd/NSBHcollision.



▶ An illustration of the gravitational waves created as a neutron star and black hole spiral in toward each other

COMET'S TRAJECTORY: NASA; GRAVITATIONAL WAVES: MARK MYERS (OZGRAV / SWINBURNE UNIVERSITY)

SOLAR SYSTEM

Evidence for Ancient Volcanoes on Asteroid Psyche

ASTEROID 16 PSYCHE is the largest metallic object in the main belt and the destination of NASA's eponymous mission, set to launch in 2022. But what the spacecraft will see when it arrives remains an open question. Evidence is mounting that it will discover a world that once oozed iron lava, a phenomenon known as *ferrovolcanism*.

The apparent presence of iron on Psyche's surface initially led astronomers to propose that the asteroid is a planetary core, exposed long ago via violent collisions. However, subsequent measurements revealed that the asteroid's overall density is surprisingly low, so it might be a porous rubble pile instead. Then, in 2020, Brandon Johnson (Purdue University) and colleagues suggested that ferrovolcanism on a differentiated body could have resulted in a metallic surface despite its low density (*S&T:* Feb. 2021, p. 11).

In a new study to appear in the *Planetary Science Journal*, Michael Shepard (Bloomsburg University) and his collaborators report evidence for that scenario in the form of the first composite albedo map of Psyche, which charts how much visible light and radar the surface reflects.

Shepard's team first used radio and visible-light observations to help compose a 3D model of the asteroid's shape. The group then took these features into account when assessing the surface's radar albedo, as measured by the Arecibo Observatory prior to its collapse (*S&T:* Aug. 2021, p. 34) and visible-light albedo measured by others. They found that areas that reflect lots of radar also tend to reflect lots of visible light.

While impacts could have produced localized areas of high radar albedo, it's unclear why the rearranged rubble would be shiny. Also, only one of the high-albedo regions coincides with a possible crater. In contrast, products of ferrovolcanic activity, such as fine-grain silicates or iron slabs, would reflect both visible light and radar. It's possible that these high-albedo sites were once centers of iron-lava eruptions.

▲ The metal-rich asteroid 16 Psyche, pictured here in an artist's illustration, may once have had iron lava flows on its surface.

Johnson agrees that Shepard's data further the case for ancient iron volcanoes, and he adds, "I fully expect to be surprised by what Psyche reveals."

■ **LAUREN SGRO**

COSMOLOGY

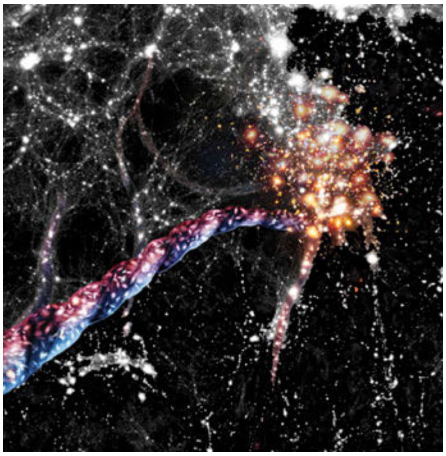
Twisters in the Cosmic Web

FILAMENTS OF THE COSMIC WEB contain galaxies, gas, and dark matter, and measure up to hundreds of millions of light-years long. And they are now the largest structures in the universe observed to rotate, according to a team led by Peng Wang (Leibniz Institute for Astrophysics Potsdam, Germany).

Much of the universe spins — stars, galaxies, and clusters. But astronomers still don't understand if and how spins on smaller scales connect to those on (much) larger scales. "The spin of intergalactic filaments is a key piece of the puzzle," comments theorist Miguel Aragon-Calvo (National Autonomous University of Mexico).

Wang and his colleagues used an algorithm to identify curvilinear structures, or filaments, in the distribution of more than 200,000 galaxies in the Sloan Digital Sky Survey. By stacking data on more than 17,000 of these structures, they found evidence that (after correcting for the expansion of the universe) galaxies on one side of filament spines tend to move toward us while galaxies on the other side are more likely to move away from us. These motion asymmetries suggest that galaxies may rotate around filament axes with velocities up to 100 kilometers per second (200,000 mph). (That may sound fast, but it's generally much too slow to complete one orbit around the filament within the present age of the universe.) The team published the results June 14th in *Nature Astronomy*.

▼ An artist's impression shows a spinning cosmic filament feeding a galaxy cluster.



Aragon-Calvo was part of a team that recently found indications of filament spin in the Millennium Simulation — a dark-matter-only model of cosmic structure growth. "Wang and his colleagues did a great job uncovering a signal that has been hiding in plain sight," he says. "This is a direct confirmation of our prediction."

The study also finds evidence that the observed spin is stronger in those filaments that connect to more massive galaxy clusters. But much work remains before we can determine how these giant cosmic twisters influence the rotation and growth of galaxy clusters.

■ **GOVERT SCHILLING**

PSYCHE ASTEROID: MAXAR / ASU / P. RUBIN / NASA / JPL-CALTECH; TWISTING FILAMENT: AIP / A. KHALATYAN / J. FOHLMEISTER

THE SUN

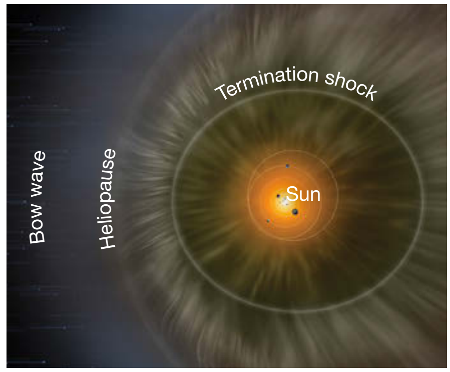
Mapping the Solar System's Edge in 3D

A COLLECTION OF HIGH-SPEED atoms has enabled researchers to trace the shape of the solar system's protective bubble, known as the *heliosphere*. Solar wind particles and the solar magnetic field carve out this region as the Sun hurls through the surrounding interstellar medium.

However, astronomers have only a vague sense of the heliosphere's dimensions based on dependable but limited data, like those gathered by the Voyager spacecraft as they crossed the heliosphere's boundary, known as the *heliopause*. Now, a new study by Daniel Reisenfeld (Los Alamos National Laboratory) and his colleagues, published in the June *Astrophysical Journal Supplement Series*, uses new data to map the heliosphere in three dimensions. Their findings confirm that the heliosphere is compressed on one side, with a tail of debatable size on the other.

Using NASA's Interstellar Boundary Explorer (IBEX) satellite, the researchers measured the distance to the heliopause with a method they call *sounding*. They detected *energetic neutral atoms* (ENAs) originating in the outer layer of the heliosphere, where fast-moving, positively charged solar wind particles steal electrons from slower interstellar atoms. Some of the newly formed ENAs fly straight back towards IBEX at high speeds. By connecting unique solar wind disturbances to variations in the amount of detected ENAs, the astronomers could gauge how long it took for particles to fly outward, change into ENAs, and head back. Using data collected over a full 11-year solar cycle, Reisenfeld's team calculated the distance to the heliopause in all directions.

The map shows that the "nose" of the heliosphere is 110 to 120 astronomical units (a.u.) out. The tail flares



▲ This illustration depicts the outer layers of the heliosphere, the bubble carved out by the Sun.

behind the Sun as it moves through space, but the team can only trace it out to 350 a.u., their method's limit.

Astronomers still debate the true extent of the tail. The upcoming Interstellar Mapping and Acceleration Probe, set to launch in 2024, will observe higher energies than IBEX and probe farther, so it may settle the tail debate once and for all.

■ LAUREN SGRO

SOLAR SYSTEM

Venus Surface Is Fragmented Like "Pack Ice"

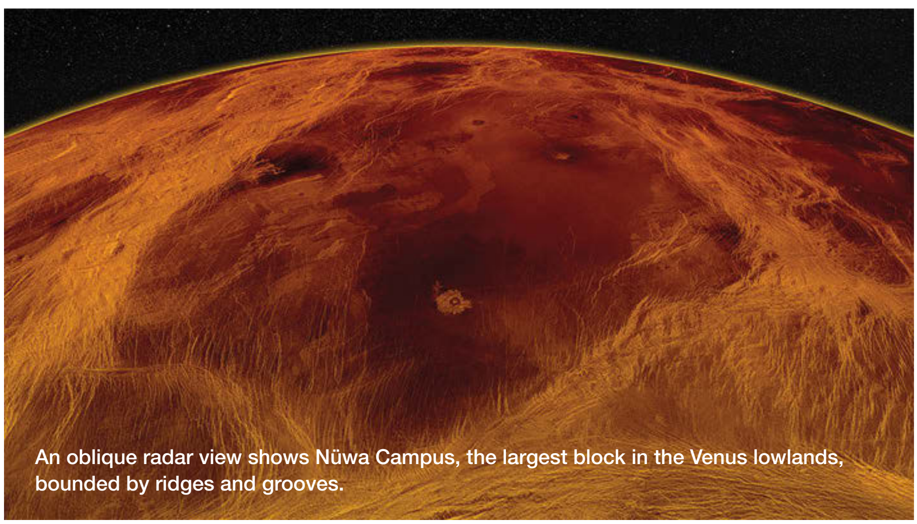
SCIENTISTS HAVE LONG THOUGHT Venus had an immobile lithosphere like Mercury, the Moon, or Mars, rather than moving tectonic plates as Earth does. But a recent study in the June *Proceedings of the National Academy of Sciences* suggests that the ground truth might lie somewhere in between.

A team of planetary scientists led by Paul Byrne (North Carolina State University) used radar imagery taken by NASA's Magellan mission to look at the lowlands that cover most of the planet's surface. Across the globe, undeformed blocks are surrounded by ridges and grooves that indicate extensive deformation. The team built a computer model to show that the blocks appear to be jostling against one another like pack ice on a frozen lake. The researchers suggest interior magma flows may drive that motion, some of it geologically recent, to create the ridges and grooves.

Colin Wilson (Oxford University, UK), who was not involved in the study, says that while the team's analysis seems robust, new and better data are needed to confirm the pack-ice scenario. That data will come from two upcoming missions: NASA's VERITAS and ESA's EnVision (see page 17). Both orbiters will map the planet's topography and gravity, providing a better look at the crustal thickness and activity in the mantle, Wilson says.

"When we get the data back from VERITAS and EnVision in 10 years' time, it will change our understanding of Venus overnight," says team member Richard Ghail (Royal Holloway, University of London). "At the moment we have a good notion of what's going on, but we don't have all the evidence yet."

■ ARWEN RIMMER



An oblique radar view shows Nüwa Campus, the largest block in the Venus lowlands, bounded by ridges and grooves.

MODEL OF SOLAR SYSTEM'S EDGE: NASA / IBEX / ADLER PLANETARIUM; VENUS SURFACE: PAUL K. BYRNE / NASA / JPL

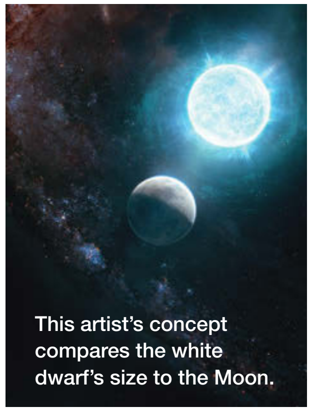
STARS

Moon-size White Dwarf Is Smallest Ever Found

MOST WHITE DWARFS are collapsed stellar cores. But in the July 1st *Nature*, Ilaria Caiazzo, Kevin Burdge (both at Caltech), and colleagues report evidence of a white dwarf born from the union of two smaller versions — and this one might be about to collapse.

Squeezed-together electrons support white dwarfs against gravity, so the more massive it is, the more compact it becomes. But when a pair of white dwarfs merges, the total mass may tip the scale over the *Chandrasekhar limit*, beyond which runaway nuclear reactions detonate the stellar cinder. But if both white dwarfs are small enough, their union might not trigger ignition.

Burdge found such a survivor while sifting through Zwicky Transient Facility data for minutes-long brightness variations. Follow-up observations confirmed this white dwarf rotates every 7 minutes (rather than hours).



This artist's concept compares the white dwarf's size to the Moon.

A fast spin is expected for a merger product and should generate a strong magnetic field. Using the W. M. Keck I Telescope on Mauna Kea, Hawai‘i, Caiazzo and colleagues found that the white dwarf's magnetism is on the extreme end — more than a billion times stronger than Earth's.

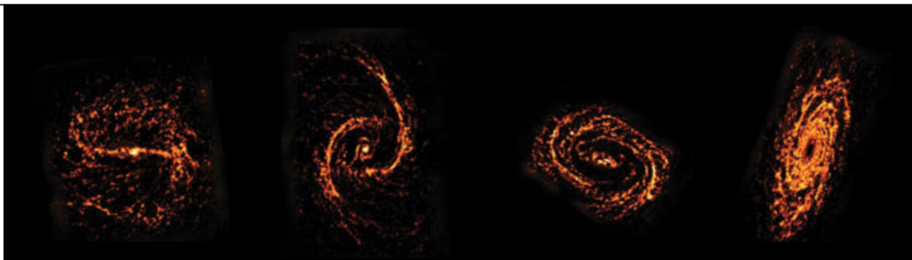
Caiazzo's team then used the white dwarf's brightness and distance to estimate its size: At 4,300 kilometers (2,700 miles) across, it's just bigger than the Moon. That diameter corresponds to a mass between 1.327 and 1.365 Suns' worth, depending on its composition.

It remains unclear if, when, and how the white dwarf might collapse further. The exact mass limit depends on its composition, which is likely changing as heavy nuclei in the core capture electrons and remove their outward pressure. Electron capture itself accelerates as heavy atoms settle into the core over time. Eventually, fusion could restart, exploding or further collapsing the white dwarf.

However, the star's core is also cooling. It will crystallize anywhere between 10 to 100 million years from now, preventing heavy elements from settling and perhaps staving off collapse.

Whatever its ultimate fate, the detection of this young object just 134 light-years away suggests there may be many more merger-born white dwarfs out there awaiting discovery.

■ MONICA YOUNG

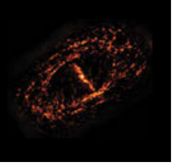


A Menagerie of Stellar Nurseries

Astronomers with the Physics at High Angular Resolution in Nearby Galaxies (PHANGS) group have created the first high-resolution maps of the big, dense gas clouds that form stars inside galaxies. The collaboration used the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile to study some 40,000 molecular clouds within 90 nearby, star-forming galaxies.

ALMA mapped carbon monoxide (orange), a tracer of hard-to-see hydrogen gas, enabling astronomers to observe gaseous structures on the scale of about 300 light-years, which happens to be around the size of an individual cloud. Within these regions of dense gas and dust, up to tens of thousands of stars form over a few million years.

While astronomers previously thought that all stellar nurseries were essentially the same, the new maps, shown at the June virtual meeting of the American Astronomical Society, illustrate that the clouds' characteristics vary with their location within their host, with those near a galaxy's center being more massive, dense, and turbulent. The results will also appear in the *Astrophysical Journal Supplement Series*.



■ LAUREN SGRO

WHITE DWARF AND MOON: GIUSEPPE PARISI; FACE-ON SPIRALS: ALMA (ESO / NAOJ / NRAO) / PHANGS / S. DAGNELLO (NRAO)

IN BRIEF

The Giant That "Blinked"

A red giant star nearly disappeared from the sky for about 200 days in 2012. In April that year, only 3% of its light was arriving at Earth, but by July its brightness was back to normal. The huge dip, cataloged as VVV-WIT-08, only happened once over the 17 years that two surveys, VISTA Variables in the Via Lactea and Optical Gravitational Lensing Experiment, monitored that portion of the sky. The star's smooth dimming and recovery contrasts with the flat-bottom dips that occur when exoplanets cross in front of their stars. This object was big, with a radius of at least 0.25 a.u., and elliptical in projection. Leigh Smith (University of Cambridge, UK) and colleagues suggest in the *Monthly Notices of the Royal Astronomical Society* that the star might have a companion, either a planet or another star, surrounded by a disk. Such a disk could be both large enough and of the right shape to block the giant star's light — and it may do so again one day.

■ MONICA YOUNG

 by Paul Byrne

VENUS: INEVITABILITY OR CATASTROPHE?

Studying Venus can help us understand how large, rocky worlds evolve — and whether the hellish surface conditions on the second planet forebode a similar fate for Earth.

Venus is a study in contrasts. From far away — say, another planetary system — Venus and Earth are essentially indistinguishable. The second planet is 82% the mass, and 95% the radius, of our own world, and orbits the Sun not very much closer: about 108 million km, versus 150 million km for Earth. By most measures, Venus is an Earth-size world (or Earth a Venus-size world).

But when it comes to details, the two couldn't be more different. Early radio observations of Venus found that the planet rotates on its axis backwards relative to Earth, Mars, and nearly every other planet in the solar system. In 1962 NASA's Mariner 2 spacecraft, as it carried out the first successful interplanetary flyby, found no intrinsic magnetic field and very high surface temperatures. These measurements in particular dispelled previous notions of a lush, warm, tropical planet imagined by scientists and science-fiction writers alike, who had proposed such scenes based on Venus's proximity to the Sun.

Subsequent Venus missions sampled the atmosphere, either on the way to the surface or, in the case of the Soviet Union's 1985 Vega missions, as balloons that floated through the middle atmosphere. These missions found an atmosphere that is 97% carbon dioxide, with a global layer of sulfuric acid clouds and an unusually high ratio of deuterium to hydrogen — more than 100 times that of Earth. (More on this finding later.)

From those landed missions that managed to return data from the surface — and many did not — a picture of hell made real came into focus (*S&T:* Sept. 2018, p. 14). The planet's surface has an average pressure of 90 bars, almost as much as 1 km underwater on Earth, and the temperature is around 460°C (860°F, or about that of a self-cleaning oven). Lush, tropical forests indeed. Those missions also found a surface of basalt, the volcanic rock that constitutes Earth's seafloors.

▼ **DESOLATE WASTELAND** Artistic depiction of one of the Venera landers on the surface of Venus. The landers' data revealed flat, angular rocks of basalt, which is volcanic in origin.

COMPOSITION: THE AUTHOR, GROUND: MATTIAS MALMER

NASA's Magellan orbiter, which operated around Venus for four years from 1990, used a powerful radar instrument to peer through the global cloud layer and acquire images of virtually the entire surface. It also took remote geophysical measurements of the interior. Of its many important findings, Magellan determined that Venus has high-standing plateaus, giant rift zones, and extensive, low-lying plains. The spacecraft's gravity data indicate that some of those high-standing regions are likely supported from below by huge upwellings of warmer material from deep in the planet's interior, akin to deep-seated conduits on Earth called mantle plumes — and thus implying a geologically active interior. Venus very likely shares the same broad interior structure as Earth, then, with a basaltic crust, an iron- and magnesium-rich mantle, and an iron core. (The physical state of the core remains an open question.)

But perhaps the most unusual finding from Magellan's global imaging of Venus was what it didn't find: many craters.

A Surprisingly Young Surface

Venus hosts fewer than 1,000 craters across its surface. This discovery alone — made by scouring through the enormous amount of radar image data returned by Magellan — was surprising: Normalized by surface area, Venus doesn't have many more impact craters than Earth does, and far less than the ancient surfaces of Mercury, Mars, or the Moon. Statistical modeling suggested that the average age for the planet's surface was about 750 million years, much less than scientists had expected.

But what was *really* strange was the distribution of those craters: There are no regions on Venus that are noticeably more cratered, and thus older, than any other — again unlike other rocky inner solar system worlds. In fact, statistical analyses carried out with Magellan data showed the craters'

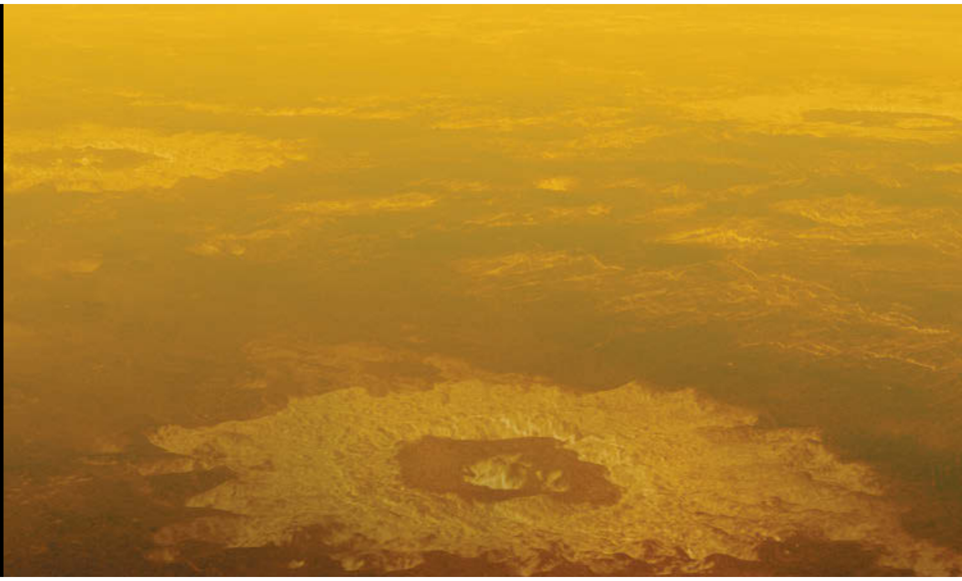
THERE ARE NO REGIONS OF VENUS THAT ARE NOTICEABLY MORE CRATERED, AND THUS OLDER, THAN ANY OTHER.

placement is indistinguishable from random. And what's more, there are no giant impact basins, again a type of feature common to Venus's planetary neighbors (with the notable exception of Earth).

These remarkable observations quickly led scientists to develop several hypotheses. One was that the planet experienced a global-scale resurfacing event by voluminous lava, burying older craters (including any gigantic basins) and essentially "resetting" the recorded age of the surface. Another hypothesis held that, although volcanic resurfacing had operated globally, it may have done so piecemeal and perhaps in a steady-state fashion, with some areas having recently been buried and others being (relatively) older. In this picture, volcanic activity takes place at some level on the planet constantly.

Indeed, there is circumstantial evidence for ongoing volcanism on Venus. The global sulfuric acid cloud layer is not chemically stable over extended periods of time, and thus presumably requires replenishment. Water and sulfur dioxide can combine to form sulfuric acid droplets, and both are volatiles released by volcanic eruptions on Earth. In addition, the European Space Agency's Venus Express spacecraft, orbiting the planet from 2006 until 2014, found that some of the most recent lavas on the planet appear to have undergone very little weathering, suggestive of their being *very* geologically young. And that same mission detected short-lived, localized increases in surface temperature in a region known

CRATERS: NASA / JPL, MODIFIED BY THE AUTHOR; GLOBE: NASA / USGS, PROJECTED BY PLANETUSER / WIKIMEDIA COMMONS / CC BY-SA 4.0 INTERNATIONAL



VENUSIAN CRATERS Venus boasts fewer than 1,000 craters, three of which appear here in this simulated 3D view of Magellan radar data. Venusian craters generally look pristine and uneroded, suggesting they're very young. From left to right the craters are Danilova (48 km wide), Saskia (37 km wide), and Aglaonice (63 km wide).

to feature abundant volcanic landforms — again consistent with, if not proof of, the presence of actively erupting volcanoes on Venus.

A Major Mystery

If widespread resurfacing by volcanism, whether episodic or sustained, regional or global in scale, was responsible for Venus's present cratering record, what did the planet look like *before* that resurfacing?

One place we might learn the answer to this question is the planet's enigmatic *tesserae* — highly faulted and folded rocks that cover about 7% of the surface. In every instance, the rocks that form tesserae are covered by later lavas, indicating that these rocks, which show the greatest amount of tectonic squashing and squeezing of any on Venus, are among the oldest preserved portions of the planet.

Recent findings using decades-old Magellan images raise new questions about the nature of these rocks. Those radar images show distinct layering in some tesserae that resembles a deck of cards. On the one hand, such layering is characteristic of thick stacks of lavas laid down extremely quickly, and there is no shortage of other volcanic evidence on Venus. On the other hand, layering is also a hallmark of sedimentary rocks — those built up by sediment deposits, often in water.

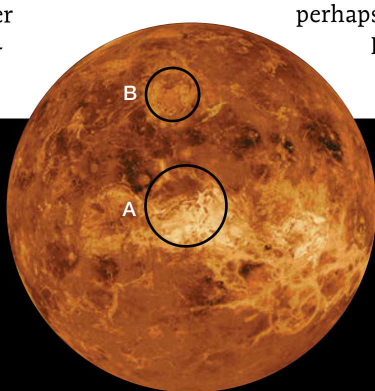
Sedimentary rock types cannot form under today's surface conditions. If some of the tesserae are in fact ancient, deformed sediments, did they form under different climatic conditions, perhaps ones that supported liquid water at the surface?

DID THE SOLAR SYSTEM HAVE TWO BLUE, EARTH-SIZE WORLDS IN THE DISTANT PAST?

Another tantalizing hint of a former climatic regime lies in the planet's elevated deuterium-to-hydrogen (D/H) ratio, which is more than 100 times that of Earth. Deuterium, an isotope of hydrogen with a neutron in the nucleus as well as a proton, is slightly heavier than regular hydrogen and, on Earth at least, much rarer.

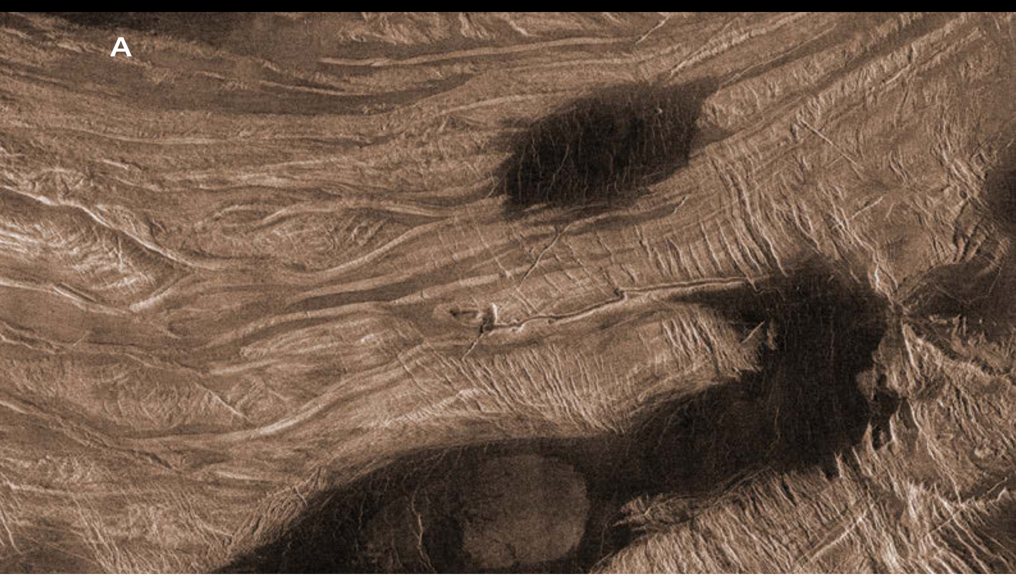
When water molecules in a planet's atmosphere reach sufficient altitudes, solar ultraviolet rays can *photodissociate* the molecules, splitting the water into its component atoms of oxygen and hydrogen — or, sometimes, deuterium. The solar wind then streams by and strips atoms from the top of the atmosphere, preferentially carrying the lighter hydrogen away into space and leaving the heavier deuterium behind. Thus, the best explanation for Venus's high D/H ratio is that the planet once had *substantially* more water than it does today — perhaps even as much as an ocean's worth.

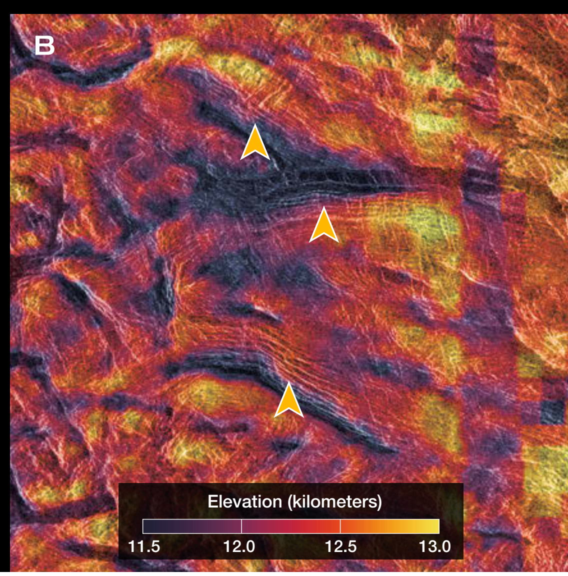
Features including the tesserae and the elevated

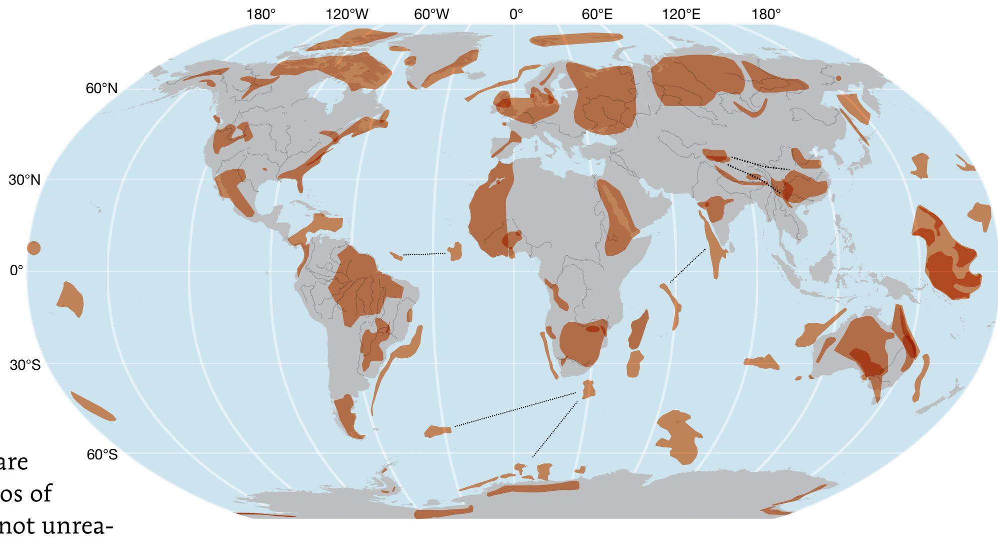


▼ **TESSERA** The northern boundary of Ovda Regio, shown here, is one of several examples of old, crunched-looking highland terrain. Tesserae appear bright in radar images because their surfaces are so rough. Darker patches are thought to be lava that filled in later. The image spans a few hundred kilometers.

▼ **LAYERS** Magellan data reveal sets of curved, parallel lines within some tesserae (arrows) that follow the ridges and troughs of the local topography (color coded by elevation relative to Venus's average radius). These lines might be ancient layers of lava or even sediment, exposed by erosion.







▶ **VOLCANIC PLANET** Earth's geologic record contains dozens of voluminous volcanic flows, called *large igneous provinces*. Shown here are those from the last billion years. On average, such eruptions occur every few tens of millions of years, and scientists have linked some to extinction events in the fossil record (see page 18).

LIP COMMISSION, UPDATED FROM R. E. ERNST AND N. YOUBI / *PALAEOGEOGRAPHY, PALAEOCLIMATOLOGY, PALAEOECOLOGY* 2017

D/H ratio raise a fascinating question: Did Venus once have liquid water on its surface? The long-standing presumption of planetary scientists is that the inner solar system worlds are largely made of about the same ratios of the same materials, so perhaps it's not unreasonable to expect a planet almost as large as Earth to have almost as much water. Did the solar system have *two* blue, Earth-size worlds in the distant past? And, if so, what happened to leave Venus the hellscape it is today?

Old Models and New Insights

One hypothesis proposed early in the exploration of Venus holds that, at some point in the past, the planet suffered a runaway greenhouse effect. The surface temperature slowly but inexorably rose, increasing the rate of evaporation of whatever liquid water was on the surface — lakes, seas, or even oceans. The moisture content of the atmosphere increased, which served to trap more and more of the outgoing radiation that would otherwise make it to space and help keep the planet's surface cool. With a warmer atmosphere came more evaporation, and ever more steam in the atmosphere. Trapped in a feedback loop, Venus ultimately reached the point of no return: The temperature continued to increase until virtually all its water was lost first to the atmosphere and then to space, and the surface became the desiccated, nightmarish place we know today.

But what drove the initial increase in temperature? The obvious suspect is the Sun. We know that stars naturally become brighter and emit more radiation as they age, a consequence of the fusion that takes place in their cores. Early models of Venus's climate therefore included a steady increase in surface temperature from the brightening of the young, nearby Sun — a scenario under which Venus's descent from clement, ocean world to its present state was simply a function of time. Such a scenario also implies something else: Since we orbit that same brightening, aging Sun, so too will Earth one day undergo the same fate that befell Venus.

But recent climate models suggest a different story. Research published in 2020 by Michael Way and Anthony Del Genio of NASA's Goddard Institute for Space Studies found that, for certain combinations of ancient planetary spin rate, surface conditions, and atmospheric compositions, Venus may have easily weathered the effects of a steadily brightening Sun. Indeed, although it remains entirely possible that Venus was always hellish — that it started that way, was never like Earth, and the two planets never diverged — if at any point Venus did possess liquid water oceans, then it would have continued to do so, regardless of what the early Sun did. That's because, per Way and Del Genio's models, once Venus made it to the point at which its climate was stable enough to support the presence of liquid water on the surface, that stability would be hardwired into the planet: Venus would remain continuously able to regulate its temperature just as Earth does today.

Our planet manages this feat via plate tectonics, in which subducting tectonic plates drag volatiles — among them, carbon compounds — into the deep interior from whence they originally came via volcanic eruptions. In doing so, Earth balances its budget of greenhouse-causing compounds, allowing the planet to radiate into space about the same amount of heat as it receives (notwithstanding human activities over the past several centuries that have upset this natural balance, see page 25). So long as Venus had its own self-regulating mechanism — whether plate tectonics or something else — then oceans would remain. We have no evidence for Earth-like tectonic plates on Venus, but since much of the surface is geologically young, absence of proof may not necessarily mean proof of absence.

So, these new models tell us that one of two things happened: Either Venus really was always different from Earth, for reasons we don't yet understand, or it was the same as

TESSERAE

These regions of crumpled highland terrain occur on Venus both as isolated fragments embayed by lava plains and as major plateaus. Venus has six major crustal plateaus, the highest points of which tower some 4 km above the surrounding terrain.

▲ **STILL ERUPTING?** This artist's impression shows an active volcano on Venus today. Data from the Venus Express orbiter found a spike in sulfur dioxide in the planet's upper atmosphere in the mid-2000s, which might have come from volcanic activity. Alternatively, it could be part of decades-scale variations — the earlier Pioneer Venus orbiter saw a range of levels, the highest of which was comparable to the Venus Express spike.

EARTH HAS BEEN LUCKY: MULTIPLE SUCH MAJOR ERUPTIONS DO NOT SEEM TO HAVE TAKEN PLACE AT THE SAME TIME.

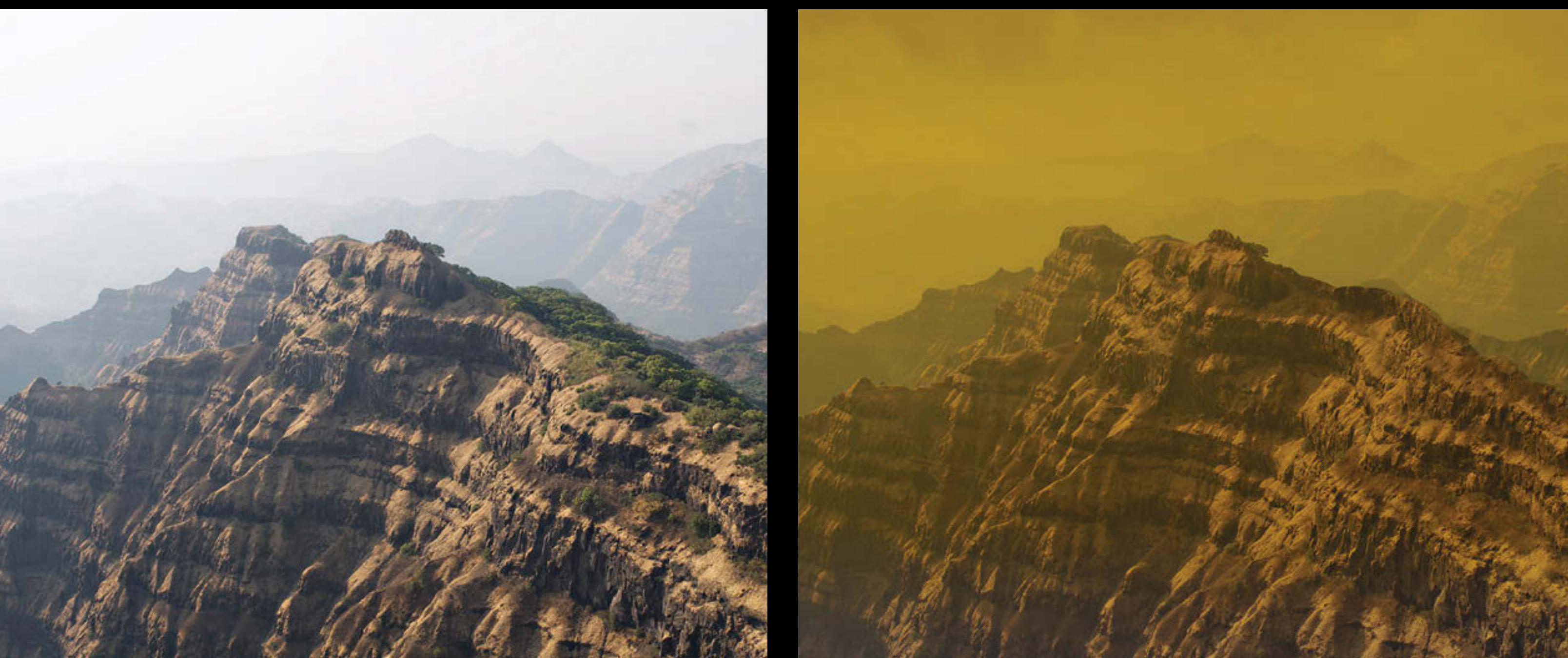
Earth — for a while. If that second scenario is correct, then we must ask an important question: What happened to that once climatically stable, blue Venus?

Way and Del Genio suggest an intriguing cause for a catastrophic change in Venus's climate, one rooted in the planet's rich history of volcanic resurfacing. A major component of terrestrial volcanic gas, in addition to water and sulfur dioxide, is carbon dioxide. Volcanoes on Earth pump out more than 200 million tons of this gas every year. Normally it would be recycled away, but volcanically sourced carbon dioxide can have a profound climatic impact *if enough of it is released quickly*.

That's what might have killed Venus.

Imagine a scenario under which a major volcanic eruption starts — the voluminous kind that produced the vast volcanic plains in India called the Deccan Traps (see page 18), or the expansive Siberian basalts emplaced some 252 million years ago. Then another such eruption takes off, and perhaps even another, all releasing gigatons of CO_2 into the atmosphere, over a geological instant. Even if Venus had plate tectonics or

VOLCANIC ILLUSTRATION: DON DAVIS; DECCAN: MARK RICHARDS; VENUSIAN DECCAN: MARK RICHARDS, MODIFIED BY THE AUTHOR



COULD TESSERAE LOOK LIKE THIS? *Left:* The Deccan Traps in India are vast, kilometers-thick stacks of lava, their layers exposed by erosion. *Right:* The same photo, with vegetation removed and edited to appear under a Venusian sky. It's possible that the ancient, layered highlands called tesserae are similar volcanic formations. Or perhaps they're instead stacks of sedimentary rock.

some other efficient means of drawing carbon out of the atmosphere and returning it to the interior, a sudden, massive influx of this greenhouse gas would overwhelm that system and quickly start to raise the surface temperature. Increasing temperatures would then lead to more evaporation of liquid water on the surface, which would trap more radiation, which would cause more evaporation . . . you get the picture.

A Matter of Luck?

The implication of this line of thinking is that as the Sun ages, it does not have as quick an inimical effect on its nearby planets as we might have feared. Sure, *eventually* a swelling red giant Sun will roast Earth (*S&T:* Oct. 2017, p. 22), but what was once seen as perhaps a climatic inevitability — that, on geological time scales, Earth would soon endure the same climate catastrophe as Venus — is now a more distant destiny.

That's the good news.

The bad news is that enormous volcanic eruptions are geologically common on our planet. In addition to the flows in India and Russia, scientists know of about 200 other examples of vast expanses of basaltic rock, both on land and under the sea. Termed *large igneous provinces* by geologists, these are regions that within only a few million years erupted enough lava to either cover an area of 100,000 km^2 — equivalent to a region the size of Iceland — or that occupy a volume of 100,000 km^3 (about four times the volume of Lake Baikal, the largest freshwater lake on Earth). The potential climate impact such events can have is profound: The Siberian eruptions may have been responsible for the Permian extinction event, the largest die-off of living creatures in Earth's history.

We don't fully understand what controls when or where a large igneous province will form; these phenomena are likely linked to the mantle plumes deep in the planet's interior. But it seems Earth has been lucky: Multiple such major eruptions do not seem to have taken place at the same time. Is that because two cannot form at the same time? Or are these events essentially random in space and time and it is *simply a coincidence* that Earth has not — yet — suffered the same fate as Venus? This is one of the biggest questions in planetary science we have yet to answer.

And answer it we can. Measurements of noble gas abundances in the middle Venusian atmosphere, for example, would give us a much better handle on how much gas has erupted from the planet's interior. Such measurements could also tell us whether the planet started off with enough water to host oceans or if, indeed, it was always a barren world. And what of those strange layers within some tessera exposures? Determining what these ancient rocks are made of, and how they formed, will help us piece together a more complete picture of Venus's geological history — at least, for that history still accessible on the surface. Recently selected missions will take us a long way toward answering the question of what happened (see sidebar at left).

If we one day establish whether Venus really ever was like Earth, and then why, and when, the paths of the two planets diverged, we will know if the relatively stable climate of our own planet has been either a foregone conclusion or simply good luck. We may also better know whether to expect Earth-like, or Venus-like, surface conditions on similarly sized worlds in orbit about other stars — even if we might not be able to say whether we're alone in the universe for quite some time.

And, whatever the reason for Venus's demise, it will give us a new appreciation for living on a world that has largely remained habitable for billions of years.

■ **PAUL BYRNE** is a planetary scientist at Washington University in St. Louis. With a combination of spacecraft data, computer and numerical modeling, and fieldwork at analog sites on Earth, he seeks to understand why planets look the way they do.

U.S. AND EUROPE RETURN TO VENUS

In June, NASA announced that it would send *two* Discovery-class missions to Venus at the end of this decade. These are the Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy orbiter (VERITAS) and the Deep Atmosphere Venus Investigation of Noble Gases, Chemistry, and Imaging (DAVINCI+) probe and spacecraft.

The VERITAS orbiter will map Venus's surface in 3D, distinguishing global features as small as 30 meters across and, for a quarter of the surface, down to 15 m — about five times better than Magellan's radar maps. Height accuracy for topographic features will be 5 m. With instruments to probe the planet's gravity and surface composition, the mission will explore the planet's geologic history, including the nature of the mysterious tesserae.

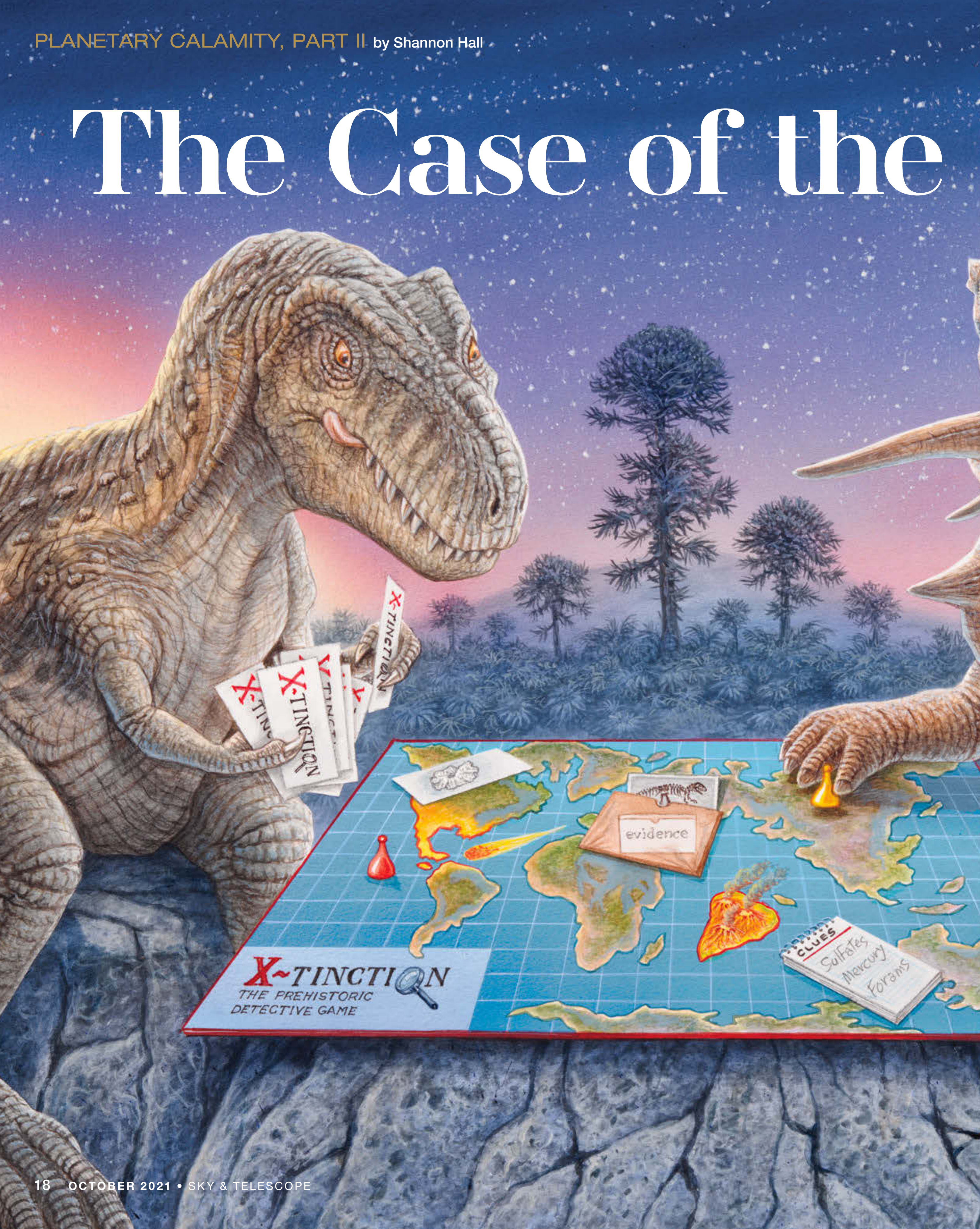
DAVINCI+ will essentially be a chemistry lab dropped into the Venusian clouds. On its plunge to a (hopefully survivable) landing in the rugged tessera region Alpha Regio, it will take images and sample the surrounding gases, providing clues about how the planet has evolved and whether it lost an early ocean. The team is also considering modifying their instrument payload to enable them to check for phosphine, a potential biosignature that might exist in Venus's cloud deck (*S&T:* Mar. 2021, p. 9). The probe's relay spacecraft will later enter orbit.

About a week after NASA's announcement, the European Space Agency declared it, too, is Venus-bound: The EnVision orbiter will launch no sooner than 2031 to study the planet's landscape, surface composition, and internal structure. It will also look for hotspots from active volcanism.

—**CAMILLE M. CARLISLE**

 by Shannon Hall

The Case of the



DEAD DINOSAURS

Scientists can't agree on whether an asteroid strike or volcanic eruptions caused the downfall of the dinosaurs.

It's the greatest whodunit in history. Roughly 66 million years ago, three-quarters of Earth's species — including the nonavian dinosaurs — were annihilated in a geological instant. The question is how.

Textbooks have long stated that the extinction occurred when a 10-km-wide asteroid (6 miles wide — larger than Mount Everest) slammed into the planet with a force of 10 billion atomic bombs. The punch would have unleashed a global darkness so powerful it shut down photosynthetic life and ultimately starved *T. rex* and its Late Cretaceous kin.

But the Hollywood scenario isn't as well accepted as it may seem.

At virtually the same time as the extinction, colossal volcanic eruptions smothered the Indian subcontinent in lava flows nearly twice as thick as the Grand Canyon is deep. Such an explosion would have belched enough carbon dioxide and other greenhouse gases into the atmosphere to raise the temperature on land and acidify the oceans — rendering the globe inhospitable. Thus some scientists argue that it was not an asteroid (or comet) but rather these volcanic eruptions that gave rise to the Age of Mammals.

And the debate is heated. Although recent improvements in rock-dating techniques, the hunt for toxic chemicals, and computer models are offering further clues, scientists remain divided. Yet the answer is crucial if we want to better understand such a dramatic event and shield the world from another mass extinction.

Death from the Skies

The asteroid theory took hold in 1980 when the Nobel Prize-winning physicist Luis Alvarez and three colleagues discovered an odd signature in the geologic record at the time of the extinction event: a layer of iridium. The element is rare in Earth's crust but common in meteorites, leading the team to conclude that a giant meteorite ended the Age of Reptiles.

The study created quite the wave. But there was one problem: Such a strike would have left a scar on Earth, and yet scientists had never discovered the culprit — until 1991. That's when scientists realized that a 200-km-wide bruise partially hidden below the Gulf of Mexico (and millions of years of marine limestone) dates back to the end of the Cretaceous Period.

ILLUSTRATION BY PHIL WILSON

CRIME SCENE RECONSTRUCTION: CHICXULUB

200-km-wide object **SLAMS** into present-day Mexico » Blast **INCINERATES** everything within roughly 1,000 km » Ejected CO_2 **ACIDIFIES** oceans, killing marine organisms » Sulfate aerosols **BLOCK** sunlight, global temperatures drop

Photosynthetic life decimated, disrupts food chain

But a better understanding of the cavity — and the mass extinction itself — has only been uncovered in recent years. In 2016, scientists used a lift boat, which traveled around the Gulf to a point midway out from the crater's center and then hoisted itself up above the water to create a platform. There it stayed for nearly three months as the team hung a drilling rig over the side and removed cores smothered in mud. Once they were cleaned, those cores revealed granite (similar to what you might find in a kitchen, but porous) beneath green and black breccia.

But there was one substance that was missing.

Earlier drilling performed on land had revealed that the area surrounding the crater was mostly composed of sedimentary rocks — including sulfur-rich evaporates. But the team found none of the evaporates in the rock cores. Instead, the hit likely ejected all of them into the atmosphere, where they vaporized and combined with water to create a dark haze of sulfate aerosols.

Those tiny particles, in turn, would have cooled the planet drastically. In fact, when scientists run climate models and release merely 100 gigatons of sulfur into the Cretaceous atmosphere, they find that the planet's temperature would have dropped 25°C (77°F). And it could be more drastic: Estimates from the drilling project are closer to 300 gigatons of sulfur.

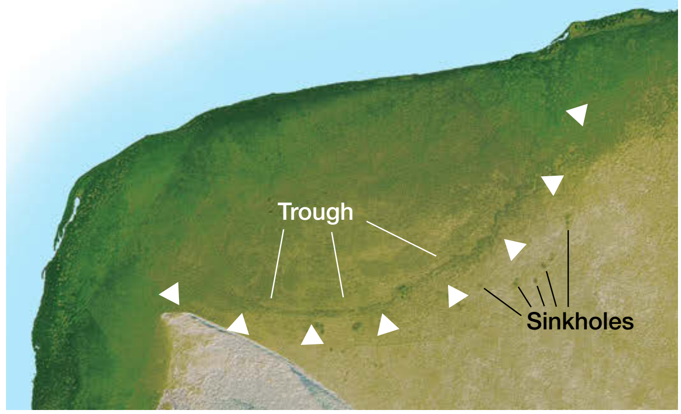
"The effect is remarkable to the planet," says Sean Gulick (University of Texas, Austin), who co-led the project. "On the order of 15 years, or even 20 years, there are close to freezing temperatures everywhere." Moreover, the aerosols would have plunged the globe into perpetual twilight, blocking enough sunlight to crush the global food chain.

The finding, combined with the geological record, led many scientists to conclude that they had caught the killer red-handed. If you look at the sediments running up to the extinction event, also known as the *K-Pg boundary*, most fossilized species vanish precisely at the iridium layer. "In every single section you look at all around the world, life is happy before the impact and then it's clearly devastated," says Joanna Morgan (Imperial College London), Gulick's co-leader.

The findings seemed so certain that many scientists turned their attention to debating the origins of the space rock (better known as the Chicxulub impactor). In 2007, astronomers argued that it was likely the result of a deadly collision beyond Mars. In 2013, a research team suggested that it was not an asteroid at all but a high-velocity comet, based on a new analysis of the chemical elements within the

◀ **CHICXULUB** A crater on the Yucatán Peninsula dates from 66 million years ago and is one of the largest known impact scars on Earth.

▼ **INVISIBLE SCAR** This shaded relief image exaggerates and color-codes topographic heights to show the subtle outline of Chicxulub Crater. A shallow trough (about 5 km wide and 3 to 5 meters deep) marks the crater's boundary. Limestone sediments formed after the impact have eroded around the rim, creating sinkholes.



ASTEROID: JOEBAKAL / SHUTTERSTOCK; MAP: GREGG DINDERMAN / S&T; CRATER GRAVITY MAP: NASA / JPL

“In every single section you look at all around the world, life is happy before the impact and then it’s clearly devastated.” —JOANNA MORGAN

K-Pg boundary. That theory was put forth again in 2014 when physicists suggested that dark matter could have dislodged a comet and again this year when a different team argued the impactor was a fragment from an icy comet that flew too close to the Sun.

But these nuances aside, the impact theory is taught in astronomy and geology courses alike, and it appears in science museums across the globe and even in children’s books. It is so well known, in fact, that if you were to take an informal poll at a party, everyone would likely say that it was an asteroid that spelled doom for the dinosaurs.

“The asteroid hypothesis is pretty much guaranteed at this point,” Gulick says.

Fire and Ash

And yet there are scientists who deny the accepted dogma. When Gerta Keller (Princeton University) peers into the geologic record, she doesn’t see a knife-sharp die-off coincident with the asteroid impact. Rather, she finds a gradual decline of fossils that began when volcanic eruptions across modern-day India belched greenhouse gases into the atmosphere.

The steady change appears across the globe. In the late 1980s, Keller analyzed rock sections in Tunisia and Texas to find that some populations of single-celled marine organisms called foraminifera started to decline 300,000 to 400,000 years before the impact. Her team released a similar story in 2012 when they discovered that plankton suffered severe losses early on. And in 2014, a separate team of scientists saw that some populations of amphibians at a site in Montana also dwindled before the asteroid struck.

“It may be presented as a closed book, but it’s definitely not,” says Courtney Sprain (University of Florida), who later worked on the Montana samples.

The culprit is obvious to Keller. Travel to India and you will see soaring plateaus and river canyons carved out of basalt — volcanic deposits known as the Deccan Traps that erupted at the end of the Cretaceous. In 2008, Keller’s team determined that the lava flows preceded the extinction, but their exact timing has long been a crucial question. So from 2013 to 2016, Keller and her colleagues made several trips to Pune, India, where roads have been carved into the Traps — revealing layer atop layer of lava flows and providing a peek into their history. Her team cut samples from the lithified windborne ash that was occasionally sandwiched between the lava layers and sent the rocks home.

Back in the lab, they dated crystals within the ash to find that there were four distinct pulses of eruptions, with the biggest occurring merely tens of thousands of years before the extinction. Those results, published in 2019, help to paint a different picture of the extinction event. Add in both the fact that species were clearly stressed during that time and a discovery in 2018 that the global temperature increased once the Deccan Traps kicked into action, and it looks like the dinosaurs’ fate was sealed long before the asteroid bore down on Earth.

It sounds wild, but it isn’t unprecedented. On four other occasions, animal life has been nearly destroyed in planet-wide extinctions — all of which potentially came after volcanic eruptions.

◀ **IMPACT DEBRIS** Taken from about 650 meters below the seafloor in the Gulf of Mexico, this core contains suevite, a rock composed of fragments of limestone and granite as well as impact-made melt, all mixed together when the crater formed.

DRILLING IN CHICXULUB Researchers used the liftboat *Myrtle* to drill into Chicxulub Crater in 2016. In this location, the ocean is about 18 meters deep; the boat was raised about 15 meters above water level, to shield it from buffets by currents and tides during drilling.

JOANNA MORGAN (2)

CRIME SCENE RECONSTRUCTION: DECCAN TRAPS

1 million km^3 of lava **ERUPT** in multiple pulses in what is today India »

Eruptions **SURGE** about 300,000 years before asteroid impact »

Released CO_2 **RAISES** global temperatures a few degrees Celsius, peaking 200,000 years before impact »

CO_2 **ACIDIFIES** oceans, killing marine organisms »

Sulfate aerosols **BLOCK** sunlight, global temperatures drop

Photosynthetic life decimated, disrupts food chain

The key is that these are no ordinary flare-ups, but giant floods of lava that smother entire continents, stacking up kilometers thick. There is simply no modern-day analogue. The largest detonation at Yellowstone, for example, unleashed 2,450 cubic kilometers of magma — enough to cover the entire lower 48 United States in 30 centimeters of lava. But the Deccan Traps unleashed roughly 1 million km^3, enough to cover the entire U.S. in nearly 125 meters of lava. Only one-third of the Space Needle would stand above the flood. "It's just beyond imagination," says Stephen Grasby (Geological Survey of Canada).

Even today, their force is undeniable. "As soon as I was in the Deccan province and looking up at all the lava flows, I kept thinking, 'There's no way this did nothing — this is huge,'" Sprain says. "It's four kilometers thick of lava. And it's all around you, and it's all your eyes can see for miles."

▼ **DECCAN TRAPS** These vast lava flows in India date to about 66 million years ago and in places pile some 2 km thick. Such *large igneous provinces* punctuate Earth's geologic history (see page 12) and are sometimes coincident with mass extinctions in the fossil record.

This magnitude, combined with the geologic record, convinces Keller that the volcanic eruptions acted as the lone offender. With more than 200 papers to her name, she argues that such colossal volcanic eruptions would have released enough carbon dioxide and methane to short-circuit the global climate — raising temperatures on land and acidifying the oceans until the microscopic organisms that formed the base of the food chain perished. Once those met their end, larger animals would have followed, causing the global ecosystem to collapse. The asteroid would have had little to do with it.

Partners in Crime

With so much data supporting both hypotheses, some scientists are beginning to accept that the asteroid and the volcanic eruptions might have colluded.

Consider a swerve in temperature. Fossil analyses indicate that the heat wave was immediately followed by a cold snap, causing some scientists to argue that the Deccan Traps first warmed the globe, then the asteroid cooled it down. It's that abrupt change, argues Paul Renne (University of California, Berkeley), that spelled disaster for the dinosaurs.

Both Morgan and Gulick agree that this is a possibility, but they argue that the main killer was certainly the asteroid. In other words, the Deccan Traps might have held Earth hostage, but the asteroid shot the gun.

Then again, maybe the Deccan Traps fired the shot under duress. In 2015, Renne, Sprain, and others put forth a curious hypothesis that suggested that the impact might have kicked the ongoing volcanism into high gear. Chicxulub's collision would have unleashed earthquakes so powerful, the researchers said, that they raced through the globe and triggered Deccan's most destructive pulses.

Earthquakes can send modern volcanoes into overdrive. The seismicity creates new cracks that allow magma to escape more easily, and it changes the chemistry of the magma. "The best way to visualize that, I think, is take a can of pop and shake it up and open it," Renne says. The gas that was dissolved in the liquid escapes, driving eruption. The same happens within the magmatic system.

The team found that after the asteroid struck Earth, the

▲ **LAVA EVERYWHERE** Vast stacks of ancient lava flows tower over the landscape in western India, dwarfing human habitations. These flows erupted over several hundred thousand years leading up to the dinosaurs' extinction, but researchers disagree about the exact timing.

BLAIR SCHOENE

lava at Deccan did appear to go into overdrive. The orientation of the cracks switched direction, the chemistry of the lava changed, and the flows might have become thicker — potentially doubling in output. But Renne notes that the latter is not statistically significant; it's suggestive, but not definitive.

Blair Schoene (Princeton University), who was not involved in the study but worked on dating the Deccan Traps with Keller, is more skeptical, arguing that the error bars on the eruption rates are too large to support that conclusion. "I don't think that holds much water at this point," he says.

On four other occasions, animal life has been nearly destroyed in planet-wide extinctions — all of which potentially came after volcanic eruptions.

Regardless, both agree that the Deccan Traps and the impact each played some role in the Cretaceous downfall. "I don't see how you can escape that," Renne says. "We're still working on the details, but the basic brushstrokes are clear."

Heated Debate

And yet, some extinction scientists remain staunchly on one side or the other.

Take two papers published last year. In one, Pincelli Hull (Yale University) and her team analyzed cores drilled off the coast of Newfoundland and found no evidence for the Deccan Traps' effects. In theory, the eruptions should have acidified the oceans and dissolved any carbonate shells. But instead, the team found carbonates that were remarkably well preserved.

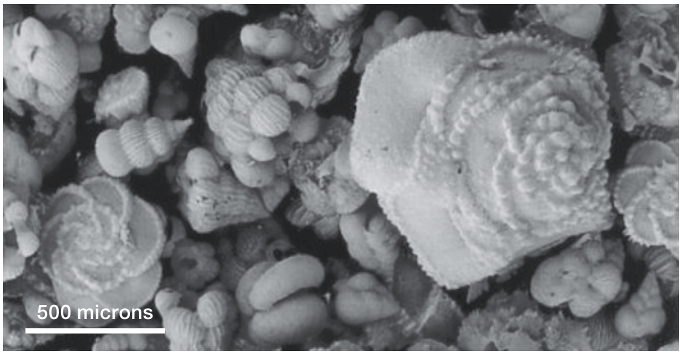
"We see an abundance of 'glassy' foraminifera with skeletons so pristine that they look like they died yesterday," says Richard Norris (University of California, San Diego), who coauthored the paper.

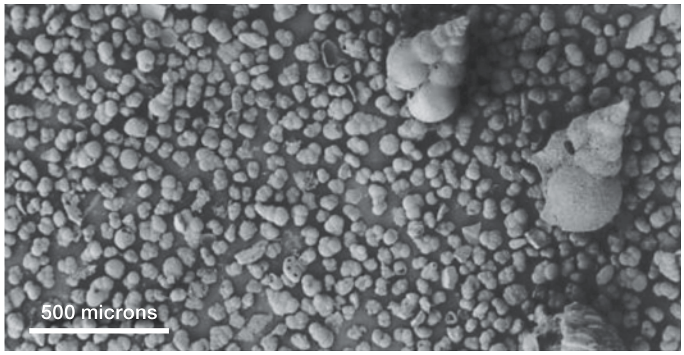
Yet the other paper suggests just the opposite. Keller's team discovered 20 different layers of mercury (a toxic metal released in volcanic eruptions) throughout the sedimentary record that coincided with an increase in temperature and (contrary to the Hull team's discovery) ocean acidification. "We have a cocktail — literally — of all the bad things that can typically end in a mass extinction," she says.

The mismatch might occur because digging through 66 million years of geologic history is, well, hard.

Remember the claim that species were dropping dead hundreds of thousands of years before the main extinction? That was based on a lack of fossils before the K-Pg boundary. Some scientists say the dearth could simply be a lack of data. On the other hand, any claim that species survived the impact would be based on fossils discovered after the K-Pg boundary — which could happen if some fossils had eroded out of an older formation and were redeposited to a younger one.

Ego might also play a role. "I mean, let's face it, a huge number of scientists in the U.S. are not just firm believers,





▲ **FORAMINIFERA** Before the K-Pg extinction event, deep-sea foram fossil specimens are large and diverse *(left)*. But after the extinction, large forams disappear *(right, note same scale)*. Abrupt environmental changes favor smaller organisms, which have more rapid life cycles and need fewer resources than larger organisms.

they've made their reputation on this — and nobody can possibly admit that they might be wrong," Keller says. "It's totally non-scientific."

And yet others would say the same about Keller. "She's made a career of being a contrarian," Norris says. "I think that her science is just driven by this idea that the impact was not the cause, and she sort of hunts around for evidence for that."

But Grasby, a leading expert on mercury who was not a coauthor on Keller's recent paper, was quite impressed by her latest work, arguing that the analysis is solid. In addition, it matches findings from the other major mass extinctions, which is promising — especially if you abide by Occam's razor, the philosophical idea that the simplest explanation is often the correct one.

Grasby is also grateful for the contrarian view. "I just appreciate that Gerta [Keller] is working hard to keep the debate going, and I think it's good for science to see some healthy active debate on these things," he says. "So it's good for her to be so doggedly pressing the cause."

Indeed, many agree that the debate fuels progress, pushing experts to dig deeper — both literally and figuratively. And that is crucial if scientists want to avoid another global catastrophe.

The Chicxulub impact, for example, is sometimes upheld as the reason why we need to scour the skies in search of other life-threatening meteoroids. Although Keller argues that justification is overblown, there is no question that Chicxulub certainly wreaked havoc on the local ecosystem. "It is a preventable natural disaster, if you go look," says Amy Mainzer (University of Arizona). And NASA *is* looking. The Center for Near Earth Object

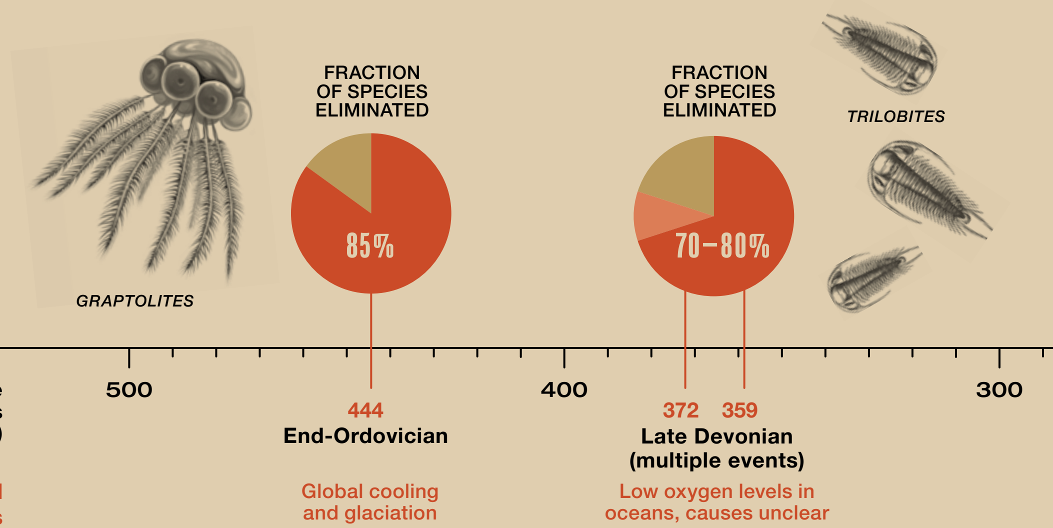
33
BILLION TONS
CO_2 emitted by energy-related human activities *in 2019*

400
BILLION TONS
Estimated O_2 released *instantaneously* by Chicxulub impact

3,000–22,000
BILLION TONS
Estimated total CO_2 released by Deccan Traps, over *several hundred thousand years*

FORAMS: SCRIPPS INSTITUTION OF OCEANOGRAPHY / UNIV. OF CALIFORNIA, SAN DIEGO (2); TIMELINE: TERRI DUBÉ / *S&T*; GRAPTOLITES: LILIYA BUTENKO / SHUTTERSTOCK; TRILOBITES: MORPHART CREATION / SHUTTERSTOCK

MASS EXTINCTION EVENTS
Five major extinction events appear in Earth's fossil record. Some, like the Permian extinction (also known as "The Great Dying"), are clearly tied to volcanic eruptions; others' causes are still debated. There are dozens more smaller extinction events in the geologic record.



Studies at the Jet Propulsion Laboratory supports a number of teams that search for life-threatening objects, and this year a mission will launch designed to test technology that could change the trajectory of an impactor in space. Although astronomers have likely found 95% of kilometer-size asteroids, they've discovered only a third of the medium-size objects out there, Mainzer estimates. Those smaller ones would bring region-level devastation.

Volcanism is not so preventable. Renne argues that something like the Deccan Traps will almost certainly happen again: On average, these colossal volcanic eruptions occur roughly every 30 million years on land. The last one — which released the Columbia River flood basalts across Washington, Oregon, and Idaho — did most of its damage roughly 16 million years ago.

Yet Keller argues that the next mass extinction will not be caused by a volcanic eruption, but by us. And here, most scientists finally agree. Myriad data, from ice core studies to chemical analyses of our atmosphere's makeup, indicate that Earth's climate is warming today due to the greenhouse gases that we alone have emitted (see sidebar). Countless species are staring down extinction. But if scientists can use the findings from both the Chicxulub impact and the Deccan Traps to better understand how much strain terrestrial life can tolerate — specifically, the amount of greenhouse gases in the atmosphere — then they will have a much better idea of what to expect from the current crisis.

And that will help us truly focus on the defense of Planet Earth, Keller argues. "Scientists can already see the end of the world as we know it, not in thousands of years but just a few generations as we speed into the sixth mass extinction."

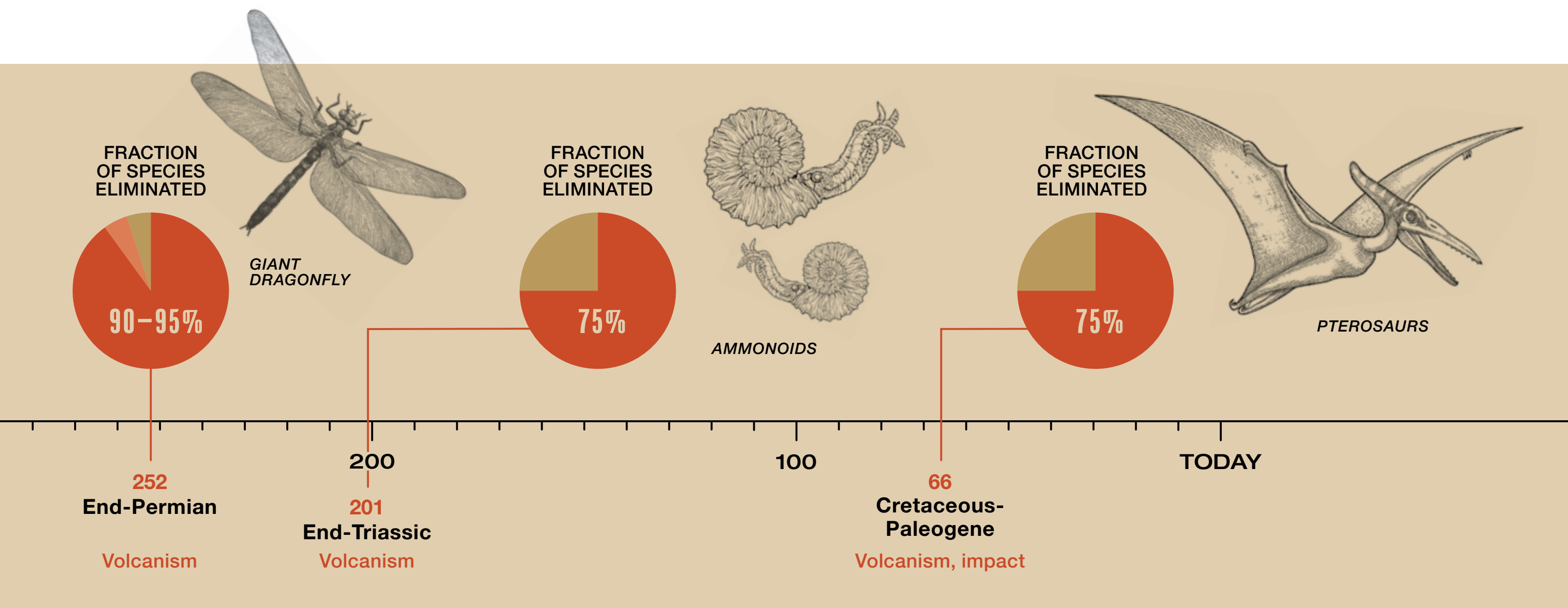
■ *S&T* Contributing Editor **SHANNON HALL** is an award-winning freelance science journalist who grew up traipsing around the Columbia River flood basalts in the Pacific Northwest.

CLIMATE CLIFF NOTES

While exactly how Earth's climate changed during the K-Pg extinction remains under debate, scientists do know that climate change today is both real and caused by human activity. Often omitted from discussions is *how* they know. Here are the key points leading to their conclusion:

- Air samples show that the atmospheric concentration of carbon dioxide (CO_2) is rising on Earth.
- CO_2 absorbs infrared radiation (heat). Adding more infrared-absorbing compounds, or *greenhouse gases*, to Earth's atmosphere throws off its energy balance and causes the planet to absorb more energy.
- This added energy should (among other things) raise the global average temperature, increase ocean temperatures, and spur more extreme weather. Absorbed CO_2 should also make the oceans more acidic. All are happening.
- Both modern and ancient air samples — the latter from air bubbles in ice cores reaching back several hundred thousand years — confirm that the CO_2 levels have spiked since the Industrial Revolution.
- The rate of atmospheric CO_2 increase matches that released by human activities for the same time period.
- The relative amounts of carbon's three isotopes — carbon-12, carbon-13, and carbon-14 — in the atmosphere will be different depending on where the carbon in the CO_2 comes from. Volcanoes and the burning of fossil fuels, for example, will lead to different proportions of carbon-13 and carbon-14 relative to carbon-12. Chemical analysis of Earth's atmosphere matches fossil fuels.

For a detailed discussion of these and other points, read Jeffrey Bennett's *A Global Warming Primer*. Find more information and resources for astronomers at **https://is.gd/astroclimate**. —*Camille M. Carlisle*



GIANT DRAGONFLY: ANDREY OLEYNIK / SHUTTERSTOCK; AMMONOIDS: ALZHAPARD / SHUTTERSTOCK; PTEROSAURS: KATRINE GLAZKOVA / SHUTTERSTOCK

Meet the Neighbors

The Sagittarius Dwarf Spheroidal Family

ESA / HUBBLE / NASA

Our Milky Way has torn a nearby galaxy to shreds. Find out how you can observe its remnants.

We've known for a long time that big galaxies grow by cannibalizing little galaxies, and their eating habits are quite messy. As they feast, they fling their scraps across the sky, forming immense stellar streams. In 1994, the team of Rodrigo Ibata, Mike Irwin, and Gerry Gilmore (Institute of Astronomy at Cambridge University in the UK) discovered a vivid example of life at the galactic dinner table. During a spectroscopic study of the Milky Way's central bulge, they noticed a group of stars moving together at a uniform velocity in a field of random motions. They had stumbled across our nearest neighbor, the Sagittarius Dwarf Spheroidal Galaxy.

The Milky Way's strong gravitational grip is a relentless force of demolition. The shredded debris of the dwarf spheroidal is strung across the sky in two tidal tails that form a prominent substructure in the galactic halo called the **Sagittarius Stream**. Sloan Digital Sky Survey (SDSS) photometry first revealed this feature in 2002, and a study of *M*-giant halo stars in the Two Micron All-Sky Survey (2MASS) catalog confirmed it. The leading and trailing tails of the stream wrap over 360° in looping rosettes around the Milky Way in a nearly vertical polar orbit, as shown in the diagram below. Astronomers refer to the primary wraps as L (leading) and T (trailing), while M represents the remnant core and its associated objects.

The Milky Way has grown via mergers with several dwarf galaxies, accreting stars, dark matter, and globular clusters in the process. Each dwarf stellar population has a unique chemical signature, helping astronomers trace their streams across the sky. After the Sagittarius Dwarf Spheroidal Galaxy stream, the largest are the Gaia-Enceladus, Sequoia, Koala, and Helmi Streams — and a newly identified High-Energy Group. A 2019 study (lead author Davide Massari, University of Groningen) concluded that 35% of all Milky Way globulars may be associated with these merger events.

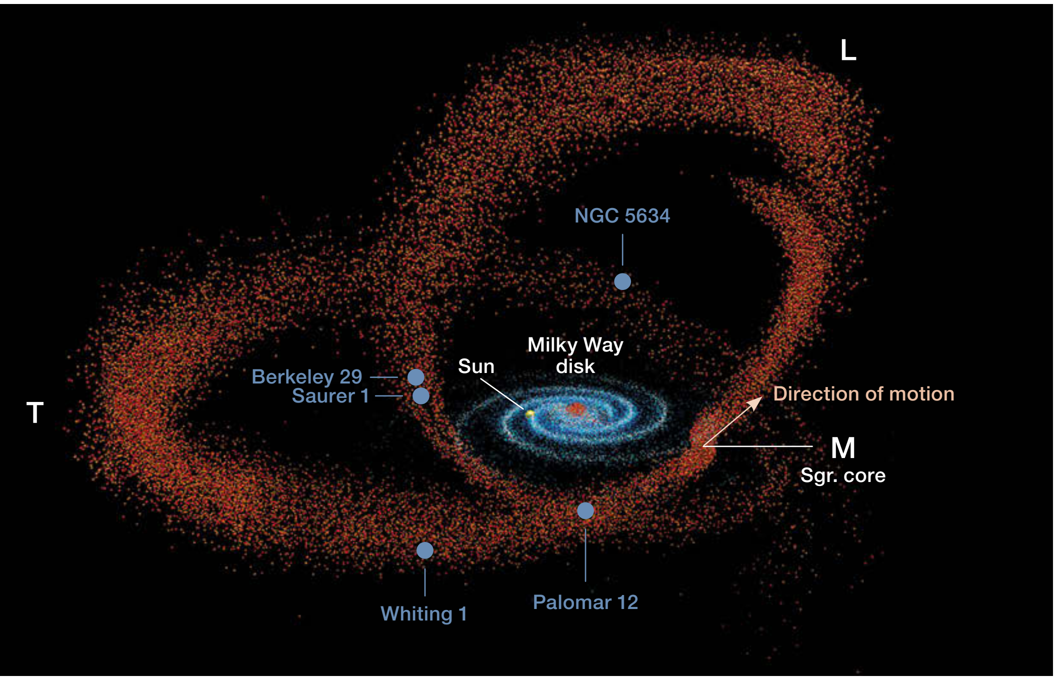
The discovery of these streams, along with data from the astrometric mission Gaia, has opened up a new research field in galactic archaeology that provides valuable information for astronomers piecing together the assembly history of our Milky Way Galaxy (see, e.g., *S&T:* Mar. 2020, p. 40). This difficult job requires precise stellar measurements of location, age, kinematics, and chemistry. The Sagittarius Dwarf provides a unique laboratory to study a galactic merger in detail.

At the beginning of its life, the youthful Sagittarius Dwarf was the most massive of numerous spheroidal dwarf satellites of the Milky Way. It has orbited our galaxy with periods ranging from 550 to 950 million years perhaps as many as 10 times during its billions of years as our hostage. During these orbits the Sagittarius Dwarf elbowed its way through the Milky Way, guided largely by its own massive body of dark matter. For the past 1.8 billion years it looped over the galactic north and south poles, and last punched through the disk 500 to 800 million years ago when it lost the last of its remaining gas.

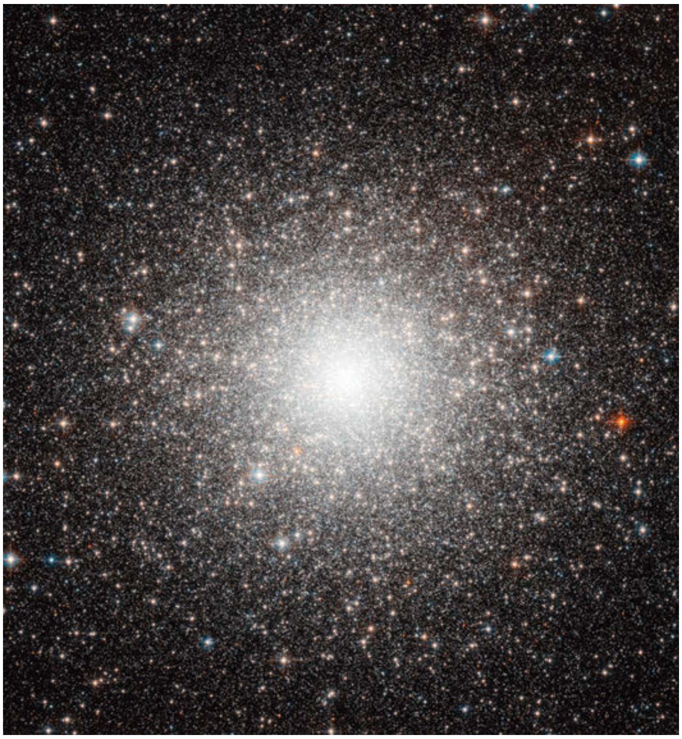
A 2011 computer simulation (lead author Chris Purcell of the University of Pittsburgh) suggests the last collision dramatically impacted the Milky Way, triggering the emergence of spiral arms and outer arcs or rings. More recent simulations show that that crossing also rocked our galaxy, initiat-

◀ **SNATCHED AWAY** The Milky Way ripped globular cluster Palomar 12 from its former host galaxy some 1.7 billion years ago. The cluster nevertheless still resides at a distance of around 60,000 light-years from the solar system in the direction of the constellation Capricornus.

SHREDS OF A FORMER GALAXY The Sagittarius Stream wraps itself around our own Milky Way and consists of tidally stripped stars from our nearest neighbor. Multiple close encounters in the past few billion years formed this structure. The diagram shows the locations of globular and open clusters in the starry trails, as well as the position of the remnant core.

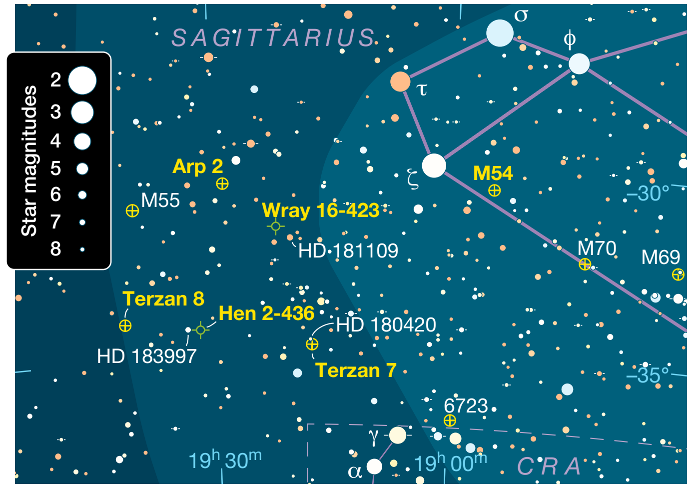


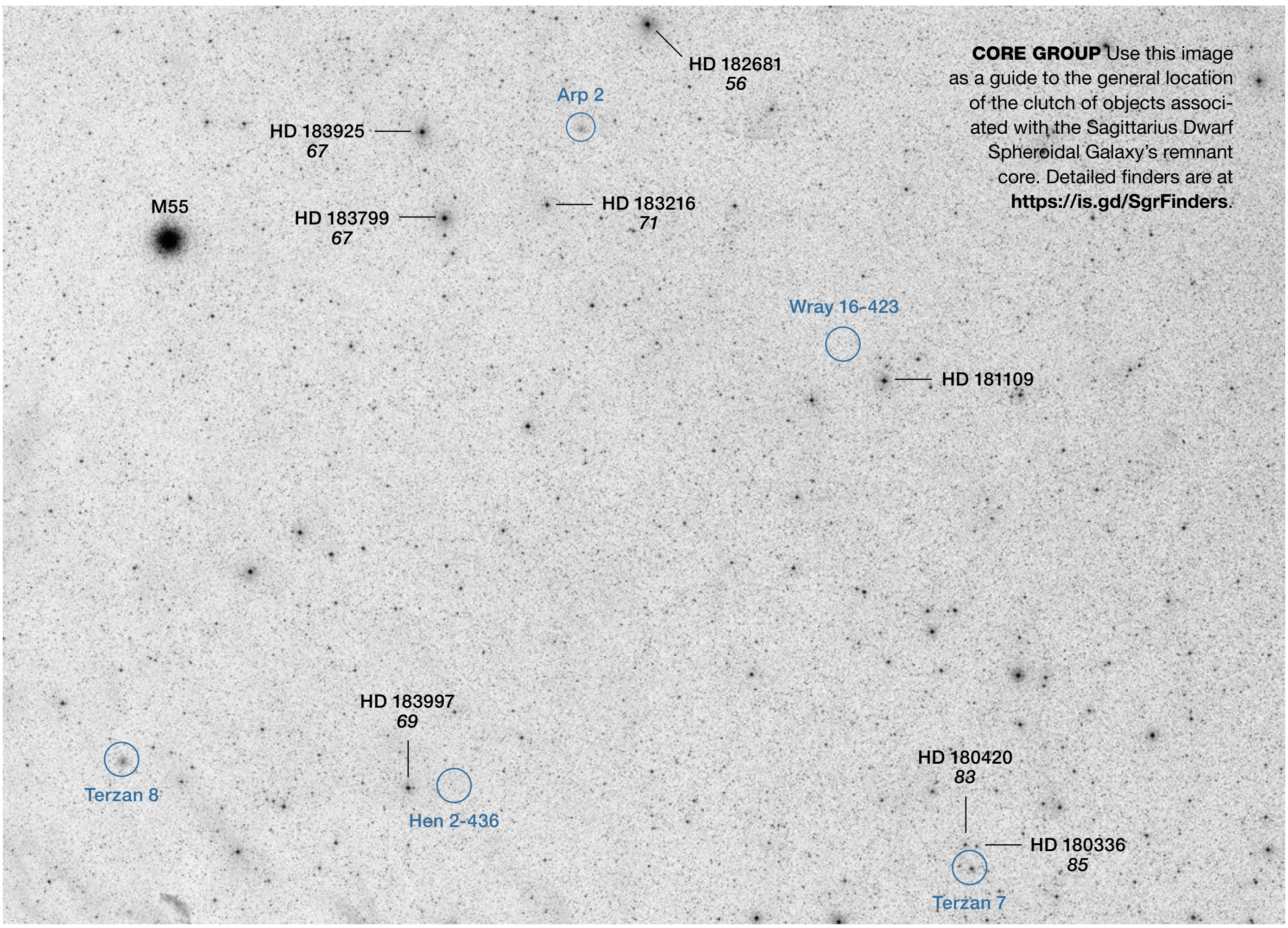
DAVID LAW



◀ **NOT ONE OF OUR OWN** Charles Messier discovered M54 in 1778, but it wasn't until 1994 that astronomers realized that the globular cluster didn't originate in the Milky Way but was in fact formerly a member of another galaxy. At 85,000 to 90,000 light-years distant, M54 is more than three times farther away than our Sun is from the center of the Milky Way.

▼ **BY THE HANDLE** Begin your perusal of targets in the Sagittarius Stream below the familiar figure of the Teapot.





CORE GROUP Use this image as a guide to the general location of the clutch of objects associated with the Sagittarius Dwarf Spheroidal Galaxy's remnant core. Detailed finders are at **https://is.gd/SgrFinders**.

M54: ESA / HUBBLE / NASA; WIDE-FIELD FINDER: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY ing vertical oscillations with stellar velocities that correlate with motion along the galactic plane. This created a snail-shell pattern known as a "phase spiral" seen in Gaia data (Data Release 2). The Sagittarius Dwarf is on course to plunge through the disk again in another 50 million years.

Today the dwarf's tidally distended remnant core is 60,000 light-years from the Milky Way's center and 80,000 light-years from Earth. This gas-stripped region is still more or less intact and forms an ill-defined oval patch spreading 15° by 7° in south-central Sagittarius. The well-known globular cluster M54 sits squarely at the oval's center, and researchers suggest the globular might be the dwarf's disjointed nucleus.

But why did our next-door neighbor stay hidden until 1994? For one, the Sagittarius Dwarf lies behind the galactic bulge on the far side of the plane of the disk (22,000 light-years below it, in fact). Light from the dwarf's core has to cross the dust of five spiral arms and the galactic bar before reaching us. Making matters worse, as the remnant galaxy's starlight angles upward in our direction, it threads its way past more and more stars along its path. The combined light from these stars confuses all but the highest-precision instruments.

The Family Crew

Although you can't directly observe or image the Sagittarius Dwarf Spheroidal Galaxy and its filamentary streams, you can explore several of its current and former residents. Soon after the Stream's discovery, Ibata and colleagues linked four globular clusters to it: M54 (as mentioned earlier), Terzan 7, Terzan 8, and Arp 2. Also, the planetary nebulae Hen 2-436 and Wray 16-423 are still under its gravitational influence and are considered bona fide members. Except for M54, these are scattered around the eastern outskirts of the distended core and will eventually disperse due to the fluctuating gravitational tides of the Milky Way's spiral arms.

You'll need a dark, transparent sky, a good southern horizon, and at least a 12-inch telescope to successfully observe these objects. Observers in the southern parts of the United States have an advantage as the declination strip between –30° and –35° (where they're found) rides higher in the sky. I used an 18-inch reflector from high-elevation sites in northern California. Deep-sky enthusiasts will enjoy the challenge of tracking down these tough targets, but the thrill is their extragalactic pedigree.

Globular Clusters

Let's visit the Sagittarius Dwarf Spheroidal Galaxy's globular cluster family in order of difficulty. **M54** is the second most massive globular after Omega Centauri, and by far the most luminous of the dwarf's quartet. Deep photometry reveals at least three stellar populations with different ages and metallicities, indicating a complex star-formation history.

Based on its location and radial velocity, astronomers once assumed M54 was the core of the stripped dwarf. More recent studies show the globular is embedded in a separate stellar nucleus of metal-rich stars with chemistries that differ slightly from the dwarf's core stars. The current hypothesis is that M54 formed before the ancient galaxy's core and gravitated into the dwarf's center as its orbit decayed through dynamical friction. Repeated galactic crossings then nudged the cluster to its current location.

▼ **THE YOUNG AND THE OLD** *Left:* At around 8 billion years, Terzan 7 is unusually young for a globular cluster — most of the Milky Way's halo globulars clock in at an average of 12 billion years, making them some of the oldest objects in the universe. *Right:* Like most of the other globular clusters associated with the Sagittarius Stream, Terzan 8 is very old and very far.

TERZAN 7: NASA / ESA / A. SARAJEDINI (UNIVERSITY OF FLORIDA); ACKNOWLEDGEMENT: GILLES CHAPDELAINE; TERZAN 8: FABIAN RRRR / CC BY-SA 3.0

▲ **ELONGATED CLUSTER** American astronomer Halton Arp didn't only discover galaxies (see page 57) — he also identified objects such as Arp 2, this tough-to-nab globular situated some 94,000 light-years away.

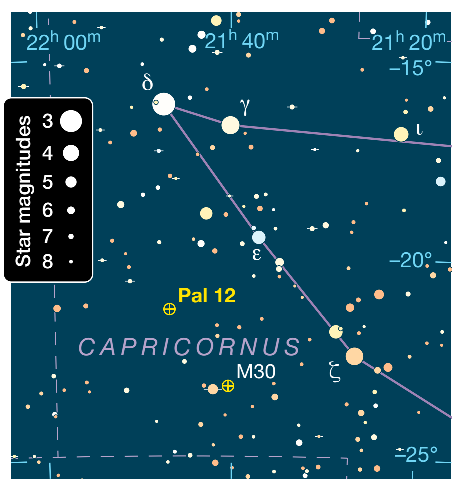
You can easily spy M54 in 10×50 binoculars as a chubby 7.7-magnitude spot. Look for it just 1¾° west-southwest of 2.6-magnitude Zeta (ζ) Sagittarii at the bottom of the Teapot's handle. But even with a large telescope, this luminous cluster is a challenge to resolve due to its remote distance and dense (Class III) concentration. A smatter of brighter stars around the globular's periphery lies in the foreground. The brightest cluster members glow weakly at magnitude 15 to 15.5. You'll need steady seeing, high power, and more than 10 inches of aperture to coax these out.

In the 1960s, French-Armenian astronomer Agop Terzan discovered 11 ultrafaint globular clusters on red-sensitive plates. **Terzan 7**, the brightest in his challenging list, is metal-rich and unusually young, having formed 4 billion years after most globular clusters. Late-onset globulars like this usually arise from the chaos of the rearranged gas of galaxies that the Milky Way has ripped to shreds.

Terzan 7 lies 4° northeast of the attractive globular cluster NGC 6723. A wide pair of 8.5-magnitude stars (HD 180336 and HD 180420) 8′ to the cluster's north are key to pinpointing its location. Through my 18-inch, I saw it as a very faint, textured glow spreading across 1.5′. A few 14th- to 15th-magnitude stars were visible around the edges of the halo, and two or three threshold stars twinkled over the cluster's face.

Terzan 8 is an ancient and metal-poor cluster, though of low mass. Although larger than Terzan 7, it has a diaphanous Class X concentration, which renders it a pale, anemic look. Spotting it requires a careful search 3° south of the large and loose globular M55 (itself a Class XI cluster). I noticed a brighter knot near the center of Terzan 8 that occasionally resolved into a pair of dim sparkles within a weak, amorphous halo.

If you successfully nab Terzan 8, continue to **Arp 2** — another daunting target. This unusual cluster is 3 to 4 billion years younger than the oldest globulars yet has a relatively low metallicity. Arm yourself with a detailed finder chart and search 2.5° west-northwest of M55. You're looking for a 2′-wide gossamer stain in a rich field peppered with 12th- to 14th-magnitude stars. I saw no sign of resolution, only a barely brighter nucleus.



▶ **POINTER GLOBULAR** Use the bright globular cluster M30 to guide your way to much more challenging Palomar 12.

Planetary Nebulae

Astronomer-turned-astronaut Karl Henize discovered **Hen 2-436** in 1954 during an Hα survey of emission stars and nebulae in the southern Milky Way. Henize published his 150 discoveries in his 1966 paper "Observations of Southern Planetary Nebulae." Later that year, James D. Wray (then at Dearborn Observatory) reexamined the Henize Hα plates as part of his PhD dissertation, *A Study of Hα-emission Objects in the Southern Milky Way*. Wray's investigation led to the discovery of two dozen planetaries, including Wray 16-423 in the Sagittarius Dwarf Galaxy's debris ring.

Hen 2-436 is immersed in a dense star field 3.7° south-southwest of M55 and 20′ west of 7th-magnitude HD 183997. Despite a distance of 80,000 light-years, it shines at 14.6-magnitude and should be visible in a 12-inch scope. Its ½″ diameter looks stellar in most telescopes, so use the "blinking" technique — rapidly alternating the view with and without a narrowband or O III filter to see the planetary brighten and dim.

Working with a photographic finder chart, I tracked down Hen 2-436 as a 14.5-magnitude "star." A 13th-magnitude star 1′ southeast is a convenient reference. Unfiltered, Hen 2-436 was fainter than the star, but the filtered view reversed the relationship — the planetary appeared a magnitude brighter.

At 14th magnitude, **Wray 16-423** should be in reach of an 8-inch to 10-inch scope. To find it, slide 3.8° west-southwest of M55 and ½° northeast of 6.6-magnitude HD 181109. I found a strong response with an O III

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY filter, which dimmed several nearby 13th-magnitude stars well below the brightness of Wray 16-423.

The Sagittarius Dwarf Galaxy Stream

Three Milky Way globular clusters, two open clusters, and a planetary nebula are one-time members of the dwarf galaxy and are now sailing along its stream. Let's take a closer look at them.

Stream Globulars

Palomar 12 is one of 15 faint globular clusters identified in the early 1950s on Palomar Observatory Sky Survey (POSS) plates. Early color-magnitude diagram studies hinted it was unusual; it lives in the outer halo 60,000 light-years away, but it's only 70% as old as other halo clusters.

A proper motion study in 2000 calculated Palomar 12's orbit using distant background galaxies for reference. The kinematic data indicate the Milky Way snatched the globular during a close passage 1.7 billion years ago. A 2004 analysis showed its element ratios matched stellar signatures in the dwarf. It's uncertain, though, whether it lies within the leading or trailing tails, as the arms overlap here along our line of sight. The diagram on page 27 shows the approximate locations of Palomar 12 and the two other globular clusters covered in this section.

Palomar 12 is easy to track down starting at M30. Head 2.4° northeast and look for a distinctive, compact triangle of 12th-magnitude stars. The globular is a misty, 2′-diameter haze immediately northwest of the triangle. Using 282×, I noted only a hint of mottling, and I resolved three 15th-magnitude stars, oriented northwest to southeast.

DIFFERENT OBJECTS

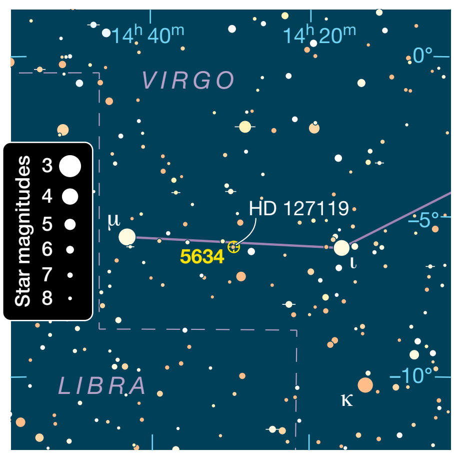
The Sagittarius Dwarf Spheroidal Galaxy — often abbreviated SagDEG or Sgr dSph — is not to be confused with the Sagittarius Dwarf Irregular Galaxy — abbreviated SagDIG. The latter is a satellite of the Milky Way that lies some 3.4 million light-years away, as opposed to the 90,000 light-years or so of the Sagittarius Stream objects.

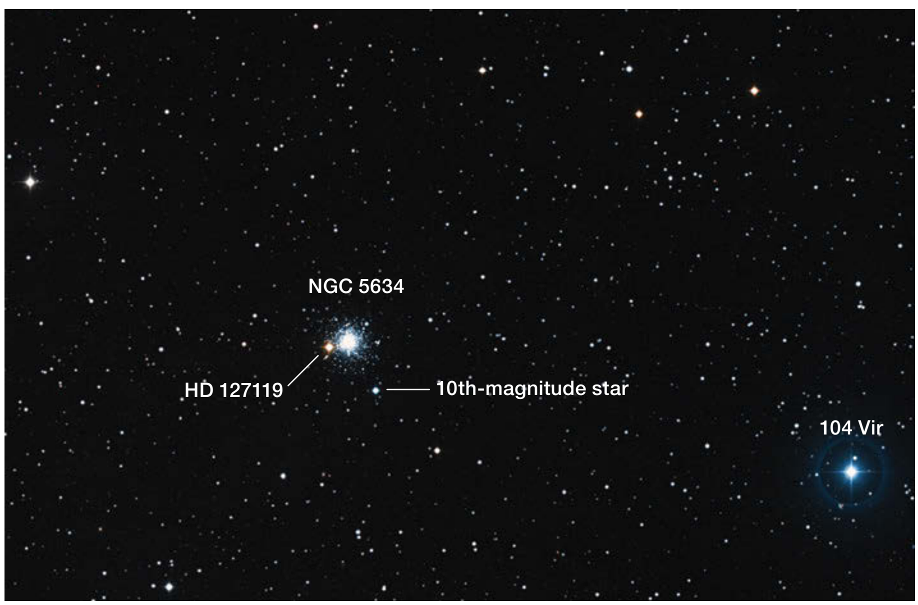
NGC 5634 seems misplaced in eastern Virgo — midway between 4th-magnitude Mu (μ) and Iota (ι) Virginis — and located far above the galactic disk. Yet, it's another Sagittarius Dwarf orphan, consistent in its distance (85,000 light-years) and radial velocity with the downstream tail. It contains a metal-poor population similar to M54, Arp 2, and Terzan 8. An orange 8th-magnitude star (HD 127119) lights up the cluster's eastern edge and creates a distraction, while a 10th-magnitude star is just 3.5′ southwest.

Using 220× in my 18-inch, NGC 5634 was a bright, compressed ball between 3′ and 4′ diameter and concentrated to a granulated core. I resolved only a few faint stars around the cluster's periphery, but the halo glittered with tiny stars when I bumped up the magnification to 325×.

In 2002, astronomers Alan Whiting, George Hau, and Mike Irwin discovered **Whiting 1** while hunting for low surface brightness Local Group dwarfs (chart on page 33). They tentatively labeled their find as an open cluster of blue stars. Later color-magnitude diagram analyses revealed an unusually young globular between 5.7 and 6.5 billion years old — the youngest known thus far.

Its radial velocity, angular position, and heliocentric distance (100,000 light-years) match the T1 stream. One model suggests the Milky Way accreted Whiting 1 during the last close passage to the Sagittarius Dwarf 500 to 600 million years ago. The globular's youthful age demonstrates that the dwarf galaxy retained enough gas to build star clusters for at least 6 billion years after it first formed 13 billion years ago. Star formation dropped sharply soon afterward as the ill-fated object began to disintegrate.





POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

▶ **LIT BY A STAR** Orange stars can be pretty, but the 8th-magnitude giant HD 127119 intrudes on the view of the globular cluster NGC 5634 in Virgo. Catch this sight during the evenings of late spring.

Whiting 1 is located 4° due west of Mira, also known as Omicron (ο) Ceti, and 40′ east of 7th-magnitude HD 12262. This ghostly globular is small, sparse, and anemic (total magnitude of 15.0). I've only viewed it through Jimi Lowrey's 48-inch reflector in west Texas and even through an enormous scope it was a faint, splotchy glow just 30″ in diameter. Whiting 1's brightest members are a paltry 18th-magnitude and only two sparkled into view at 488×.

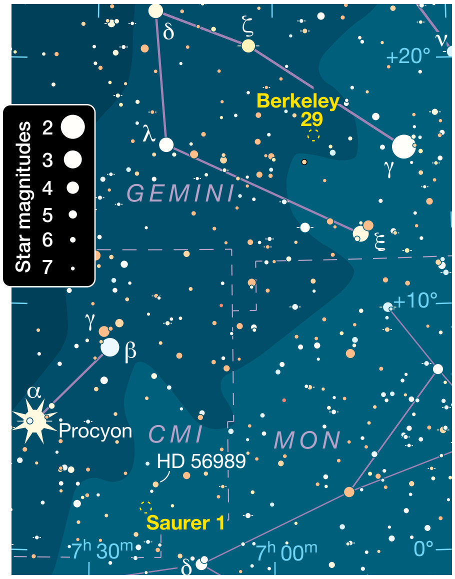
Stream Open Clusters

Arthur Setteducati and Harold Weaver (University of California, Berkeley) discovered **Berkeley 29** in 1962 during a systematic search for faint open clusters on POSS plates. Berkeley 29 is an ancient 3.5-to-4 billion years old and holds the distinction as the most distant known cluster, lying 70,000 light-years from the galactic center.

A 2009 investigation found Berkeley 29's location falls within the L arm as it passes through the outer disk towards the *galactic anticenter*, a region directly opposite the galactic center from the Sun. As this cluster is wrapped so far from the Sagittarius Dwarf, it was likely torn off shortly after its formation and has since orbited at least three times around the Milky Way.

Visually the cluster is a small collection of dim stars 3.7° east-northeast of 2nd-magnitude Alhena, or Gamma (γ) Geminorum, the southern foot of Gemini. A short line of three 11th-magnitude stars oriented north-south is 3′ west of the cluster, and a 10th-magnitude luminary is off the east side. At 175× I spotted a fairly faint 2′-long patch with just two resolved stars. Increasing the power to 285×, a half dozen stars between magnitude 14 and 15.5 emerged from the background haze.

Later searches of POSS and European Southern Observatory survey plates picked up several clusters missed by Set-



◀ **OPEN CLUSTERS** You'll have to stay up until the wee hours of the morning to spot Berkeley 29 and Saurer 1 — or wait until late winter to observe them in the evening.

FARAWAY TWINKLES Berkeley 29 currently holds the record for the most distant open cluster known.

DAN CROWSON

teducati and Weaver. In 1994, Walter Saurer (University of Innsbruck) and his colleagues announced the identification of six meager clusters, including **Saurer 1**, a 2′ sprinkling of 17th-magnitude and fainter stars. Its distance of 63,000 light-years and location are compatible with the trailing tail.

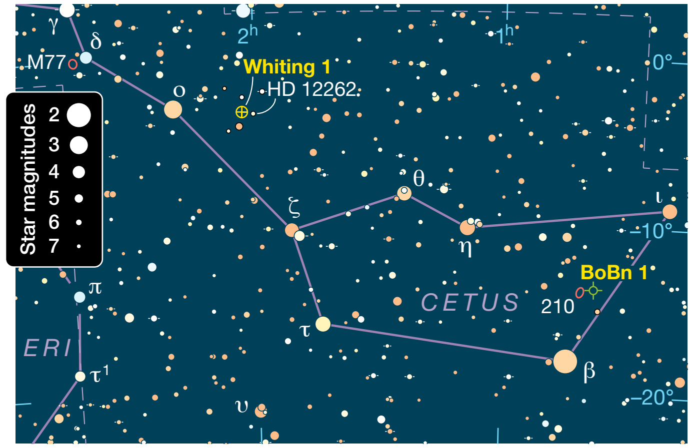
Saurer 1 hides in the southwest corner of Canis Minor, 1° south-southeast of 5.9-magnitude HD 56989. I found it a tough sighting and only detected a dim 20″ smudge — the combined glow of the brightest four or five red giants.

In Conclusion

In 1975 Howard Bond (Pennsylvania State University) discovered **BoBn 1** during an objective-prism survey at the Cerro Tololo Inter-American Observatory in northern Chile. At the eyepiece of the 60-inch reflector, he reported a "slightly soft appearance in good seeing," suggesting a diameter of 1″ to 2″. Further analysis in 2006 found a high-excitation spectrum and a distance of 65,000 light-years within the leading wing of L.

Look for BoBn 1 in western Cetus, 50′ west-northwest of the 11th-magnitude galaxy NGC 210. A 10th-magnitude star 8′ due east provides a handy marker as the planetary is stellar and shines feebly at magnitude 15.7. I used a narrowband filter to quickly "blink" and confirm the identification.

A final census of Milky Way globulars stolen from the Sagittarius Dwarf galaxy (and other former dwarfs) is incomplete. NGC 5634 lies in a region shared by stellar debris from other progenitors including the Helmi Stream, so it may have a different origin. Several recent studies show the kinematics of the Intergalactic Wanderer, NGC 2419, is consistent with the Sagittarius Stream, so it may be added to the list. Future improved data and models of the tidal streams should help sort out a complete inventory.



▲ **FINAL CHALLENGE** Wrap up your survey of the Sagittarius Stream with the challenging planetary nebula BoBn 1.

The Sagittarius Dwarf Spheroidal's traces are huge indeed. Every time the galaxy orbits the Milky Way, several million solar masses are yanked away from our hapless neighbor. But although its star streams and globulars will ultimately disperse across the Milky Way halo and into the disk, they'll never completely lose their ancestral roots.

■ Contributing Editor **STEVE GOTTLIEB** has been exploring galaxies, both near and far, for more than 40 years. He can be reached at **astrogottlieb@gmail.com**.

EXTRA MATERIAL For an animation of the Milky Way's "phase spiral" see **https://is.gd/galactic_whack**. Also, to better understand the movements of stars in the galaxy, see this post by Ronald Drimmel: **https://is.gd/drimmel**. For finder charts/images, go to **https://is.gd/SgrFinders**.

Riders on the Stream

Object	Type	Mag(v)	Size	RA	Dec.	Arm	Dist. (k l-y)	Age (My)
M54	Globular cluster	7.7	9.1′	18^h 55.0^m	–30° 29′	M	90	13.5
Terzan 7	Globular cluster	12.0	2.6′	19^h 17.7^m	–34° 39′	M	80	8.0
Terzan 8	Globular cluster	12.4	5.0′	19^h 41.7^m	–34° 00′	M/T	90	13.0
Arp 2	Globular cluster	12.3	2.5′	19^h 28.7^m	–30° 21′	M/T	94	13.5
Hen 2-436	Planetary nebula	14.2	0.5″	19^h 32.1^m	–34° 13′	M	—	—
Wray 16-423	Planetary nebula	13.8	1″	19^h 22.2^m	–31° 31′	M	—	—
Palomar 12	Globular cluster	11.7	2.9′	21^h 46.6^m	–21° 15′	T/L?	60	—
NGC 5634	Globular cluster	9.4	4.9′	14^h 29.6^m	–05° 59′	T	85	—
Whiting 1	Globular cluster	15	0.5′	02^h 02.9^m	–03° 15′	T	95	5.7
Berkeley 29	Open cluster	—	3.7′	06^h 53.1^m	+16° 56′	L	43	—
Saurer 1	Open cluster	—	2.6′	07^h 20.9^m	+01° 48′	L?	43	—
BoBn 1	Planetary nebula	15.7	2″	00^h 37.3^m	–13° 43′	L	—	—

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

Who Discovered the

LAS CAMPANAS GEGENSCHEIN This remarkable photograph was captured in November 2013, under the exceptionally dark and transparent skies over Las Campanas Observatory in Chile. It shows the zodiacal band (extending from upper left to lower right) and, along this band, the patch of light called the gegenschein, where the zodiacal band brightens near the anti-Sun (the point opposite the Sun). This rich swath of sky includes the constellation Orion at the right edge of the image — since this site is in the Southern Hemisphere the constellation appears upside down.

Gegenschein?

It's time to set the record straight and finally give credit where credit is due.

Three related celestial glows — the zodiacal light, the zodiacal band, and gegenschein — all arise from sunlight reflected and scattered by dust in or near the *ecliptic*, the plane defined by Earth's orbit around the Sun. Along the ecliptic is where you'll also find the Sun, the Moon, the planets, and the stars of the zodiacal constellations.

The *zodiacal light* appears with the shape of a tilted pyramid with its base at the Sun, below the horizon. Due to seasonal variations in the angle of the ecliptic relative to the horizon, observers in the Northern Hemisphere find that the zodiacal light is best seen in the west after sunset in February and March, and in the east before sunrise in September and October. This magazine's Sky at a Glance (on page 41) lists each season's prime, Moon-free observing windows for observing the zodiacal light.

The *zodiacal band* is a dim and narrow glow that extends from the zodiacal light pyramid and continues along the ecliptic across the entire night sky through the constellations of the zodiac.

The *gegenschein* (German for "counterglow") appears as a diffuse brightening of the zodiacal band at the *anti-Sun* (or *anti-solar point*) — the spot 180° opposite the Sun's position on the celestial sphere.

Ghosts in the Night

Detecting these faint phenomena — especially the zodiacal band and gegenschein — requires a moonless night and a site with dark and transparent skies. Moreover, the overwhelmingly bright glow of our home galaxy washes away the gegenschein during months when the anti-Sun lies in or near the Milky Way. The gegenschein is positioned relatively far from the Milky Way during favorable viewing months of (late) September, October, and November, and then again in February, March, and April.

The best time of night to search for the gegenschein is near local midnight, when it appears as an oval patch in the zodiacal constellation highest in the sky and far from the atmospheric absorption that prevails near the horizon. *Sky & Telescope* columnist and experienced observer Bob King noted that "you can see it an hour or two earlier or later, but it's highest and easiest to spot during the midnight hour."

Harlan Smith, director of McDonald Observatory for many years, related similar stories of viewing the gegenschein from the dark skies of West Texas. He told me he always found the time to step outside the telescope dome and carefully note the position of the gegenschein among the stars.

If you've been fortunate enough to see any of these faint zodiacal glows, you may wonder who was the first to observe and describe the gegenschein. The answer may surprise you.

A Popular Choice

According to the Wikipedia entry for "Gegenschein," five different astronomers independently discovered the phenomenon, with the first sighting credited to Esprit Pezenas:

> The gegenschein was first described by the French Jesuit astronomer and professor Esprit Pézenas (1692–1776) in 1730. Further observations were made by the German explorer Alexander von Humboldt during his South American journey from 1799 to 1803. It was also Humboldt who gave the phenomenon its German name *Gegenschein*.

▲ **GHOSTLY PYRAMID** In this illustration, the luminous cone of the zodiacal light extends obliquely into the sky on the evening of February 20, 1876, with the Pleiades star cluster just to the north (to the right) of the tip of the triangular glow. Étienne Léopold Trouvelot created this chromolithograph as part of *The Trouvelot Astronomical Drawings Manual* published in 1882.

GEGENSCHEIN FROM LAS CAMPANAS: YURI BELETSKY; ILLUSTRATION: COURTESY DON OLSON

> The Danish astronomer Theodor Brorsen published the first thorough investigations of the gegenschein in 1854 . . . T. W. Backhouse discovered it independently in 1876, as did Edward Emerson Barnard in 1882.

This conclusion is certainly the prevailing one. Hungarian author August Kržiž included the same claim in the 1901 edition of an astronomical dictionary, as did science writer Willy Ley in his 1966 book *Watchers of the Skies*. Famed astronomy popularizer Patrick Moore concurred, writing in *History of Astronomy* that the phenomenon ". . . was first described by Esprit Pézénas in 1731."

William Sheehan, in his 1995 biography of Edward Emerson Barnard, *The Immortal Fire Within*, mentioned Barnard's independent discovery and then acknowledged that ". . . the gegenschein had been seen by the Jesuit priest Esprit Pezenas, who published a note about it in the *Memoirs* of the Parisian Academy in 1731."

Some of these assertions can be traced back to the Swiss astronomer Rudolf Wolf. In 1893 Wolf completed a two-volume set on the history of astronomy and included the claim:

> In 1730 Pézénas discovered the so-called "Gegenschein," the brightest part of which is opposite the Sun's location . . . see the Mémoires of the Paris Academy for 1731.
>
> (Wolf, *Handbuch der Astronomie*, 1893, volume 2, section 573, pp. 504–505; translated from the German)

Guy Boistel, an astronomer at the University of Nantes and an expert on the printed works and manuscripts written by Pezenas, spells the name of this 18th-century French astronomer with no accents. Indeed, that's how his name appears in his original printed articles. However, Wolf writes "Pézénas," with two accents, as did Kržiž, Ley, and Moore. This supports the idea that Wolf's influential books provided the original source for some of the later claims that Pezenas discovered the gegenschein.

However, a few authorities expressed skepticism on whether Pezenas actually saw the gegenschein.

A Light by Any Other Name

In 1867 the Italian astronomer Giovanni Schiaparelli described the zodiacal light as a "beautiful luminous pyramid" near the setting or rising Sun, and he compared it to the fainter glow near the anti-Sun, which exhibited:

> . . . incomparably much paler light; the center is always at the point of the ecliptic diametrically opposite to the Sun . . . This is what the Germans call "Gegenschein" . . . In 1730, Pezenas saw the zodiacal light occupying all

ESO / PETR HORÁLEK

HORIZON TO HORIZON The Milky Way slices obliquely though the center of this panorama, oriented so that the zodiacal band runs horizontally across the frame. The zodiacal light pyramid dominates the right side of this photo, while the glow of the gegenschein appears on the left side, adjacent to the bright star Spica in the constellation Virgo. The image, captured on April 14, 2016, records three planets, including Jupiter, positioned near the left edge of the image.

the visible parts of the zodiac . . . but his observations include some circumstances that leave us in doubt whether on that date he saw the zodiacal light or an aurora borealis.

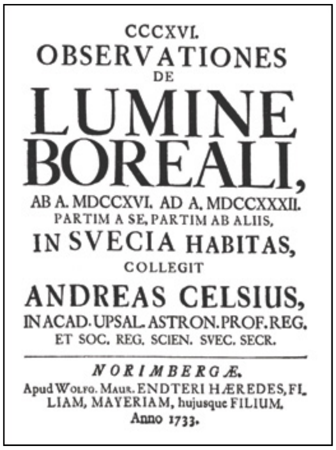
(Schiaparelli, *Note e riflessioni intorno alla teoria astronomica delle stelle cadenti*, 1867, pp. 117–119; translated from the Italian)

Schiaparelli provided no details to explain his skepticism, but he at least raised the possibility that Pezenas observed an aurora and not the gegenschein.

In 1925 the Swiss astronomer Franz Flury also expressed doubts, based in part on a literature search by Pierre Salet, an astronomer at the Paris Observatory. Salet consulted old publications in the Observatory's library and found an aurora observation by another astronomer in 1730. Flury eventually concluded that perhaps Pezenas saw both an aurora and the gegenschein at the same time.

In 2003, in *Revue d'histoire des sciences*, Guy Boistel was more definite and concluded "without doubt" that "Pezenas . . . observed an aurora borealis in February 1730."

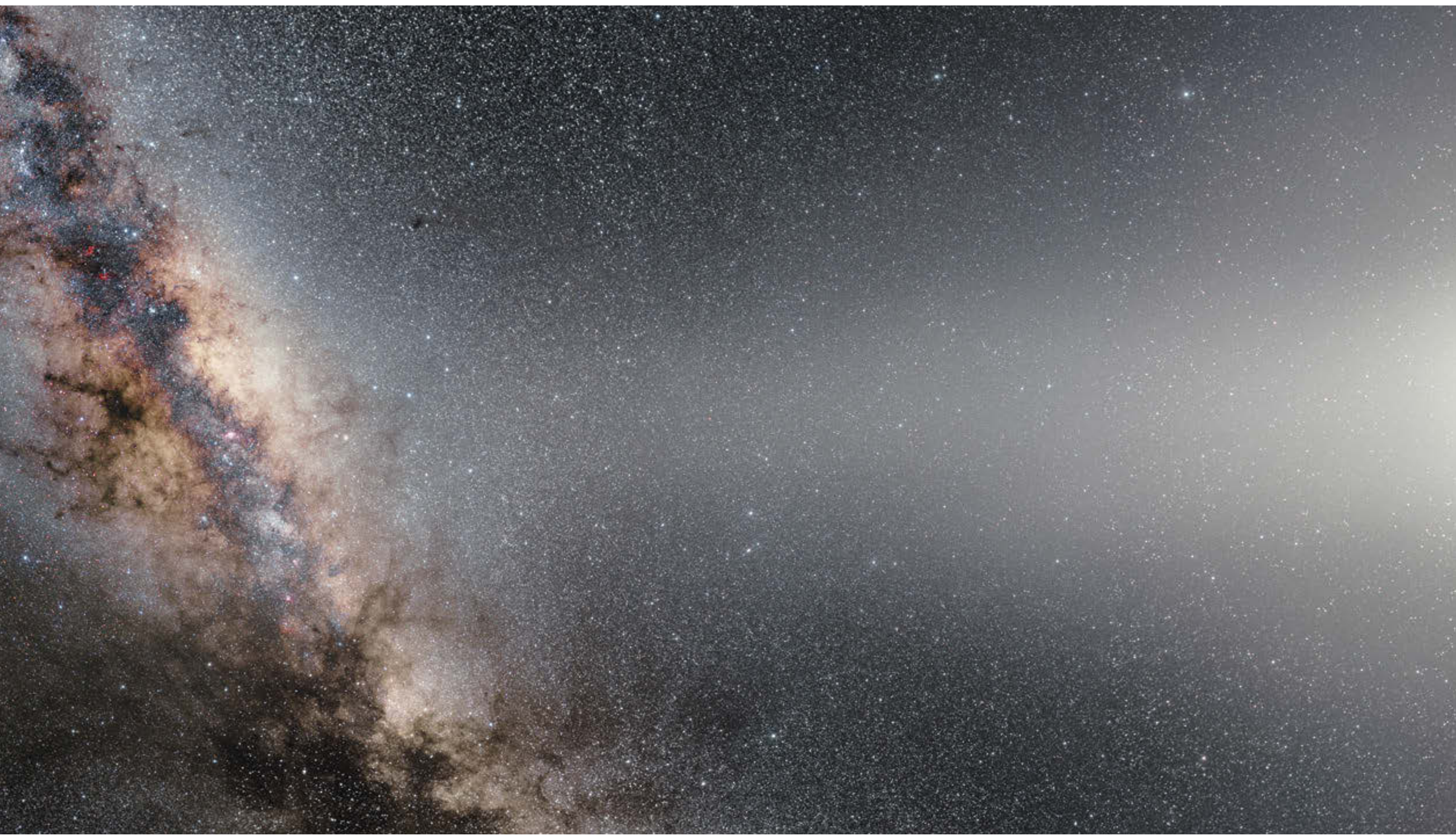
So, which is it? Did Pezenas discover the gegenschein or did he simply observe a fine auroral display? As a first step, I wanted to see exactly how Pezenas himself described his observations. Although Wolf and several later authors cited the 1731 *Mémoires* of the Paris Academy, I found an earlier account by Pezenas in the May 1730 issue of a more obscure publication, the *Journal de Trévoux*. There, Pezenas wrote:


CCCXVI.
OBSERVATIONES
DE
LUMINE
BOREALI,
AB A. MDCCXVI. AD A. MDCCXXXII.
PARTIM A SE, PARTIM AB ALIIS,
IN SVECIA HABITAS,
COLLEGIT
ANDREAS CELSIUS,
IN ACAD. UPSAL. ASTRON. PROF. REG.
ET SOC. REG. SCIEN. SVEC. SECR.
NORIMBERGÆ.
Apud Wolfg. Maur. ENDTERI HÆREDES, FI-
LIAM, MAYERIAM, hujusque FILIUM.
Anno 1733.

◀ **AURORAL RECORDS** Accounts describing the aurora of February 15, 1730, are found in volumes like the one pictured here. This illustration shows the title page of a publication by Anders Celsius (1733).

COURTESY DON OLSON

FROM MARSEILLE I noticed on the 15th of February of this year a great light along the zodiac. . . . It extended obliquely, nearly according to the position of the zodiac, and it formed a kind of belt, 10 to 12 degrees wide . . . in the northeast, it appeared a bright red which illuminated all the countryside. It passed by the heart of the Lion and by Cancer, where it somewhat covered Jupiter; it grazed the eastern shoulder of Orion, and it passed above this constellation; it also covered the Pleiades, and it appeared to be directed towards the Sun. This light did not prevent



> us from seeing the smallest stars, even in the northeast where it was denser; it was much as we see them through the tails of comets. It weakened in the northeast at 8 o'clock. . . . Its brilliancy was renewed at 9 o'clock, and the horizon in the northeast appeared until 10 o'clock just as bright, as if the Moon had been present. About half past 10 o'clock it diminished imperceptibly, and I saw almost nothing at 11 o'clock.
>
> (Pezenas, *Journal de Trévoux*, May 1730, pp. 906–907; translated from the French)

The same observation — with almost identical wording — was reprinted in 1731 in the *Mémoires* of the Académie Royale, the publication that Wolf and some later authors referred to.

On the evening of February 15, 1730, the Sun was in Aquarius, and therefore the anti-Sun fell in Leo — a constellation Pezenas mentioned. That reference, along with the comment that the light "extended obliquely" along the zodiac, probably contributed to Wolf's judgment that this documented the discovery of the gegenschein.

However, two factors strongly argue against Wolf's conclusion. Pezenas saw the glow in the evening before 8 o'clock, when the anti-Sun was less than 30° above the eastern horizon. He noted that the light disappeared by 11 o'clock — exactly the opposite behavior expected from the gegenschein, which becomes most visible as the anti-Sun rises high in the sky at local midnight. An even stronger reason for doubt is that the true gegenschein is near the limit of human vision, where colors are difficult or impossible to detect. Yet Pezenas described the glow as "a bright red which illuminated all the countryside." It's almost certain that he observed a red auroral arc that happened to fall along the ecliptic.

If a brilliant celestial glow graced skies in the south of France on February 15, 1730, the scientific literature should turn up more reports from observers at other locations.

And so I began my search.

Fire in the Sky

I looked in an English-language journal, *Philosophical Transactions of the Royal Society*, and was immediately rewarded when I found mention of an aurora observation by the mathematician Gabriel Cramer (1704–1752). (Anyone who studied advanced algebra in school will recognize this name from "Cramer's rule" for solving N linear equations in N unknowns.)

From Geneva on February 15, 1730, Cramer witnessed a display with two components: a normal aurora in the "boreal" sky (that is, the northern sky) and an unusual red arc in the "meridional" sky (the southern sky). Cramer detailed his observations in a letter to the Royal Society in London:

> . . . an Aurora Borealis, which appeared here the 15th of Feb. N.S. accompanied with some Circumstances rare enough to be worth your Consideration . . . The greatest Part did fix it to the Polar Star . . . what was chiefly to be considered, was a great Meridional Zone pretty like a Rainbow in its Figure, but broader. . . .
>
> The Colour of this Zone was Red, Scarlet, inclined to Purple . . . the red meridional Zone, which dyed with its reddish Colour the Stars that appeared behind. When that Zone was the highest, it covered Jupiter; and some Gentlemen, which at that Time had not yet remarked the Aurora, looking at Jupiter through a Telescope, affirm they could hardly see it, but that it seemed as intercepted by some dark Cloud; and indeed it looked at that Time as if it had been seen through a red Glass.

ALAN DYER

YOU CAN CALL ME STEVE Contrary to popular opinion, Esprit Pezenas did not discover the gegenschein. Viewing the southern sky of Marseille, France, Pezenas actually observed a red arc associated with a worldwide auroral display on the evening of February 15, 1730. This fisheye photograph shows a magenta arc (the phenomenon now known as STEVE) in the southern sky of Alberta, Canada, on September 27, 2017. A more normal green aurora graces the northern horizon at the top of this view.

(Cramer, *Philosophical Transactions of the Royal Society*, 1730, volume 36, pp. 279–282)

The abbreviation "N.S." stands for "New Style" calendar, that is, the same Gregorian calendar that Pezenas used.

An online search turned up numerous reports of this auroral display. I found primary sources by first consulting compilations of historical aurora observations in publications like those by Anders Celsius (1733), Jean Jacques d'Ortous Mairan (1733), Hermann Fritz (1873), and Alfred Angot (1897).

For the arc observed in the southern sky on February 15, 1730, most of these accounts described the color as red, blood-red, scarlet, crimson, or russet, with some mentions of purple and violet hues. Many observers described the shape as "a form like that of the rainbow" or along similar lines.

Based on reports from locations throughout Europe and Asia, the brightness of the light, and the intensely red color, it's clear that Pezenas did not observe the gegenschein. Indeed, his observation may represent an early sighting of the atmospheric phenomenon now known as STEVE (Strong Thermal Emission Velocity Enhancement), which can appear as a red or magenta arc in the southern sky and accompany a more normal green aurora in the northern sky.

If Pezenas didn't discover the gegenschein, the question still remains: Who did? Many later writers accept that famed German explorer Alexander von Humboldt observed this elusive glow in 1803. Based on entries in his journal from March that year, Humboldt wrote the following description in his monumental compilation titled *Cosmos*:

> . . . the zodiacal light. . . . An hour after sunset it suddenly becomes visible in great brilliancy. . . . On the 16th of March, when the phenomenon presented itself in the greatest splendor, a faint counter glow ["Gegenschein" in the original German] was visible in the east.
>
> (Humboldt, *Kosmos, Erster Band,* 1845, pp. 143–144; translated from the German)

Another account by Humboldt gives more detail regarding the sky on the evening of March 16, 1803:

> . . . the Zodiacal Light. . . . The luminous pyramid terminated between Aldebaran and the Pleiades . . . after 7h 15m [7:15 p.m.] the luminous spindle appeared at once in all its beauty. . . . While the light was very bright in the west, we constantly perceived in the east . . . a whitish light, which was also of a pyramidal form . . . this double light in the west and the east.
>
> (Humboldt, *Monthly Notices of the Royal Astronomical Society*, 1855, volume 16, p. 17)

It's not clear what Humboldt actually saw. He described luminous pyramids near both the western horizon and the eastern horizon during the early evening, not near midnight when the oval of the gegenschein is high overhead. The astronomer Robert Roosen, an expert on night-sky glows, completely rejects Humboldt's account as describing the discovery of the gegenschein. Roosen points out that some scholars were:

> . . . very impressed with Humboldt's claim, primarily because Humboldt used the word "Gegenschein" in describing his observation. However . . . his observation was made shortly after sunset (when the Gegenschein is of course impossible to see) . . . Humboldt neither observed nor suggested the existence of 'the' Gegenschein.
>
> (Roosen, *The Gegenschein*, PhD thesis, University of Texas at Austin, 1969, pp. 2–3)

BILL & SALLY FLETCHER

▲ **COMET CATCHER** Of the five comets Brorsen discovered, the one most familiar to *Sky & Telescope* readers is Comet 1847 V, later known as 23P/Brorsen-Metcalf. This periodic comet returned in 1919 and again in 1989, when the photo above was captured.

A Comet Hunter Extraordinaire

Many readers will likely be familiar with Danish astronomer Theodor Johann Christian Ambders Brorsen (1819–1895) from his comet discoveries. Brorsen was a philosophy student at the University of Kiel, in northern Germany, when he discovered his first comet on February 26, 1846. Initially designated 1846 III, this object — later classified as the periodic comet 5D/Brorsen — was observed during returns in 1857, 1868, 1873, and 1879, after which it was lost. Brorsen discovered his second comet, 1846 VII, at Kiel on May 1, 1846.

With a growing interest in astronomy, he relocated to Altona Observatory near Hamburg, Germany, where he discovered comet 1847 V on July 20, 1847. This periodic comet became known as 23P/Brorsen-Metcalf and made returns in 1919 (when it was recovered by the American astronomer Joel

Metcalf) and again in 1989. It is the object that Brorsen is best known for today.

Later in 1847, the wealthy businessman John Parish offered Brorsen a position at his private observatory in the town of Senftenberg, Bohemia (now Žamberk in the Czech Republic). There Brorsen found two more comets: 1851 III on August 1, 1851, and 1851 IV on October 22, 1851.

Brorsen was not only a prolific comet hunter, but also a student of the zodiacal light. He observed the zodiacal band and noticed a brighter patch near the anti-Sun and carefully measured its position among the stars during March and April 1854.

◀ **SKY WATCHER** Danish astronomer Theodor Johann Christian Ambders Brorsen was the first to give a clear and accurate description of the gegenschein in publications from 1854 and 1855.

Brorsen's 1854 article "Concerning a New Phenomenon of the Zodiacal Light" cited Humboldt and borrowed the term "Gegenschein" from him. Unlike Humboldt, however, Brorsen offered an unambiguous description of his observations, which took advantage of

> . . . the often extraordinarily pure mountain sky here . . . after 11 p.m. the Gegenschein appeared, which consisted of a brighter elongated round patch . . . the middle of it coincided almost exactly with the point opposite the Sun . . . a round glow, almost exactly opposite the Sun's location.
>
> (Brorsen, *Unterhaltungen im Gebiete der Astronomie, Geographie und Meteorologie*, 1854, volume 8, number 20, pp. 156–160; translated from the German)

Brorsen continued his observations into 1855, and wrote:

> I have convinced myself by repeated observations that the brightest part of it lies exactly opposite the Sun's position, so that an estimate of the point of greatest light intensity coincides generally within a degree of the point which is in opposition to the Sun.
>
> (Brorsen, *Astronomische Nachrichten*, 1855, volume 42, number 998, cols. 219–220; translated from the German)

On September 17, 1856, Brorsen published his measurements of "the brightest point of the Gegenschein."

After John Parish's death in 1858, his heirs dismantled the private observatory. Brorsen continued to observe from Senftenberg for another 12 years with his own instruments before returning to Denmark, where he remained until his death in 1895.

▲ **GLOBULAR FIND** On September 17, 1856, Brorsen published his continued measurements of "the brightest point of the Gegenschein" and also reported the discovery of "a new nebula in the Milky Way, in the Serpent of Ophiuchus." That object is now recognized as the globular cluster NGC 6539 in Serpens Cauda. The cluster is at upper left, while the bright star at lower right is 5.2-magnitude Tau Ophiuchi.

A Discovery Put to Rest

Although Esprit Pezenas is usually credited with the discovery of the gegenschein, the first observer to give a clear and accurate description of the phenomenon was in fact Theodor Brorsen in 1854. There were, however, subsequent independent discoveries of this elusive, faint glow. English astronomer Thomas William Backhouse described it in 1875, as did American astronomer Edward Emerson Barnard in 1883. Between 1884 and 1921 Barnard carried out detailed studies of the gegenschein and reported his results in a series of articles in *The Sidereal Messenger*, *The Astronomical Journal*, and *Popular Astronomy*. Barnard's publications raised sufficient awareness of the gegenschein that no more independent "discoveries" followed.

Let's celebrate Theodor Brorsen not only for the five comets he found but also for discovering the gegenschein.

■ **DON OLSON** is professor emeritus of physics at Texas State University and the author of the books *Celestial Sleuth* (2014) and *Further Adventures of the Celestial Sleuth* (2018). He is currently completing a third volume, *Celestial Sleuthing: Methods and Examples*.

OBSERVING
October 2021

2 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 10:24 p.m. PDT (see page 50).

3 **DAWN:** The waning crescent Moon and Regulus rise in tandem in the east; a bit more than 4° separates the pair.

4 **MORNING:** Look toward the east before morning twilight from a dark spot to see the zodiacal light. For the next two weeks, viewers at northern latitudes should see a tall and dim pyramid of light stretching up through Cancer and Gemini into Taurus. (See our feature about its relative, the gegenschein, on page 34.)

5 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 10:13 p.m. EDT.

9 **DUSK:** Low in the southwest, the waxing lunar sliver and brilliant Venus are some 2½° apart in the Scorpion's head, while Antares smolders 6° to their left. See pages 46–47 for more details on this and other events outlined here.

14 **DUSK:** The waxing gibbous Moon, Jupiter, and Saturn form a triangle above the south-southeastern horizon after sunset.

15 **DUSK:** Venus is positioned 1½° upper right of the Scorpion's heart, Antares. The Evening Star remains close to the red supergiant the next two evenings.

20 **DAWN:** Mercury shepherds Porrima, Gamma (γ) Virginis, as they rise together in the east. Bring binoculars.

21 **MORNING:** The Orionid meteor shower peaks in the early hours. The Moon is just past full, severely hampering viewing.

23 **DAWN:** If you're up before sunrise, look for Taurus high in the west-southwest to see the waning gibbous Moon some 4° left of the Pleiades.

24 **DAWN:** This morning the Moon is on the other side of the Bull's head, around 6½° upper right of Aldebaran, the Bull's eye.

25 **DAWN:** Still in Taurus, the Moon is neatly positioned midway between Zeta (ζ) and Beta (β) Tauri, the tips of the Bull's horns.

25 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 8:54 p.m. PDT (11:54 p.m. EDT).

27 **DAWN:** High in the south, the waning gibbous Moon visits Gemini and is around 5° lower right of Pollux.

28 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 8:43 p.m. EDT.

31 **DAWN:** Tiny Mercury is still in Virgo, and this morning it leads Spica above the horizon, with less than 5° separating the brilliant duo.
— DIANA HANNIKAINEN

▲ Venus is the blazing Evening Star this month. On the 9th it's joined by the waxing crescent Moon in a scene that will be similar to the one pictured here from June 2021.
ALAN DYER

OCTOBER 2021 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart

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

NASA / LRO

MOON PHASES

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

NEW MOON
October 6
11:05 UT

FIRST QUARTER
October 13
03:25 UT

FULL MOON
October 20
14:57 UT

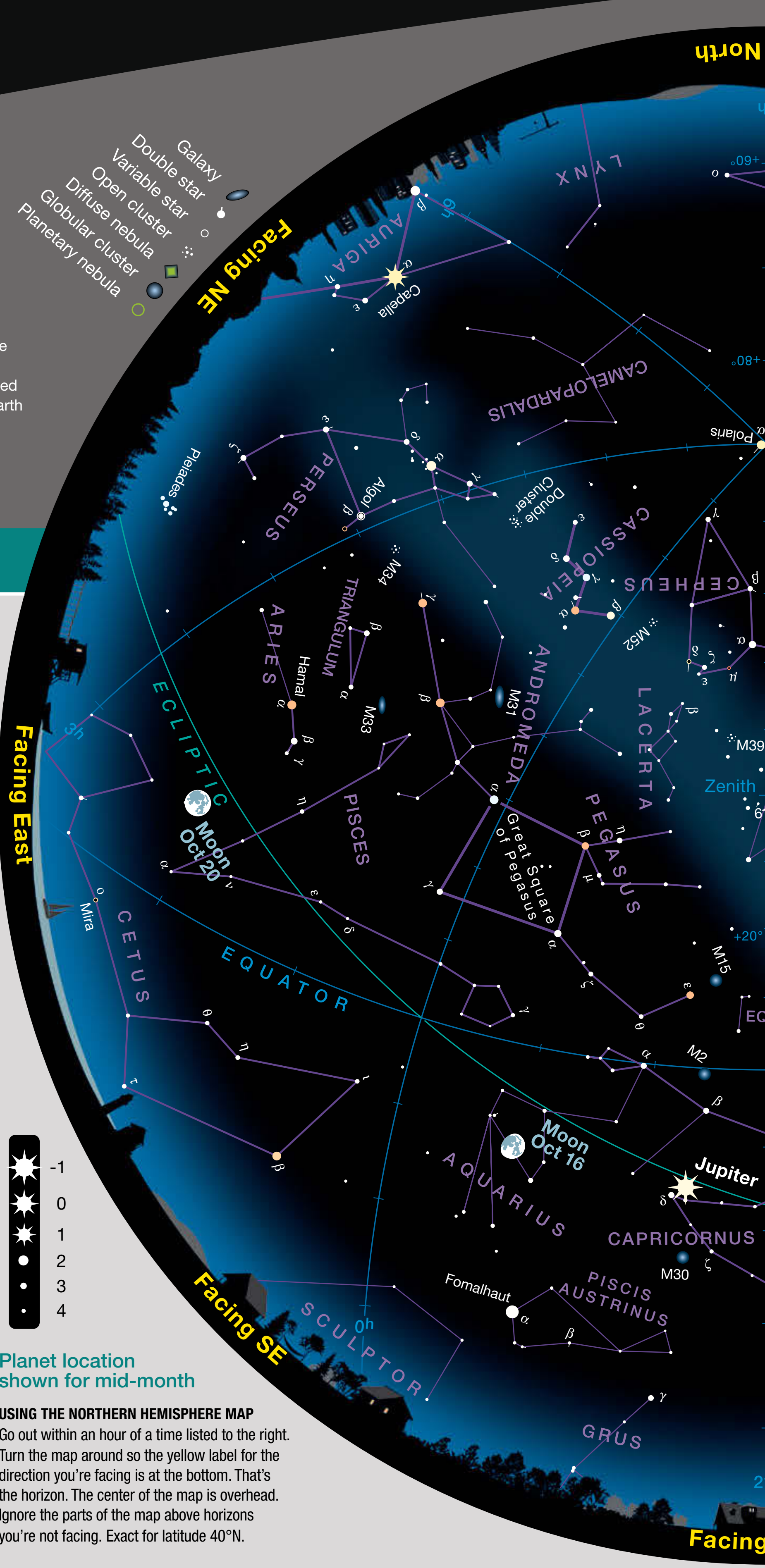
LAST QUARTER
October 28
20:05 UT

DISTANCES

Perigee	October 8, 17ʰ UT
363,388 km	Diameter 32′ 53″
Apogee	October 24, 15ʰ UT
405,613 km	Diameter 29′ 28″

FAVORABLE LIBRATIONS

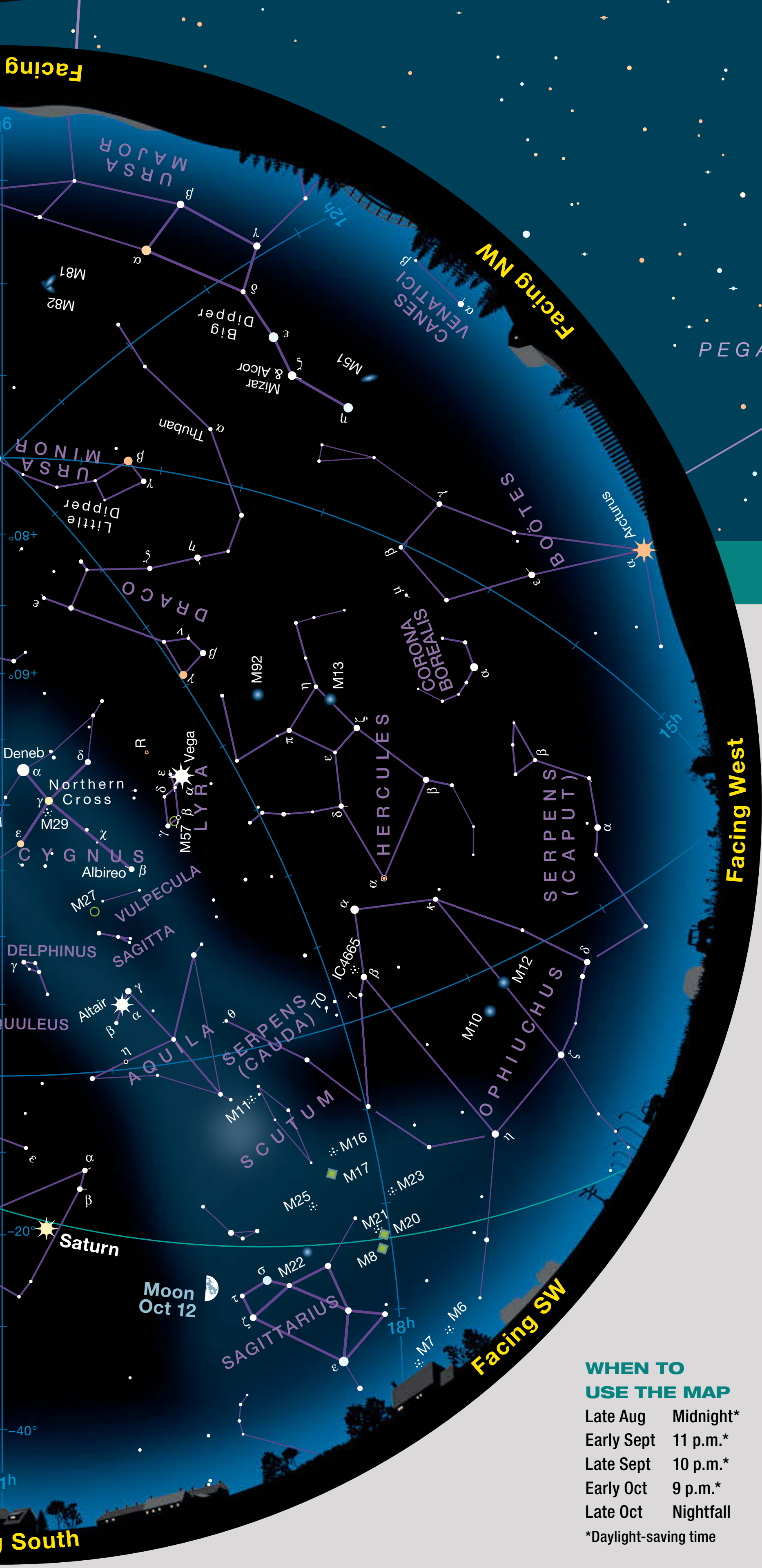
• Rydberg Crater	October 3
• Riemann Crater	October 12
• Mercurius Crater	October 16
• Vallis Baade	October 31

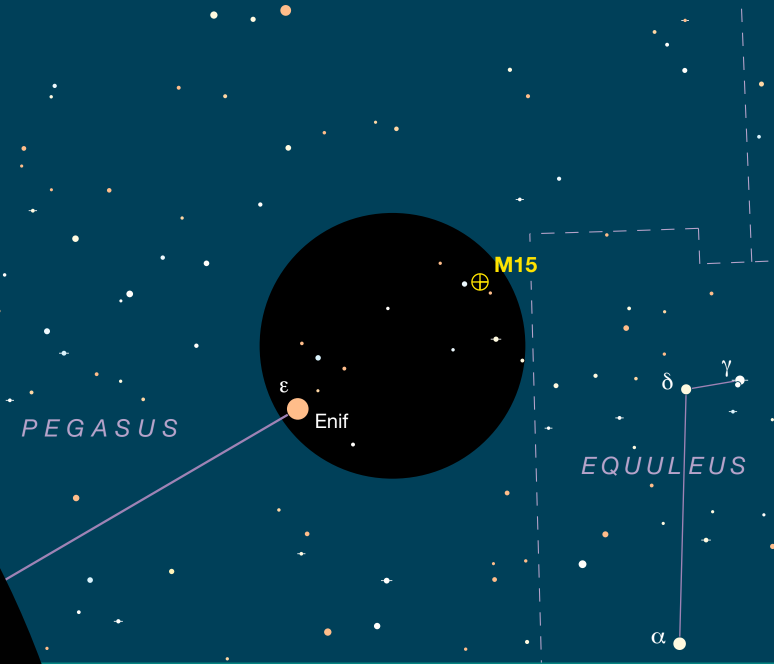


Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

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





WHEN TO USE THE MAP

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

*Daylight-saving time

Binocular Highlight by Mathew Wedel

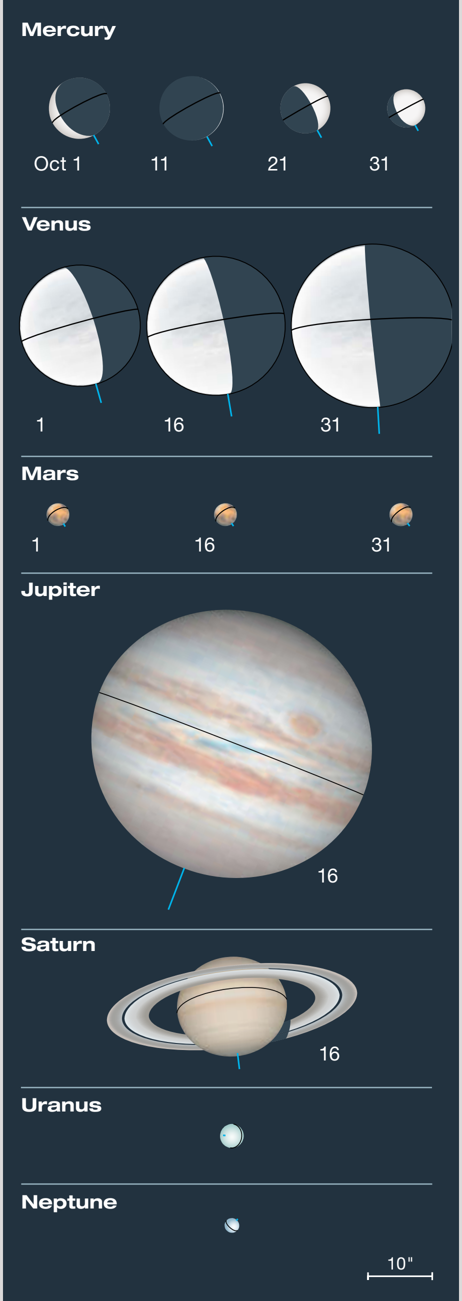
Fuzzy Ball of Light

Binoculars offer a wonderful, wide window to the cosmos. Their expansive views are perfect for capturing big open clusters, and for scanning rich, Milky Way star fields. But no single tool is perfect for every application. A spoon makes a lousy knife, and a knife makes a lousy spoon. And so it is with binoculars and telescopes. Targets that call for a lot of magnification are especially challenging for binos. Globular clusters fall into this category — some are absolutely stunning in a telescope used at high magnification but can be tricky in binoculars. Nonetheless, some are pretty easy in binos, and **M15** in westernmost Pegasus is a shining example.

A number of factors work in M15's favor. First, at magnitude 6.2, it's one of the brightest Messier globulars — it's less than half a magnitude fainter than the famed Hercules cluster, M13. Even better, M15 shares its binocular field with the lovely, 2.4-magnitude yellow star Enif, Epsilon (ε) Pegasi. If you can find Enif, you can find M15. Since most globulars look like stars with little, fuzzy halos in binos, it's handy to have a similarly bright star nearby for comparison. Here again M15 obliges: Just a hair to its east is a nearly identically bright field star.

M15 is one of the most densely packed globular clusters in the Milky Way. While it spans some 180 light-years edge to edge, more than half of its 100,000 sparkling stars are crammed into a space a mere 10 light-years across. As you contemplate this stellar metropolis, reflect upon the fact that the light you're now seeing embarked on its interstellar journey around 34,000 years ago, when modern humans hunted mammoths in desolate, Ice Age landscapes while saber-toothed cats prowled alongside.

■ Globular clusters like M15 make **MATT WEDEL** feel all warm and fuzzy.



PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible from the 17th to the end of the month • **Venus** shines brightly at dusk • **Mars** is too close to the Sun to be viewed all month • **Jupiter** and **Saturn** transit in the early evening and set after midnight.

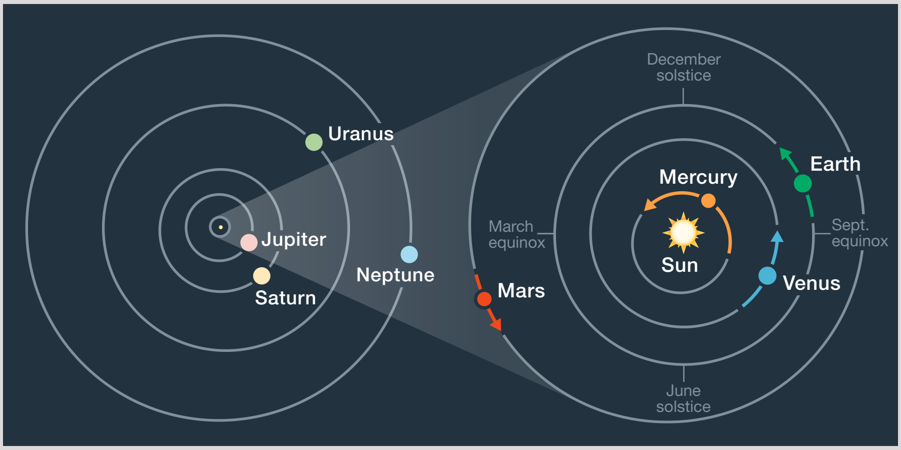
October Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$12^h\ 28.4^m$	–3° 04′	—	–26.8	31′ 57″	—	1.001
	31	$14^h\ 20.5^m$	–14° 00′	—	–26.8	32′ 13″	—	0.993
Mercury	1	$13^h\ 24.6^m$	–12° 49′	17° Ev	+1.5	9.5″	17%	0.705
	11	$12^h\ 52.1^m$	–7° 10′	3° Mo	—	10.0″	1%	0.671
	21	$12^h\ 40.3^m$	–2° 46′	17° Mo	–0.1	7.8″	36%	0.863
	31	$13^h\ 19.4^m$	–6° 06′	17° Mo	–0.8	5.9″	76%	1.130
Venus	1	$15^h\ 18.2^m$	–20° 32′	45° Ev	–4.3	18.8″	62%	0.888
	11	$16^h\ 03.8^m$	–23° 38′	46° Ev	–4.3	20.5″	58%	0.812
	21	$16^h\ 49.8^m$	–25° 49′	47° Ev	–4.4	22.7″	54%	0.735
	31	$17^h\ 34.9^m$	–27° 01′	47° Ev	–4.6	25.3″	49%	0.659
Mars	1	$12^h\ 38.2^m$	–3° 21′	2° Ev	+1.7	3.6″	100%	2.635
	16	$13^h\ 14.7^m$	–7° 16′	3° Mo	+1.6	3.6″	100%	2.618
	31	$13^h\ 52.2^m$	–11° 01′	8° Mo	+1.7	3.6″	100%	2.588
Jupiter	1	$21^h\ 41.1^m$	–15° 07′	135° Ev	–2.7	46.3″	99%	4.258
	31	$21^h\ 40.1^m$	–15° 08′	105° Ev	–2.5	42.3″	99%	4.660
Saturn	1	$20^h\ 37.1^m$	–19° 24′	119° Ev	+0.5	17.7″	100%	9.416
	31	$20^h\ 38.1^m$	–19° 20′	89° Ev	+0.6	16.8″	100%	9.893
Uranus	16	$2^h\ 43.8^m$	+15° 25′	159° Mo	+5.7	3.7″	100%	18.798
Neptune	16	$23^h\ 27.5^m$	–4° 46′	148° Ev	+7.8	2.3″	100%	29.071

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

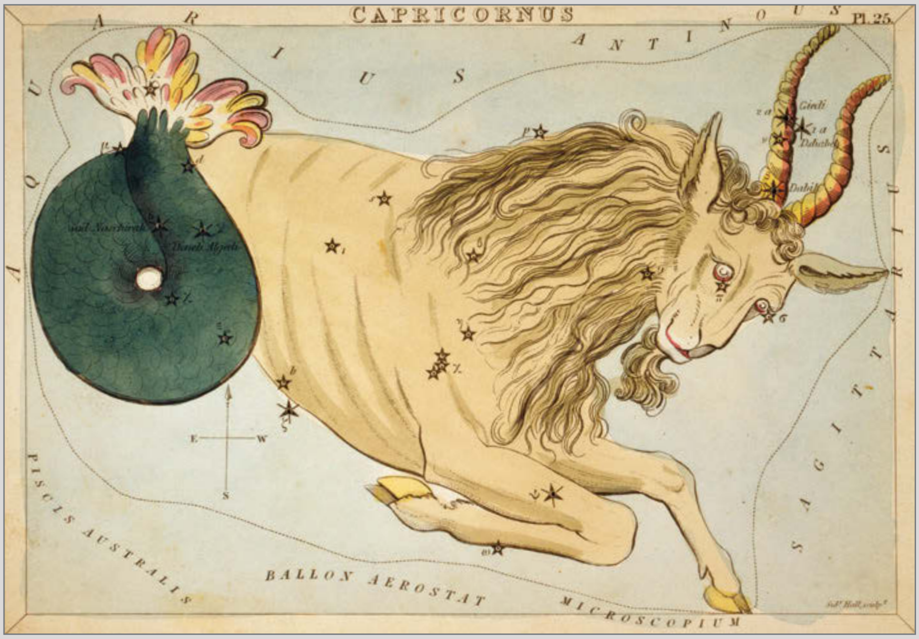
▲ **PLANET DISKS** have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

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



Capricious Capricornus

This strange zodiacal constellation offers more than first meets the eye.



▲ **CURIOUS CREATURE** Shown above is the zodiacal constellation Capricornus, the Sea Goat, as depicted in *Urania's Mirror*, a set of 32 star-chart cards published in 1824.

A constellation doesn't have to be bright to be interesting. For instance, there's Capricornus, the Sea Goat or Goat-Fish — the mythological creature's front half is goat and its back half is fish. Interesting indeed! And yet, this mix-and-match figure's brightest stars are only of 3rd magnitude.

Along the zodiac, Capricornus follows showier Sagittarius, the Archer, with its familiar Teapot asterism. Sagittarius not only has brighter stars, but it's also richly endowed with the glorious central region of the Milky Way and a host of deep-sky treasures, including 15 Messier objects. Capricornus, by comparison has just one Messier — globular cluster M30.

If your sky is light polluted, you might struggle to locate Capricornus. However, this month both Jupiter and Saturn visit the constellation, as shown on our Sky Chart on pages 42 and 43. The bright duo should make finding Capricornus a bit easier. You can also locate the front (western) end of the constellation by drawing a line from brilliant Vega to bright Altair, and then extending it one additional length farther. At the end of that line, you'll find the two most prominent star systems in Capricornus — Alpha (α) Capricorni (Algiedi) and Beta (β) Capricorni (Dabih).

I wrote *star systems* because both Alpha and Beta Capricorni are remarkable, wide double stars. Alpha comprises α^1 (magnitude 4.3) and α^2 (magnitude 3.7) about 6½′ apart. That's a lot closer than the better-known pair of Alcor and Mizar at the bend in the Big Dipper's handle. But unlike the Dipper duo, Alpha Capricorni's stars are similar in brightness and thus fairly easy to split without optical aid if you have good vision. However, Alpha Capricorni is a line-of-sight double with α^2 at a distance of 109 light-years and α^1 about 700 light-years away.

A little less than 2½° south-southeast from Alpha is Beta Capricorni, whose component suns are just under 3½′ apart. That should be wide enough for a naked-eye split, but because one component shines at magnitude 3.2 and the other at only magnitude 6.1, you'll need binoculars to see both. Unlike Alpha, however, Beta is a true double, with both stars moving through space in tandem. A small telescope shows the brighter member of the Beta system as yellow, contrasting nicely with its blue companion.

The eastern end of Capricornus is also marked by a pair of stars a few degrees apart. There you'll find magnitude-2.9 Delta (δ) Capricorni (Deneb Algiedi) and magnitude-3.7 Gamma (γ) Capricorni (Nashira). It was near Delta that German astronomer Johann Galle discovered the planet Neptune in September 1846. At the time, Neptune was about 5° northeast of the star. Sadly for the Sea Goat, if we apply modern constellation boundaries, Neptune lay just over the border in neighboring Aquarius at the time. But Delta retains a bit of glory for Capricornus as the brightest star near where that distant world was discovered.

What shape does the main pattern of Capricornus resemble to the modern eye? Astronomy writer Guy Ottewell says that of a boat. I've thought of a misshapen half-sandwich, a slightly twisted origami bird, or a bandit's bandana. What do you see?

You may not be aware of Capricornus's connection with a variety of English words. To *caper* is to make a frolicsome leap like young goats do. People can be involved in a *caper* — a capricious (impulsive, unpredictable) adventure. In ancient times, the famous island of *Capri* was indeed "the isle of goats." As for the second half of Capricornus, we all know that *unicorn* means "one horn," but as we progress into autumn, consider that a *cornucopia* is a "horn of plenty" (*copious* being plenty).

All things considered, for such a faint constellation, Capricornus has plenty to offer.

■ **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 skyandtelescope.org.

Plenty of Dawn Action

The Moon buzzes the Beehive, and Mercury is at its morning best.

FRIDAY, OCTOBER 1

The month kicks off with an event exclusively for those skywatchers who don't mind getting up in the wee hours before dawn. I've heard rumors such odd creatures exist, but I can't truthfully count myself among their number. In any case, if you have the fortitude (and/or the coffee) to handle an early start to your day, here's your reward: a waning crescent **Moon** sitting 3° north-northwest of the Beehive Cluster, **M44**. The longer you wait (or the farther west you happen to be), the closer the two objects appear. I'd suggest holding off until just before morning astronomical twilight, which at mid-northern latitudes starts at around 5:30 a.m. local daylight time. This is a binoculars-only sight, however. You'll need the extra light grasp and wide fields of view binos provide to see the Beehive's little swarm of stellar bees next to the 27%-illuminated lunar crescent.

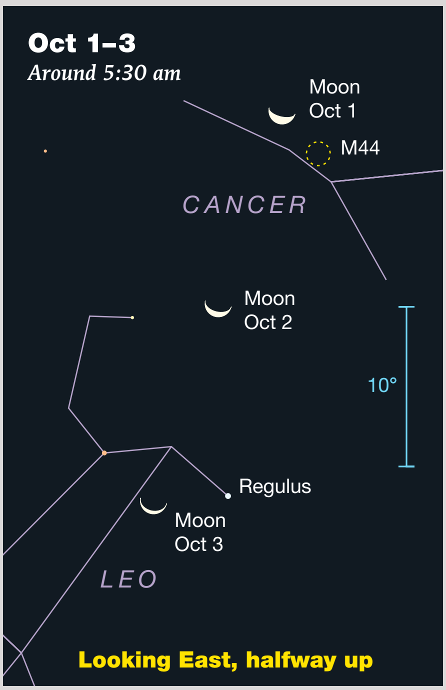
FRIDAY, OCTOBER 8

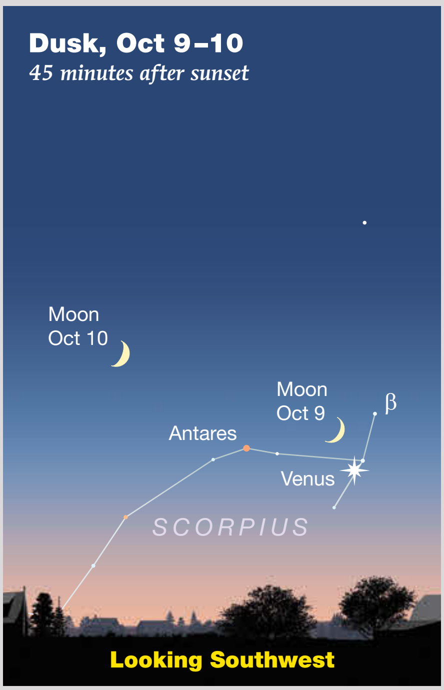
This is a big day for **Mars** observers as the Red Planet at long last has its conjunction with the Sun. It's not an event you can view, but it's worth noting nonetheless — it marks the end of the current apparition, which reached its climax a year ago in October 2020. Today also signals the beginning of a new apparition. However, patience is the Martian watchword. Mars does everything at a leisurely pace and won't emerge as a naked-eye object at dawn until late November. Looking further ahead, the next Mars opposition is another good one for Northern Hemisphere observers since it takes place in December 2022, high in Taurus. At its biggest, the planet's disk will span 17.2″, which is a far cry from its 2020 max of 22.6″, but still perfectly respectable.

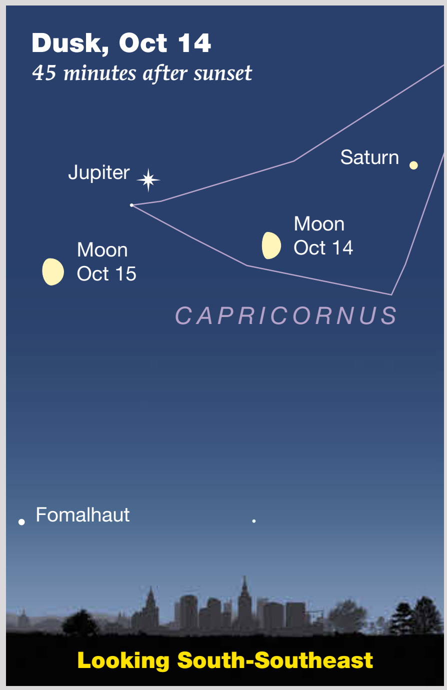
SATURDAY, OCTOBER 9

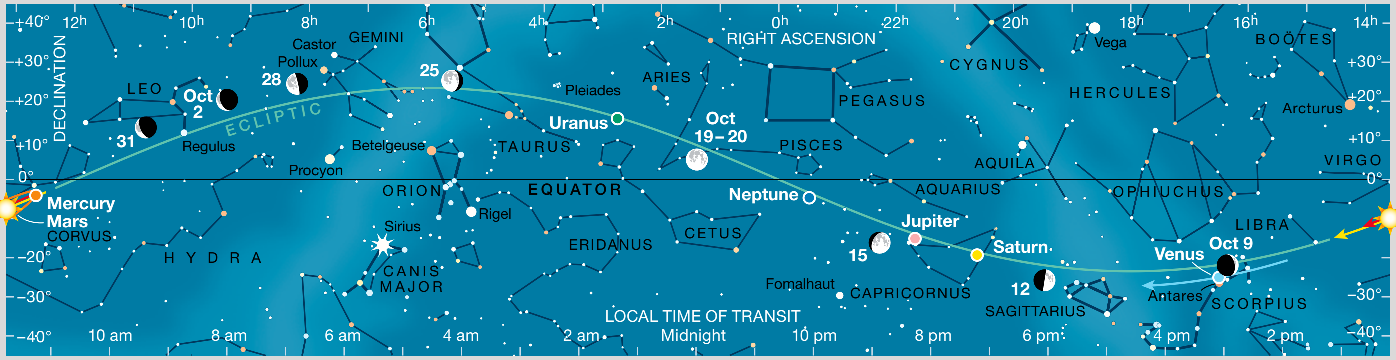
This evening we get to enjoy what is by far the most arresting conjunction of the month. Look to the southwest at

▼▶ 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.





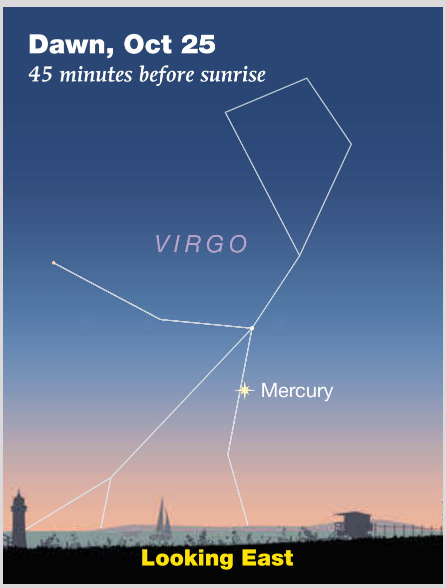




▲ The Sun and planets are positioned for mid-October; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit" tells when (in Local Mean Time) objects cross the meridian — that is, when they appear due south and at their highest — at mid-month. Transits occur an hour later on the 1st, and an hour earlier at month's end.

dusk to see a four-day-old **Moon** hanging less than 2½° above left of brilliant **Venus**. The one slight caveat to that "most arresting" claim is that the eye-catching pair won't be terribly high in the sky. Half an hour after sunset Venus will have an altitude of only 12°, while the lunar crescent will be a little higher. And the later you look, the lower they'll be. At magnitude –4.3, Venus is the reigning Evening Star — a title it'll hang on to until January.

There are two additional elements that add a bit of spice to tonight's twilight conjunction. First, you should be able to see earthshine illuminating the "dark" portion of the lunar disk. Second, the luminous twosome is accompanied by a retinue of modestly bright stars. Within a single 5° binocular field you'll see the Moon and Venus together, along with 2.3-magnitude Delta Scorpii, 2.6-magnitude Beta Scorpii, 4.4-magnitude Nu Scorpii, and the pretty binocular double star Omega Scorpii with its components of magnitude 3.9 and 4.3. Not a bad haul.



THURSDAY, OCTOBER 14

The flattened V of the constellation Capricornus is nicely positioned due south as twilight fades to night. This otherwise modest figure is currently adorned by **Jupiter** and **Saturn**. On this night the planetary duo is by a waxing gibbous **Moon**, which parks itself directly between the two planets. Indeed, so luminous is the trio of interlopers that you might not notice Capricornus at all. The 70%-illuminated Moon is less than 8° from Jupiter (magnitude –2.6) and about 10° from Saturn (magnitude +0.5).

SATURDAY, OCTOBER 16

Just a week after its meet-and-greet with the Moon, **Venus** approaches to less than 1½° of **Antares**, the Alpha star of Scorpius. Even though 1st-magnitude Antares is the 15th brightest star in the night sky, it doesn't hold a candle to Venus — the planet is 140 times brighter. What makes this particular conjunction visually interesting, however, is the contrast between the silvery-white gleam of Venus and the ruddy hue of Antares. It's also worth noting that Venus and Antares don't get this close very often. Although they typically meet up annually, close encounters only happen every eight years. So, if you miss this evening's conjunction, you'll have to wait until October 2029 before you'll get to see them so close together again.

MONDAY, OCTOBER 25

Last month I noted that **Mercury** apparitions tend to be either long and low or short and high. In September we had one of the former, and this month we have one of the latter. You'll want to get another pot of coffee going because it's another early-morning event.

This is Mercury's finest dawn showing of 2021, and only the second time this year the planet sits above the horizon during astronomical night, albeit barely so. From mid-northern latitudes on this date, Mercury rises more than 1½ hours ahead of the Sun and stands 12° above the east-southeastern horizon at the start of civil twilight. The planet gleams at magnitude –0.7 from Virgo. Interestingly, some 30° left of Mercury is similarly bright Arcturus (magnitude –0.1), positioned roughly the same altitude above the horizon. Mercury will remain well placed through the end of the month and into the first week of November, after which it becomes increasingly difficult to see. But if mornings aren't your thing, don't despair. In December, the innermost planet makes its final 2021 appearance at dusk.

■ Consulting Editor **GARY SERONIK** has been observing long enough to appreciate the value of caffeine.

Aurora Season Arrives

October is one of the most rewarding times of year to monitor the midnight sky.

In recent years, social media has been instrumental in fueling the desire of many to experience and share one-of-a-kind natural events. Near the top of the "must-see" list is the aurora borealis.

Thanks to magnetometer and satellite data readily available on the internet, you can monitor the state of Earth's magnetic field and be ready to jump into action to chase down an aurora at a moment's notice. Or you can connect with a Facebook group and receive regular updates. The Alberta Aurora Chasers and the Great Lakes Aurora Hunters are two of my favorites. I first heard the delightful expression "Pants on!" in the Alberta group, which some members use to alert the group that a full-blown display is underway.

David Hathaway, a NASA solar physicist, analyzed 70 years of data from 1932 to 2002 and found that the greatest number of geomagnetic disturbances that produce aurorae occur during the months of March and October. I've seen the northern lights where I live in Duluth, Minnesota, every month of the year, but my journals clearly show spikes in activity around the equinoxes.

At those times, the tilt of Earth's magnetic poles is perpendicular to the flow of material from the Sun — an orientation that increases the probability that the solar

▲ The author captured this spectacular series of narrow, bright auroral rays dancing across the northern sky during a moderate geomagnetic storm on the night of March 12-13, 2021. To photograph an aurora, he recommends a 20- to 30-second exposure with a wide-angle lens set to its widest aperture. For a weak display use ISO 1600 to 3200 and for a bright aurora a 10-second exposure at ISO 800 works well.

and terrestrial magnetic fields will realign in a process called *reconnection*.

Whether it's a solar flare that burps out a coronal mass ejection (CME) or the breezy flow from a coronal hole, both types of events release clouds of (mostly) high-speed electrons and protons into the *solar wind* — the continuous flow of charged particles emanating from the Sun. Entrained within each outburst is part of the Sun's magnetic field with north and south domains, just like a magnet. If the field points south when it blows past our planet, it will reconnect with Earth's north-pointing field like the north and south poles of two magnets snapping together.

A moving magnetic field also generates an electric field, so the arriving material acts like a battery, chock-full of electrons eager to do work. When the solar and terrestrial field lines reconnect, the subatomic cargo spirals down Earth's magnetic field lines like so many firemen hurrying down fire poles.

If the outburst's magnetic field points north (what's called *positive Bz*), Earth's magnetic field will deflect the particles and no geomagnetic storm takes place. But if Bz is negative (points south), linkage occurs and current flows into Earth's magnetosphere.

Our planet's magnetic field lines direct the particles toward the polar regions, where they slam into atoms and molecules of oxygen and nitrogen in the upper atmosphere at speeds up to 72 million kilometers per hour. Energized by the collisions, the atoms and molecules soon return to their ground state, emitting red and green photons in the process. These myriad bursts of light paint the shimmering curtains and dancing pillars of the aurorae.

"It's very much like a neon light," explains Terry Onsager, a physicist with the National Oceanic and Atmospheric Administration's (NOAA) Space Weather Prediction Center in Boulder, Colorado. "Put a current through [the atmosphere], and it glows."

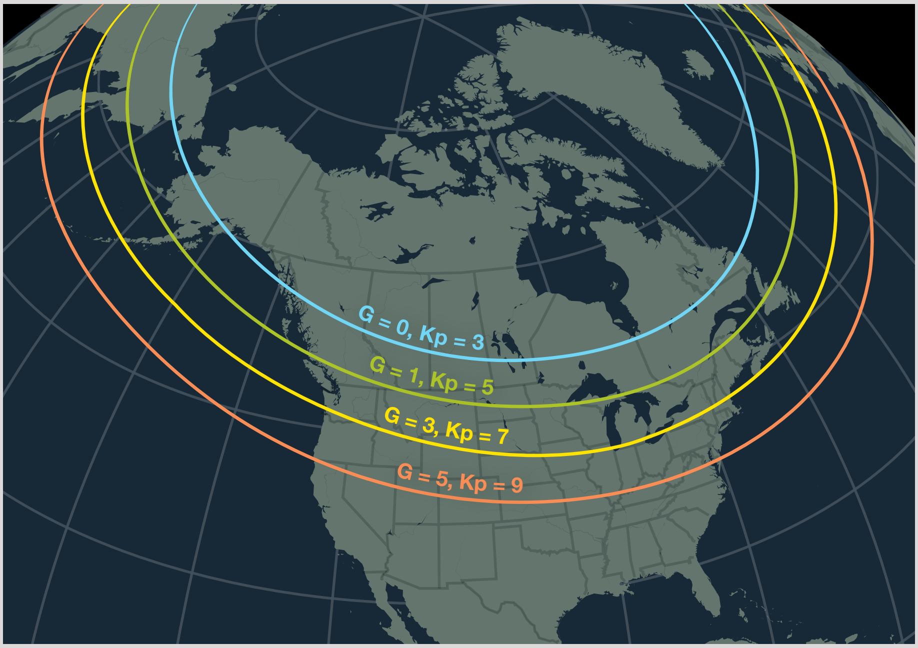
Linkage begins when solar plasma connects with magnetic field lines on the Sun-facing side of Earth to spark the dayside aurora. As the CME streams past the Earth the field lines are swept back behind the planet, where they reconnect with each other and slingshot plasma towards Earth's night-side to create the nighttime aurora.

With the 11-year solar cycle currently rising toward a predicted maximum in 2025, auroral activity will likely increase in the coming years. Northern Canada, Scandinavia, Iceland, Siberia, and Alaska are the best places in the Northern Hemisphere to see an aurora, especially within a band stretching from latitude 65° to 72° north. This is the location of the northern *auroral oval*, a donut of activity centered on the magnetic north pole. (There's also a southern version that resides above Antarctica.) When solar electrons pummel the upper atmosphere during a geomagnetic storm, the oval expands southward into the northern United States and Europe, where observers at more southerly latitudes get a shot at seeing the aurorae.

To anticipate a potential auroral display, I recommend getting the NOAA 3-Day Forecast, delivered free a couple of times a day to your email inbox. (Subscribe by visiting **https://is.gd/noaa_subscribe**.) You'll receive the latest forecast for the *Kp index*, an indicator of magnetic activity in the Earth's magnetic field based on data from ground magnetometers in both Hemispheres. Kp is rated from 0 to 9, with 1 indicating calm conditions, and 5 or greater corresponding to geomagnetic storms of increasing severity. Generally, the higher the Kp index, the farther south the aurora appears. For example, in northern Minnesota the aurora is weakly visible low in the northern sky when Kp = 4. If you live in Kansas or Kentucky, the threshold climbs to 8 or 9.

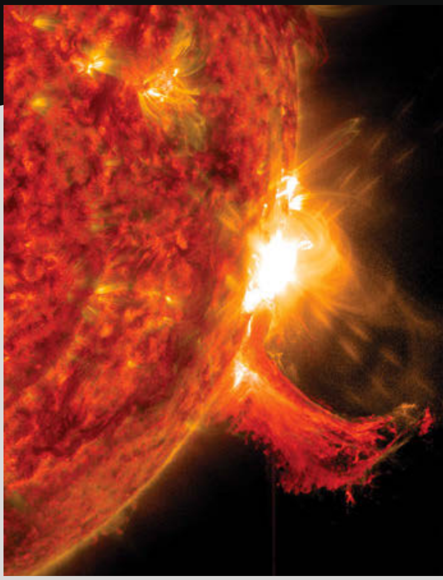
Kp numbers are regularly updated at **spaceweatherLive.com**, where you can also view a graph depicting the current *Bz*, which indicates the solar wind's magnetic strength and direction. Bz data are based on real-time monitoring by NASA's DSCOVR satellite, which hovers at the L^1 Langrangian point, about 1.5 million kilometers from Earth. My favorite monitoring site

▲ Iceland is one of the most popular destinations for aurora chasers. This shot was captured during an especially active display in March 2015, as the northern lights dance above the Hotel Rangá, located in the island country's southwest.



▶ The Kp index is a good indicator of disturbances in Earth's magnetic field caused by enhancements in the solar wind. This map shows the minimum Kp value required to see an aurora from different locations in North America. A Kp of 5 is associated with a minor, G1 geomagnetic storm. Storm levels at Kp = 9 are classified as G5 or extreme.

AURORA: GARY SERONIK; KP MAP: *S&T* / NOAA



▲ Solar flares are one key source of the Sun's plasma reaching Earth. These are explosive events that propel material into space at extreme speeds. Only those that direct particles at our planet possess the potential to produce an auroral display.

NASA / GODDARD / SDO

is NOAA's Real Time Solar Wind live feed at **https://is.gd/noaa_solarwind**. Bz is the topmost graph on the page. When the Bz dips below the centerline to −5° or more, a bundle of south-directed plasma is approximately 45 to 60 minutes from banging into Earth's magnetosphere. Add in another 15 to 30 minutes for reconnection on the nightside . . . and Pants On!

The aurora is fickle. Sometimes the lights arrive early, sometimes late, or sometimes not at all. We can't always be certain which way the magnetic field of the plasma blast will be oriented at arrival time. But don't be discouraged — our understanding of this spellbinding and complex phenomenon is imperfect.

"The hardest part of forecasting is predicting the Bz," says Onsager. "We only get 45 minutes lead time from DSCOVR. It's very complicated and difficult to determine the Bz en route from the Sun."

The best time to watch for the northern lights is from about 10 p.m. to 2 a.m. local standard time (11 p.m. to 3 a.m. local daylight-saving time), with the sweet spot lasting from about 11 p.m. to 1 a.m. A display often begins with little fanfare as a low, pale green arc 5° to 10° above the northern horizon. If the arc brightens or a second arc forms, stick around — you may soon witness a pretty display of feathery plumes slowly parading across the bottom third of the northern sky. If the predicted Kp is high and the sky explodes with auroral splendor, forget about going to bed — you may find yourself in the throes of that hoped for "one-of-a-kind" experience.

Action at Jupiter

AS OCTOBER OPENS, Jupiter rises well before sunset and reaches the meridian at about 10 p.m. local daylight-saving time, when it's well placed for telescopic viewing. The giant planet shines at magnitude –2.7 from eastern Capricornus and presents a disk 46″ across.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. The moons orbit Jupiter at different rates, changing positions along an almost straight line from our point of view on Earth. Use the diagram on the facing page to identify them by their relative positions on any given date and time. All the observable interactions between Jupiter and its satellites and their shadows are listed on the facing page. Find events timed for when Jupiter is at its highest.

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.)

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

October 1: 6:03, 15:58; **2**: 1:54, 11:50, 21:45; **3**: 7:41, 17:37; **4**: 3:32, 13:28, 23:24; **5**: 9:19, 19:15; **6**: 5:11, 15:07; **7**: 1:02, 10:58, 20:54; **8**: 6:49, 16:45; **9**: 2:41, 12:36, 22:32; **10**: 8:28, 18:24; **11**: 4:19, 14:15; **12**: 0:11, 10:06, 20:02; **13**: 5:58, 15:54; **14**: 1:49, 11:45, 21:41; **15**: 7:36, 17:32; **16**: 3:28, 13:24, 23:19; **17**: 9:15, 19:11; **18**: 5:07, 15:02; **19**: 0:58, 10:54, 20:49; **20**: 6:45, 16:41; **21**: 2:37, 12:32, 22:28; **22**: 8:24, 18:20; **23**: 4:15, 14:11; **24**: 0:07, 10:03, 19:58; **25**: 5:54, 15:50; **26**: 1:46, 11:41,

Minima of Algol

Sept.	UT	Oct.	UT
1	16:29	3	5:24
4	13:18	6	2:13
7	10:07	8	23:02
10	6:55	11	19:50
13	3:44	14	16:39
16	0:32	17	13:28
18	21:21	20	10:17
21	18:10	23	7:05
24	14:58	26	3:54
27	11:47	29	0:43
30	8:36	31	21:32

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

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

21:37; **27**: 7:33, 17:29; **28**: 3:24, 13:20, 23:16; **29**: 9:12, 19:07; **30**: 5:03, 14:59; **31**: 0:55, 10:50, 20:46

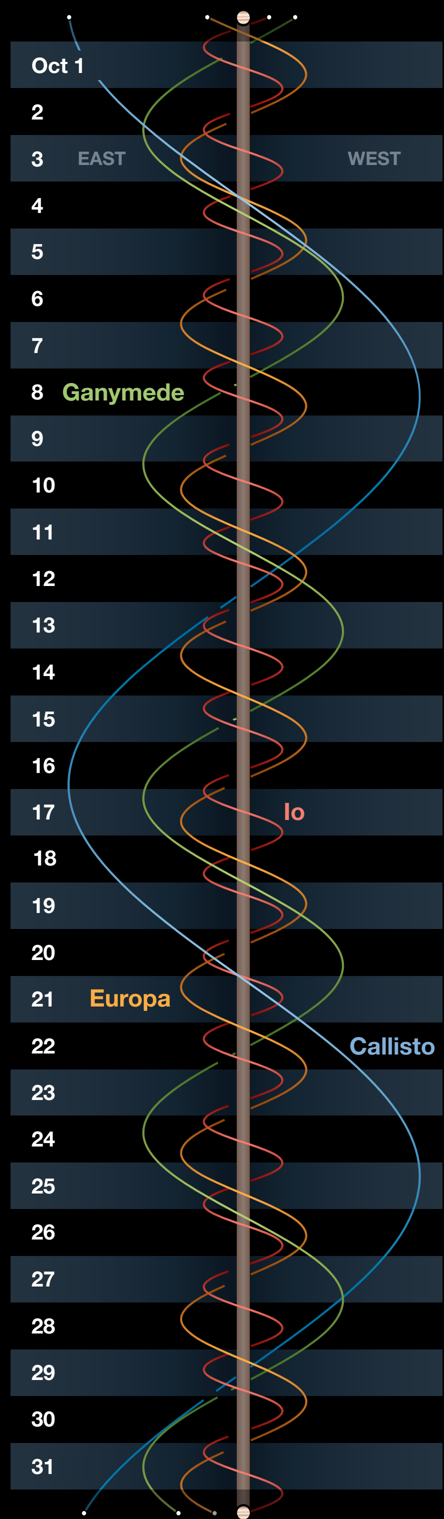
These times assume that the spot will be centered at System II longitude 7° on October 1st. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 7° and $1\frac{2}{3}$ minutes later for each degree more than 7°.

Phenomena of Jupiter's Moons, October 2021

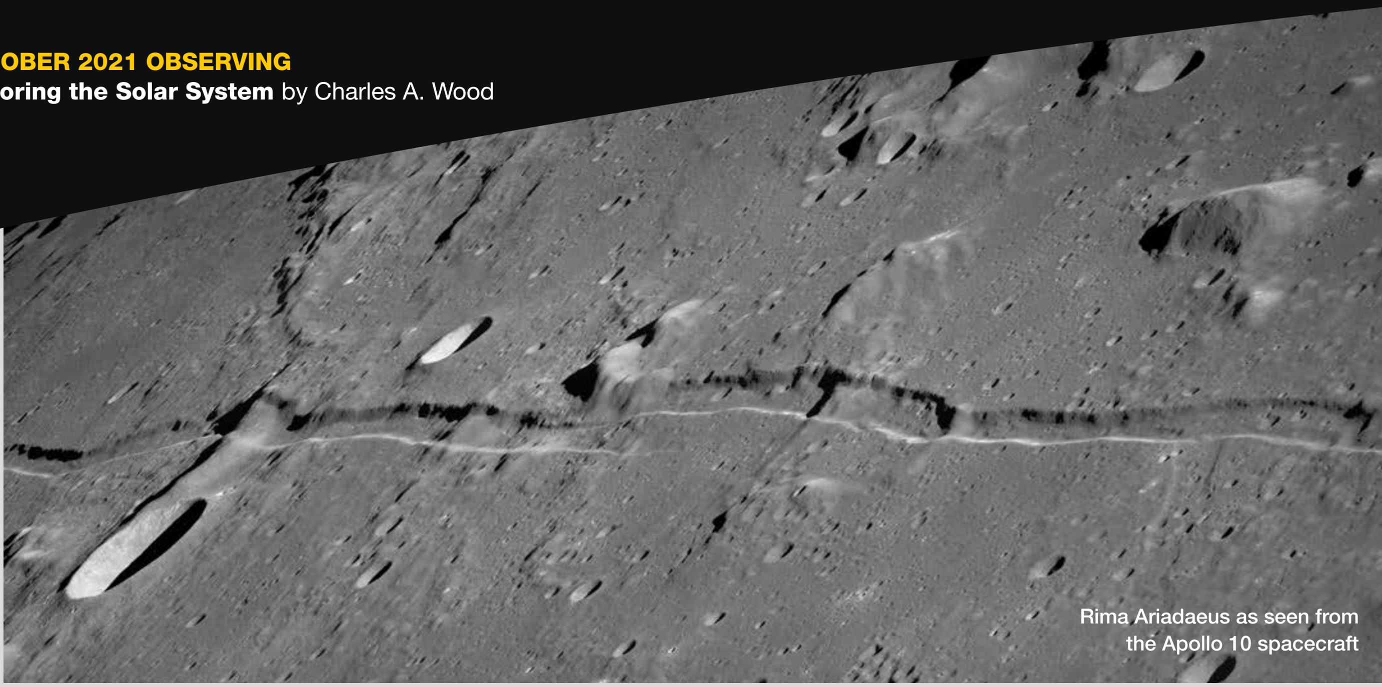
Date	Time	Event
Oct. 1	0:55	III.Oc.D
	4:32	III.Oc.R
	4:49	III.Ec.D
	8:25	III.Ec.R
	12:24	I.Tr.I
	13:22	I.Sh.I
	14:42	I.Tr.E
	15:40	I.Sh.E
Oct. 2	9:34	I.Oc.D
	12:50	I.Ec.R
	13:01	II.Oc.D
	17:55	II.Ec.R
Oct. 3	6:52	I.Tr.I
	7:51	I.Sh.I
	9:09	I.Tr.E
	10:09	I.Sh.E
Oct. 4	4:01	I.Oc.D
	7:11	IV.Tr.I
	7:19	I.Ec.R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


Rima Ariadaeus as seen from the Apollo 10 spacecraft

Hot and Cold Lunar Rilles

Understanding the origins of these fine Moon features can enhance your observing experience.

Lunar *rilles*, or *rimae*, are long, narrow trenches that often go unnoticed at the telescope. In the late 1680s, Dutch astronomer Christiaan Huygens detected the features later named **Schröter's Valley** and **Rima Hyginus**. About 120 years later, German observer Johann Schröter rediscovered the valley that bears his name today and included it in his catalog of 11 linear depressions that he called "rilles," the German word for grooves.

Understanding their origins starts by noting that rilles have three different morphologies and distributions. In general, the biggest and easiest to see are linear rilles. The widest and deepest on the Moon is **Rima Ariadaeus,** found west of **Mare Serenitatis**. This rille measures 4.5 kilometers (2.8 miles) wide, 425 meters (1,400 feet) deep, and 245 km (150 km) long. Apollo 10 astronauts photographed an oblique view of the Ariadaeus Rille (see above), which beautifully illustrates that hills are down-dropped when pierced by a rille — the rille floor must have subsided. The parallel sides of the rille have smooth, sloping surfaces — characteristics geologists recognize as belonging to fault scarps. Linear rilles are *graben* — a German term meaning "ditch" or "trench," which refers to fault-bounded trenches that cut pre-existing terrain.

Rima Sirsalis, is 3.5 km wide, 300 m deep, and about 450 km long and cuts through highlands and Orientale ejecta east and south of its patronymic crater. **Rima Hesiodus**, along the southern edge of **Mare Nubium**, is also 350 m wide, but only 100 m deep and 260 km long. Rima Sirsalis extends roughly north to south and is conspicuous when the terminator is nearby due to the long, dark shadow cast by the rille's eastern wall. Rima Hesiodus runs more east to west, so sunlight often shines along it, revealing its flat, depressed floor.

The Parry Rilles (**Rimae Parry**) south of **Copernicus** provide clues to the origin of linear rilles. These linear features are the remnants of five or more rilles that intrude into the old craters **Parry**, **Bonpland**, and **Fra Mauro**. One rille that cuts the rim between Bonpland and Frau Mauro has a line of minute volcanic cones along its western edge. The cones support the interpretation that linear rilles are the surface manifestation of *dikes* — near vertical sheets of magma that rose through the lunar crust and erupted the lavas that formed maria. Those dikes that didn't erupt onto the surface produced great stress that exerted an extensional force in the rocks above them. This in turn created parallel faults and collapsed the ribbon of land between to form a rille.

A number of long linear rilles traverse the highlands facing the western shore of **Oceanus Procellarum**. Rima Sirsalis and the rilles west of **Gassendi**, near **Grimaldi**, and east of **Galvani**, are all approximately radial to the Imbrium Basin, indicating that they're linked to the tectonic forces associated with the basin.

A second type of rille looks very much like the linear version but is *concentric* to impact basins. Among the most conspicuous and beautiful examples is **Rimae Hippalus** — three rilles near the eastern edge of **Mare Humorum**. These didn't form over dikes but by the flexure created when the stable Humorum lavas near the basin's edge fractured as the center of the mare subsided due to the weight of its thick pile of lavas. A similar but smaller concentric pattern of rilles is found around the southern and eastern margins of the Serenitatis Basin. A much less conspicu-

NASA

ous concentric rille system along the western shore of **Mare Tranquillitatis** marks the region of maximum bending/fracturing where the Tranquillitatis lavas subsided.

The third and most common type of narrow depression is the *sinuous rille*. These have meandering, curving shapes not unlike many terrestrial rivers. Sinuous rilles occur on mare lavas, though some, like **Rima Hadley**, start in small, deep pits in the mountainous terrains bordering maria. The Hadley Rille is 144 km long, 1.2 km wide, and 220 m deep, and is the only rille visited by Apollo astronauts.

Debra Hurwitz (then Brown University) and colleagues assembled a comprehensive survey of sinuous rilles using data from NASA's Lunar Reconnaissance Orbiter and JAXA's Kaguya spacecraft. She tabulated 194 sinuous mare rilles and determined the median dimensions for these features as 33 km long, 480 m wide, and 49 m deep. The fact that the median values are so tiny indicates that many sinuous rilles are smaller than can be detected telescopically. Hurwitz's invaluable rille atlas is available at **https://is.gd/rilles**.

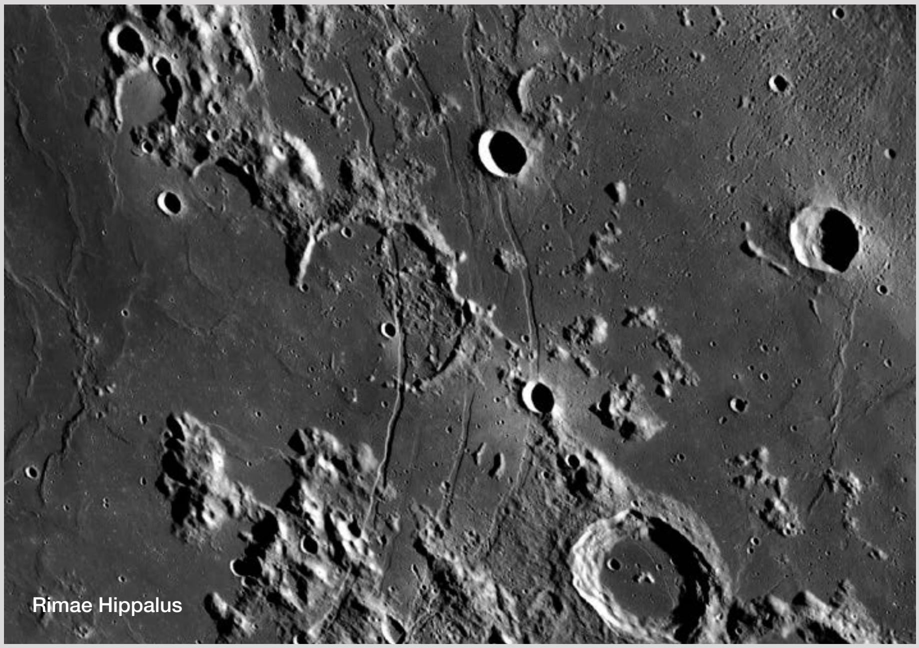
The biggest sinuous rille is Schröter's Valley. It starts at the informally named Cobra Head, a 2-km-tall conical volcano topped with an 11-km-wide, 1.6-km-deep pit. The first third of the valley consists of two fairly straight segments but then continues on with sinuous bends for a total length of 145 km. Over its length, the rille's width decreases from 11 km at the Cobra Head to 2.5 km at its end. A very thin, sinuous, inner rille extends a further 40 km, reaching the surrounding mare.

Hurwitz also found that nearly half of all sinuous rilles occur in Oceanus Procellarum, concentrated around the Aristarchus Plateau and the Marius Hills — two major centers of volcanism. In fact, nearly all sinuous rilles are within the geologically distinct Procellarum-KREEP Terrain (known as PKT with K standing for Potassium, REE being rare earth elements, and P representing phosphorus). this terrain geographically coincides with a proposed 3,400-km-wide Procellarum Basin that covers the area between Oceanus Procellarum and Mare Serenitatis. The PKT also contains the Moon's highest concentration of radioactive thorium, which may explain why so much volcanism occurs in the region.

The meandering curves of sinuous rilles reveal that they were formed by flowing fluid. Thermal erosion from flowing lava deepens a surface lava channel and plucks out chunks of underlying lava layers.

Now that you're familiar with all three types of rilles, as you examine these features in your telescope you can consider whether or not a particular one formed hot or cold. Sinuous rilles formed entirely by volcanic processes — hot lava flowing downhill in channels or lava tubes. Upward pressure of magma in dikes causing parallel faulting and the collapse of cold, near-surface rocks created linear rilles. Concentric rilles formed without any volcanic input when cold surface rocks fractured due to bending at the edges of subsiding maria.

■ Contributing Editor **CHUCK WOOD** witnessed the formation of a rille during a volcanic eruption in Hawai'i.



Rimae Hippalus

Rima Hadley

Schröter's Valley

NASA / ARIZONA STATE UNIVERSITY (3)

◀ The effect of Earth's rotation (along with the unwelcome trails of some passing aircraft) is easily visible in this unguided, 18-minute exposure. The stars appear to trace concentric circles around the celestial pole. Motorized sky trackers and equatorial mounts can eliminate this trailing, but only if the mount is properly polar aligned.

Mastering Polar Alignment

Setting up your mount correctly is an important first step in creating great astrophotos.

Fast, wide-angle lenses let you capture stunning nightscapes with your camera mounted on a regular photo tripod. But as you increase the focal length of the lens or the exposure time, you'll start to see star trails appearing in your images. This can be an interesting visual effect, but if the goal is natural-looking stars, you'll need to mount your camera on a motorized sky-tracker or equatorial telescope mount.

These devices work by counteracting Earth's rotation and let you take multi-minute exposures with a telephoto lens or even a telescope. But to work properly, such a mount needs to be *polar aligned* — its right-ascension axis has to point directly at the celestial pole to match Earth's axis of rotation. There are several ways to accomplish this: by using a polar scope, by computer-assisted alignment, or by analyzing star drift.

No matter which method you choose, your mount needs to be at least roughly aimed at the celestial pole. Although it's not strictly necessary to level your tripod, doing so helps because you can then use the graduated scale on the side of your mount to correctly set your location's latitude. This ensures the vertical tilt of the mount matches the elevation of the celestial pole.

Next (for those of us in the Northern Hemisphere), you'll need to swivel your mount horizontally so it's facing true north. You can use a compass or even a north-south road or other landmark to get close. After dusk, you can get a more accurate estimate by dropping an imaginary line directly down to the horizon from Polaris, the North Star.

This rough polar alignment may be all you need for relatively short exposures captured with a wide-angle lens. Longer exposures or longer lenses will require greater precision.

Celestial Target Practice

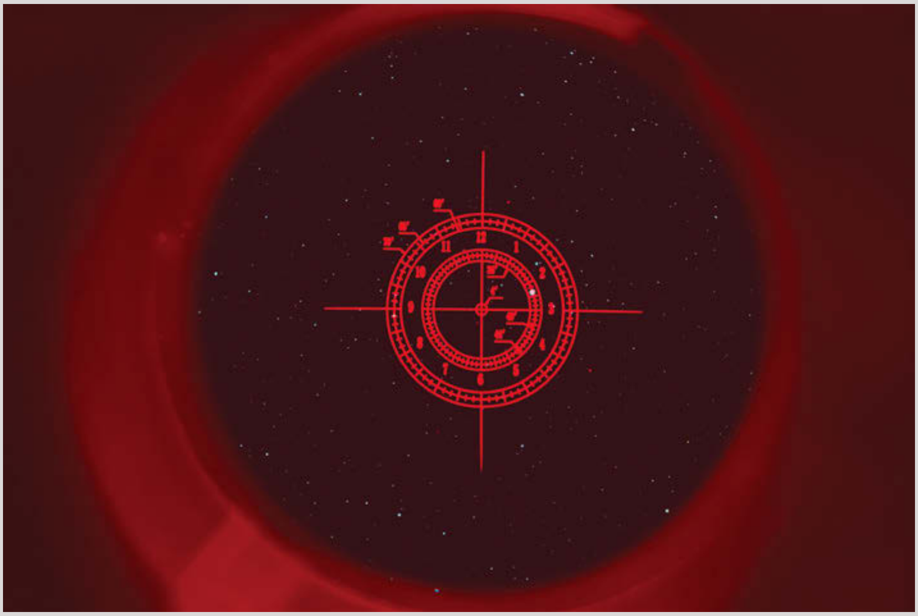
Many equatorial mounts and portable star-trackers use small, low-power optical finders to improve your pointing accuracy. Such polar scopes are either built into the mount or available as an optional accessory. Instead of a simple crosshair like you see in a regular finderscope, polar scopes employ an etched-glass reticle that shows the position of Polaris offset from celestial north. (Polaris doesn't lie *exactly* at true north.) Astrophotographers in the Southern Hemisphere will use the star Sigma Octantis instead.

You can use an app to look up Polaris's precise position relative to the pole for your specific location at the current date and time. Then, by working with the altitude and azimuth adjustments of your mount, you move Polaris to the indicated mark on the reticle. With that, you're all set.

What are the downsides to this method? There are only a few. First, you obviously have to be able to see Polaris from your observing site. Second, at a truly dark sky location your polar scope can reveal a myriad of stars, which can make identifying Polaris tricky. In these situations, it's better to begin alignment during twilight, when

▶ This view of the iOptron SkyTracker Pro shows the removable polar scope (the small black tube on the left side) used to polar align the unit. The tracker's base features knobs that permit fine altitude and azimuth adjustments.

ALL IMAGES COURTESY OF THE AUTHOR



▲ Looking through the iOptron polar scope, you'll see an illuminated reticle etched with a clock face and concentric rings, similar to what's shown in this composite image. Many equatorial mounts are equipped with similar optical pole finders. You can download an app that displays precisely where Polaris needs to be placed at a specific date and time from your location.

only the brightest stars are visible. Finally, you'll need to perform some odd nocturnal contortions to look through the polar-scope eyepiece since it's pointing skyward at an awkward angle, just a few feet above the ground. You can, however, purchase an optional right-angle viewfinder adapter (see the September issue, page 68), which makes the process less neck-straining.

Masters of the Universe

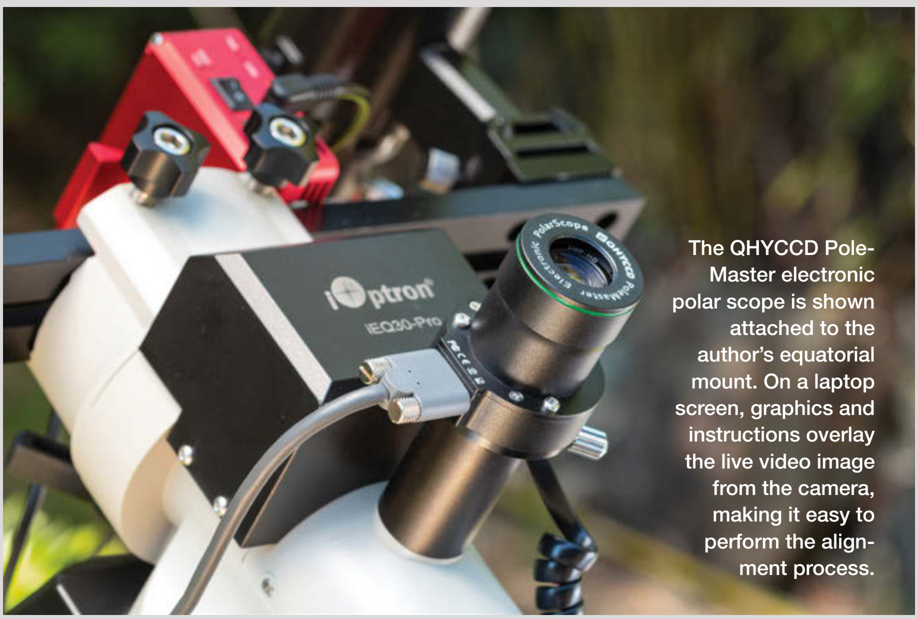
A new, high-tech method is to use an electronic pole finder, such as the PoleMaster, made by QHYCCD. It's a small digital camera with a wide-angle lens that's used to display the field around the celestial pole on your laptop computer. On-screen text and graphics overlay the live video feed, guiding you through the polar-alignment process step by step. Adjustments take just a few minutes to complete and are extremely accurate. iOptron offers a similar device called the iPolar Scope, which fits many of the company's mounts, replacing the standard optical polar scope.

Electronic polar scopes work very well, but they do require you to spend extra money on a single-purpose device. Luckily, some software packages allow you to use your imaging camera and lens as a virtual polar scope, thereby avoiding the need to purchase extra hardware. *SharpCap Pro* (**sharpcap.co.uk**), a well-respected planetary imaging software, includes a polar-alignment feature that supports a wide range of camera and lens combinations. After you capture an initial image, you rotate the mount 90° to capture a second image. The software automatically compares the two images to determine the mount's center of rotation. Any deviation from the actual celestial pole is displayed and can then be eliminated by tweaking the aim of the mount's altitude and azimuth. Importantly, the method works on any part of the sky within 7° of the pole, so it's a good solution if your view of Polaris is partially obstructed.

The ASIAIR PRO smart Wi-Fi device by ZWO has a similar feature that works with the cameras it supports. The device connects wirelessly to an app on your phone or tablet — a real plus if you prefer to leave your laptop at home.

Drifting Into Alignment

So far we've looked at solutions that measure the position of your mount relative to the celestial pole. A slightly different approach is to monitor how well your mount tracks a star along the celestial equator. The process is known as *drift alignment* and can be performed visually with an illuminated reticle eyepiece, or photographically using your camera. Camera-control software such as *BackYardEOS, BackYardNIKON,* (available at **otelescope.com**) and *Astro Photography Tool* (**astrophotography.app**) include a feature that superimposes a crosshair reticle over the live view from your camera for improved alignment accuracy.



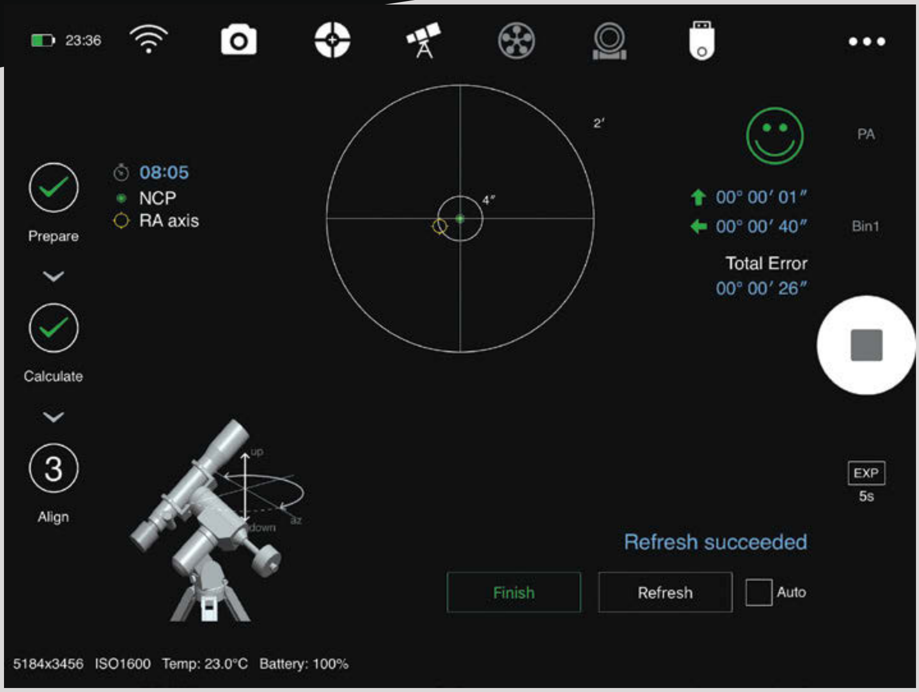
The QHYCCD PoleMaster electronic polar scope is shown attached to the author's equatorial mount. On a laptop screen, graphics and instructions overlay the live video image from the camera, making it easy to perform the alignment process.

So how does drift alignment work? First, you locate a star near the meridian and within 20° of the celestial equator. Center it on the crosshairs, then watch for any movement north or south over time (ignore any east-west motion). If the star drifts south, your mount is pointing too far east. If it drifts north, your mount is aimed too far west. Adjust your mount horizontally as needed and then repeat the observation. You'll make successively smaller and smaller motions as you fine-tune the alignment, and eventually you won't detect any north-south drift.

Next, aim at a star that's low in the eastern sky and near the celestial equator. Again, you monitor for north-south drift, but this time, if the star wanders south, your mount's polar axis is aimed too low. If the star drifts north, your mount is pointed too high. Use the same iterative process to fine-tune the altitude adjustment. (If the eastern sky is blocked, you can use a star in the west, but you'll need to reverse the altitude corrections.)

The drift method is simple and accurate but can be time-consuming to perform. There's a quicker variation called Drift Alignment by Robert Vice (DARV) that utilizes your camera and the mount's hand-controller. Instead of viewing the two target stars, you take individual time exposures of them with your camera.

During the first half of the exposure, slew the mount west at its slowest rate using the hand-controller. Then, during the remaining part, you slew the mount east. If your polar alignment is perfect, the resulting star image will be a single line. Otherwise, it will appear as a V-shaped wedge. Depending on which of the two reference stars you're working with, you then adjust either the altitude or azimuth position of the mount and take another time exposure. As the alignment improves the width of the wedge will narrow, eventually becoming a straight line.



▲ Many apps are available for computers, smartphones, and tablets to guide you through the process of polar alignment using your camera and lens. The ASIAIR PRO Polar Alignment screen is shown in the image above. The app works with the company's smart Wi-Fi unit.

▲ Drift Alignment by Robert Vice (DARV) is a photographic variation of the traditional drift alignment method. As described in the text, DARV involves slewing your mount east then west, while making an exposure of a reference star. Initially the star will appear as a V-shaped wedge, as shown in this test shot. As the alignment improves the wedge will close, eventually becoming a perfectly straight line when polar alignment is achieved.

Drift alignment is a great way to cross-check the accuracy of the other methods and is particularly handy if your view of the celestial pole region is blocked — a common situation.

Although polar alignment can initially feel overwhelming, with a little practice any of the techniques described here will eventually become second nature. The trick is to take your time and proceed methodically. Once you master polar alignment, you'll be on your way to creating beautiful long-exposure astrophotos.

■ **TONY PUERZER** has come to the conclusion that nothing beats a clear dark sky and a well-aligned mount.

The Odd World of Peculiar Galaxies

Galaxies with singular features present intriguing views in the eyepiece.

"Every galaxy is peculiar." So wrote Halton Arp in the introduction to his pioneering work, *Atlas of Peculiar Galaxies* (1966), specifying, "when looked at closely enough." At the time, Arp was working at the largest telescope in the world — the 200-inch at Palomar.

Arp's mentor, Edwin Hubble, had famously classified galaxies into various subsets, depending on their elongation and how tightly their arms (if present) wound around the core. An ever-increasing body of data, however, suggested that galaxies not conforming to this classification system abounded in the universe. Moreover, deep photographs showed unexpected — and odd — details in familiar and seemingly orderly galaxies.

Arp obtained hours-long photographic exposures of these distant "island universes" (as 18th-century philosopher Immanuel Kant described galaxies) that revealed subtle structural features in many of them. He used these details to expand upon his mentor's original classification scheme. Arp subsequently compiled a list of galaxies with unusual morphologies, in what eventually became the *Atlas of Peculiar Galaxies*. The astrophysical interpretation of these peculiarities has changed — in many cases quite dramatically — since the time of that seminal publication, but nevertheless galaxies from Arp's catalog continue to attract the attention of professional astronomers.

Seeing any level of detail in a galaxy visually using amateur telescopes can be a challenge. However, any observer who has mastered the art might soon begin to wonder if so-called grand-design spirals are the only ones out there. This is where Arp's catalog can come to the rescue. With the advent of more affordable, large-aperture telescopes, amateurs began to observe these often-faint Arp galaxies systematically. As with other challenging deep-sky objects, dark skies can be at least as important, if not more so, than telescope aperture when striving to see all 338 objects in the *Atlas*. High magnification is essential for discerning the details of the peculiarities of these galaxies, as are finder charts for guiding you to their locations.

Let's take a look at a sample of targets from the *Atlas* — hopefully this selection will whet your appetite for these space oddities.

▲▲ **ARP 164** Also known as NGC 455, this Arp specimen in Pisces is a prime example of a peculiar galaxy. Like many objects in Arp's *Atlas*, NGC 455's messy look is likely due to a close encounter with another galaxy.

▲ **SKETCHES AT THE EYEPIECE** The drawings (all north up) represent the view as seen through the author's 20-inch scope.

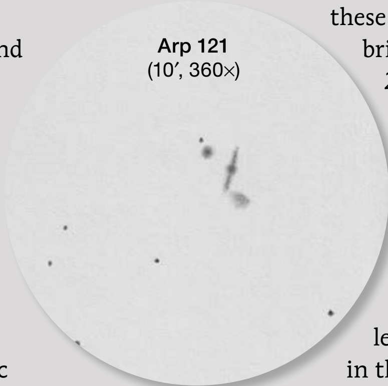
The Peculiar Set

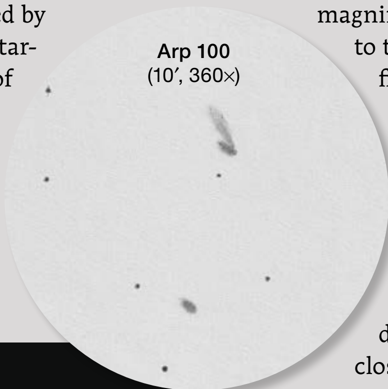
Arp No.	Object	Surface Brightness	Mag(v)	Size	RA	Dec.
164	NGC 455	13.4	12.7	1.9′ × 1.2′	01ʰ 16.0ᵐ	+05° 11′
121	MCG-1-3-51	13.8	13.7	2.1′ × 0.6′	00ʰ 59.4ᵐ	−04° 48′
121	MCG-1-3-52	12.8	14.1	0.6′ × 0.6′	00ʰ 59.4ᵐ	−04° 48′
100	IC 18	14.0	14.6	1.1′ × 0.6′	00ʰ 28.6ᵐ	−11° 35′
100	IC 19	13.8	14.1	1.0′ × 0.7′	00ʰ 28.7ᵐ	−11° 38′
133	NGC 541	13.2	12.1	1.8′ × 1.7′	01ʰ 25.7ᵐ	−01° 23′
308	NGC 545	13.5	12.2	2.4′ × 1.6′	01ʰ 26.0ᵐ	−01° 20′
308	NGC 547	12.7	12.2	1.3′ × 1.3′	01ʰ 26.0ᵐ	−01° 21′
230	IC 51	13.2	12.8	1.5′ × 1.1′	00ʰ 46.4ᵐ	−13° 26′
126	UGC 1449	12.5	13.3	1.1′ × 0.5′	01ʰ 58.1ᵐ	+03° 05′

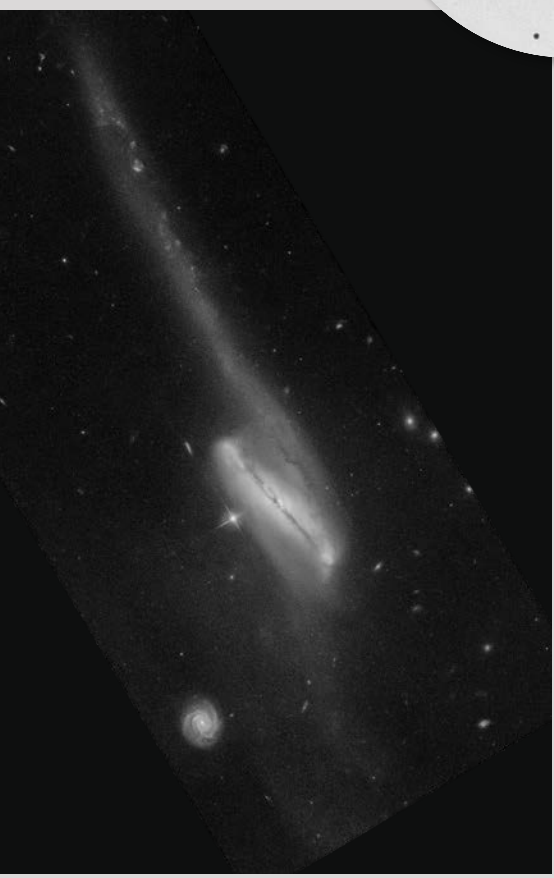
Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

Take the Plunge

Start in eastern Pisces and slew a little more than 4° southeast of Epsilon (ε) Piscium to find **Arp 164** (NGC 455). Arp listed this object in his *Atlas* as an example of a galaxy "with diffuse filaments." Images reveal a highly perturbed galactic structure dominated by an elongated core and girded by intersecting strands of star-forming material. One of these strands is particularly bright, and I saw it in my 20-inch telescope (which I used for all the observations detailed here) from a dark location. The segment lying north of the nucleus is especially pronounced and could be an excellent target for telescopes in the 16-inch class under good conditions. Use high magnification of around 300× to tease out this luminous finger from the glow of the galactic nucleus. Gravitational interactions with other members of the galaxy group Mahtessian 16 might be responsible for NGC 455's disturbed structure. The closest galaxy in the field of view is PGC 4583, which lies a bit more than 3½′ east of NGC 455, but I couldn't detect it in my 20-inch.





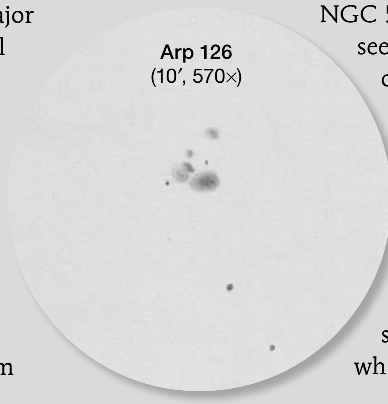


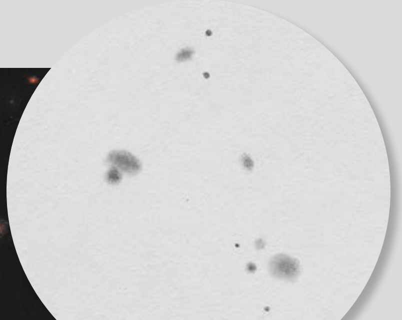
▼**ARP 100** This Hubble Space Telescope image captured the northern of the two tails of IC 18. Its companion, IC 19, is outside the field of view. The spiral at the bottom is a 2MASS object.

Snagging **Arp 121**, a pair of galaxies in Cetus, is a challenge — not surprising given that its original designation is MCG-1-3-51/52. However, should you be able to catch it, you'll see the beautiful details it presents in the eyepiece. Look for the field a little less than 6° north-northwest of Eta (η) Ceti. The more compact galaxy (PGC 3553) appears to distort the larger of the pair (PGC 3547) — the latter's core is at an angle to the major axis, and the equatorial dust lane undulates across the twisted disc. Under excellent conditions, I saw the large galaxy as a sharp edge-on with a distinct core. Warping wasn't noticeable as such, but an enormous flare extends from the southern end. This flaring feature corresponds to the farthest extension of the warped disk. I needed a magnification of 360× to detect this peripheral region, which looks almost separated from the main disk in that view.

Around 3½° southeast of Iota (ι) Ceti, you'll find **Arp 100** (IC 18/19). The northern galaxy (IC 18) consists of a small, elongated core and two very long tails. One of the tails extends in the general direction of nearby IC 19, the component to the south. I could only see the brighter, northern tail, which appeared hanging by a thread but that widened as it extended farther from the galaxy's core. However, this is a trick of how the brain interprets what the eye sees, especially when gauging the dimensions of a fainter feature next to a brighter one. In fact, images show that the tail is fairly uniform as it stretches northeast from IC 18.

At magnitude 12.1, one of the easier objects to bag in Arp's *Atlas* is **Arp 133** (NGC 541). Look for it 6¾° almost due north of Theta (θ) Ceti. It's classified as a transitional object between an elliptical and a lenticular and is also a member of the galaxy cluster Abell 194, which lies at a distance of some 240 million light-years. Arp described NGC 541 as an "elliptical with nearby fragments." In fact, images reveal several small smudges lying on the northeastern outskirts of the galaxy's halo. We now know that two of these are galaxies in the line of sight, but nestled between them is a third one that's physically associated with NGC 541. Astronomers suggest that Minkowski's Object, as it's known, is a region of starbursts triggered by a radio jet emanating from NGC 541. In my scope I could see the brighter of the line-of-sight galaxies immediately east of the core of NGC 541, PGC 86298, and the much fainter Minkowski's Object. The latter appeared similar in size to PGC 86298 but in comparison lacked concentration, while its edges were toler-





Arp 133 and 308
(10′, 570×)

◀ **ARP 133** The elliptical NGC 541 has a curious clustering of galaxies to its upper left, seemingly just beyond its halo. While the outermost two are likely line-of-sight coincidences, the middle of the trio is called Minkowski's Object. It's a young galaxy, and researchers believe that the observed star formation was triggered by a radio jet emanating from NGC 541.

ably well-defined. At magnifications exceeding 500×, a wide gap separates this pair of "dust motes" from NGC 541, and a 17th-magnitude star is situated a bit farther to the northeast.

A Duo of Pairs

Staying in Cetus, just 4.3′ northeast of NGC 541, we come to the close pair of **Arp 308** (NGC 545/547). They're listed in the *Atlas* as an example of a double galaxy. NGC 545, an unbarred lenticular galaxy, appears to cradle NGC 547, a nearly spherical elliptical. At first, I took the "cradling" to be another eye-brain response, but deep survey images show this effect as well. William Herschel discovered the duo in October 1785, and they're easy to see in a modern amateur telescope.

Arp 230 (IC 51) is a near-twin of NGC 545/547: a semicircular form embracing a nebulous knot. In reality, however, this object is a single, isolated galaxy in which we are observing a ring of star formation oriented almost edge-on with the galaxy's nucleus peeking over the rim. Images (such as the one at right) show an extensive halo terminating in a series of segments. This galaxy is located a little more than 4½° north of Beta (β) Ceti and is listed in the *Atlas* as a representative of the group with the peculiarity of "concentric rings." The outer rings remained invisible in my telescope, although at high magnification the central structure is quite robust.

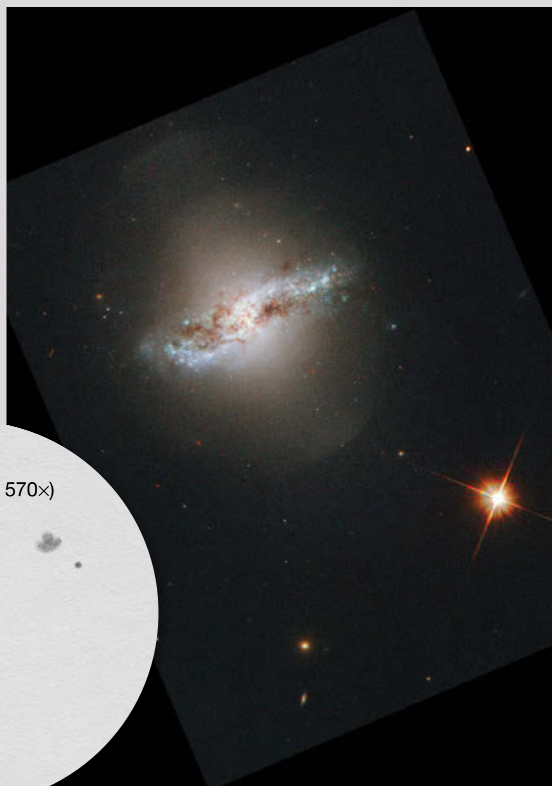
Finishing in the Fish

Returning to Pisces — the easternmost part of the constellation, about halfway between Alpha (α) and Xi (ξ) Piscium — we find the strongly interacting galaxy pair **Arp 126** (UGC 1449). Using my scope at very high magnification from a dark, elevated location reveals a wealth of fine detail, making it a fitting object with which to conclude our survey. The compact western component, PGC 7415, exhibits a broken ring of star-forming regions around its nucleus, but this feature is far too small to be seen visually. The larger, low surface brightness eastern component (Mrk 582) consists of little more than scattered knots of star formation. I could see four of these knots, including what passes for a core, in my scope at 570×, each showing a different brightness and shape. Two field stars (magnitudes 15 and 18) flank the main agglomeration of knots.

Chasing the whole collection of targets listed in the *Atlas of Peculiar Galaxies* is a wonderfully engrossing way to pass time under the stars. You're sure to come across some of the stranger sights in the universe, ranging from odd, little-known features in some of the brighter galaxies to truly elusive targets. Don't let the challenges that mark many of the objects listed in the *Atlas* deter you — dare, instead, to set out with your telescope to explore the realm of peculiar galaxies.

■ **IVAN MALY** is a biologist living in upstate New York. His observations can be found at **www.deepskyblog.net**.

FURTHER MATERIAL For an online version of Arp's *Atlas of Peculiar Galaxies*, go to **https://is.gd/ArpCat**. Finder charts and images for the targets discussed here are at **https://is.gd/ArpCharts**.



Arp 230
(10′, 360× and 570×)

▶ **ARP 230** A long-ago collision with another galaxy likely gave Arp 230 its irregular shape. Its outer ring — the site of ongoing star formation — rotates over the poles of the galaxy.

Flying into ANNULARITY

***Sky & Telescope*'s June solar-eclipse flight was an event worth losing sleep for.**

▲ **BULLSEYE** Eliot Herman of Tucson, Arizona, recorded this sequence of images before, during, and after annularity (left to right, respectively) while aboard the *Sky & Telescope* Annular Eclipse Flight. He used a Nikon D850 camera with a 300-mm lens and a 1.4× teleconverter.

I wasn't going to miss this eclipse. That's why I asked the friendly face at the hotel front desk to wake me at 1:30 a.m. I set my cell phone alarm for good measure and, as backup, the room clock. The plan worked — I was on time to line up at the Minneapolis–St. Paul airport with 31 other eclipse chasers boarding a chartered Delta Airlines Airbus. Our destination: a mid-air alignment with the Sun and Moon over central Canada at sunrise.

We possessed the meteorological equivalent of a "get out of jail free" card — a flight above the clouds to see the June 10th annular solar eclipse. And since we had no plans to land in Canada, our flight wasn't subject to the border restrictions imposed by COVID-19 concerns.

Kelly Beatty, *Sky & Telescope* Senior Editor, took on the task of arranging the flight back in July 2020 during the worst of the pandemic. The night before takeoff, Kelly briefed us on flight details, eclipse circumstances, and to make sure everyone had a safe solar filter. Afterward we had a chance to meet our fellow passengers and share eclipse stories and preparations.

There's a reason eclipse flights are generally half-full — everyone gets a window. During takeoff, we sat in assigned seats to balance the plane. Closer to sunrise passengers moved over to the sunny side to set up their camera equipment.

The plan was to fly northeast towards southern Ontario. Shortly before entering the path of annularity, the flight plan called for a pivot northwest, so all onboard would face northeast in anticipation of the rising Sun. Despite storms over Lake Superior, strong headwinds, and an untimely computer glitch that slightly delayed our progress, we arrived on the viewing track in time for most of sunrise.

▶ **PATH TO ANNULARITY** This map traces the path of the eclipse flight from Minneapolis–St. Paul airport over northwestern Wisconsin, Michigan's Upper Peninsula, and Lake Superior. The plane then turned and headed northwest across southern Ontario. Passengers witnessed mid-eclipse about 87 km east of Lake Nipigon, a large body of water north of Lake Superior.

FLIGHTAWARE.COM

You can simulate an eclipse with software, but it won't prepare you for the power of the real thing. The cabin erupted in whoops and hollers as an eagle's claw of the blazing solar crescent freed itself from a distant tuft of cirrus. Rob Marciano, chief meteorologist for ABC News, and his film crew were on board to document the event. Marciano remarked on the brilliance of the Sun even though it was so close to the horizon. The extremely thin air in the troposphere meant that virtually no water vapor, dust, or smoke from distant fires was high enough to dim the view.

The Moon slowly eased across the Sun until the cusps of the solar crescent merged into a circle of sunlight, a moment visible in real time. We witnessed mid-eclipse from an altitude of 11,900 meters (39,000 feet), about 87 kilometers (54 miles) due east of Lake Nipigon over a landscape blanketed by clouds below. Annularity lasted 4 minutes, 12 seconds — 11 seconds longer than the maximum possible from the ground.

No one ever wants an eclipse to end, but soon the Moon's ceaseless motion carried it eastward, cleaving the ring of sunlight and transforming it back into a crescent again. One of my favorite moments was when I perceived the Moon as a foreground body moving in front of the distant Sun. I wasn't expecting that strong 3D impression, which made it that much more compelling. Eclipses offer soul-sustaining nourishment and astronomical instruction in equal measure.

About 25 minutes after annularity, the plane swung around and headed back to Minneapolis. We cheered, clapped, and toasted our success with champagne.

"It moved me to tears," said Sarah Azizi of Philadelphia, who watched the eclipse as part of her 35th birthday celebration. "It felt like a cosmic communion."

After the toast, veteran "eclipsophile" Craig Small, formerly of New York's Hayden Planetarium, unpacked his embroidered eclipse flag (seen at bottom right), which featured a total eclipse design. He (or a proxy) has carried the flag to 34 total eclipses since 1973. Joined by a pair of merry first-time eclipse-watchers, Small marched the flag up and down the aisle of the plane, much to the delight of the crowd.

Sky & Telescope's next eclipse flight occurs this December 4th, with the flight entering the path of totality east of Tierra del Fuego, off the tip of South America (see **skyandtelescope.org/2021eclipseflight**). My advice is simple: Go!

▲ **LENS STABILIZATION** Fred Walden of San Francisco, California, steadies his camera and telephoto lens with a suction-cup mount affixed to the window.

■ *Sky & Telescope* Contributing Editor **BOB KING** looks forward to his next date with the Moon's shadow.

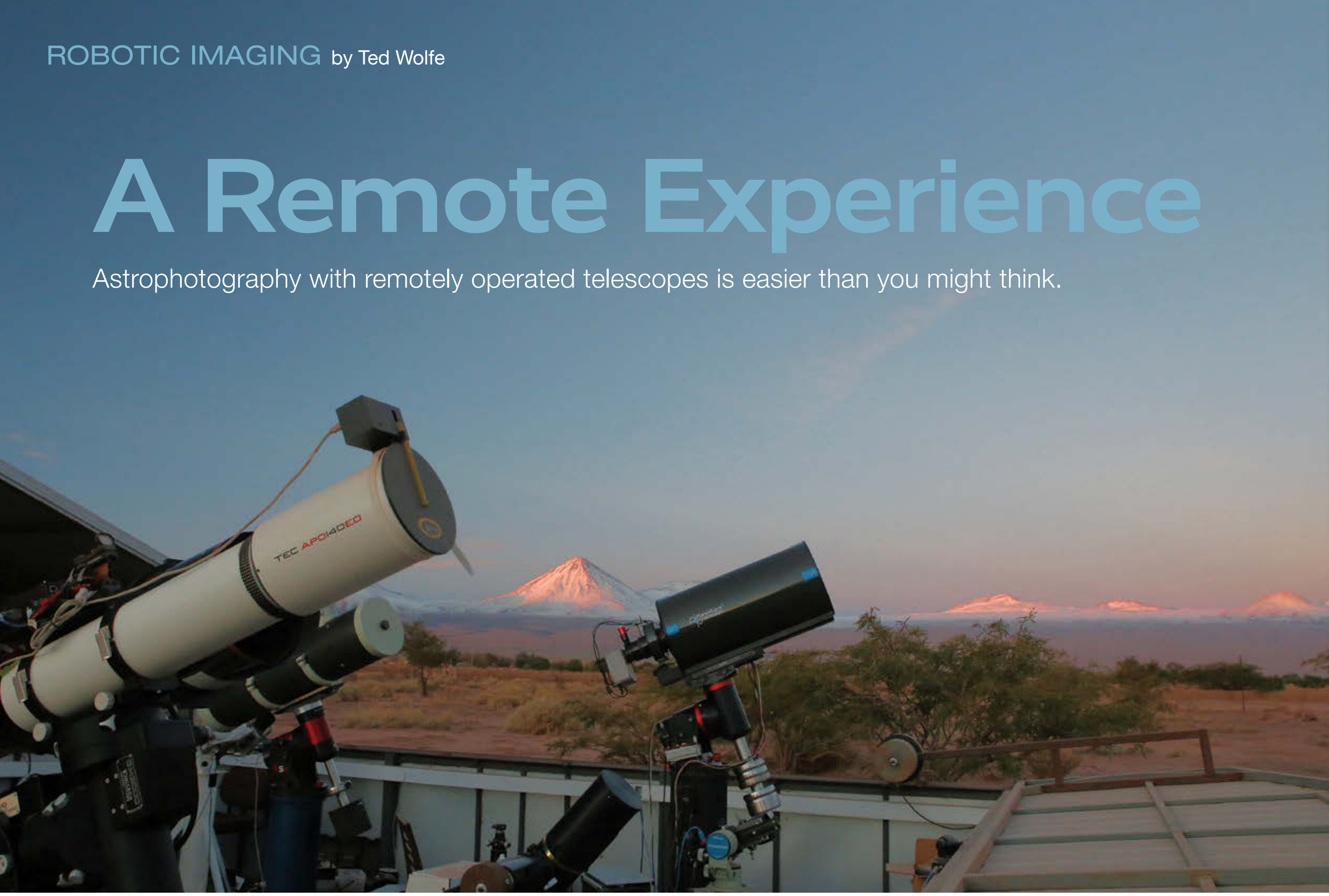
HAPPY ECLIPSOPHILES The eclipse participants, joined by Delta Airlines pilots and flight attendants, celebrate a successful eclipse adventure with a group photo on the tarmac after the flight.

BOB KING (2)

 by Ted Wolfe

A Remote Experience

Astrophotography with remotely operated telescopes is easier than you might think.



▲ **READY TO SHOOT** Several remotely operated telescopes stand ready to capture the splendors of the night sky from the Atacama Desert.

ALAIN MAURY

Deep-sky astrophotography has many challenges, particularly when practiced under less-than-ideal skies. The difficulty of imaging through light pollution and poor seeing limits the targets you can capture to bright objects often recorded at low resolution. Additionally, long spans of cloudy weather can further reduce your output.

Fortunately, astrophotographers no longer have to remain tethered to equipment in the backyard, nor be forced to travel far afield for clear, steady, dark skies. The accessibility of high-speed internet even in remote locations has fostered the growth of remote-imaging facilities, where astrophotographers willing to invest in the support and maintenance of their equipment can capture deep-sky wonders under some of the most pristine skies on Earth. Here are my suggestions for getting great results delivered to your computer each clear night.

Moving Away from the Scope

I began shooting the night sky when I retired to Naples, Florida, and I quickly began to experiment with ways I could remain comfortable indoors while my scope was dutifully recording targets outside. Over the course of several years, and with frequent telescope and camera upgrades, I managed to cobble together a system that could perform remotely, about 50 meters (165 feet) away.

But the humid, often cloudy skies of southern Florida, especially during the warm season, meant I had few opportunities to capture images. Additionally, the steady increase in the population of Naples brought with it the problem of brighter skies due to increased light pollution. Eventually, I wanted more usable and dark nights for imaging fainter targets. That's when I came across a story on remote imaging by Tom Polakis. It immediately inspired me to find a new home for my scope.

Tom's article highlighted the benefits of locating one's scope in the facilities of San Pedro de Atacama Celestial Explorations, or SPACE (**spaceobs.com**), owned and operated by Alain Maury and his wife, Alejandra. SPACE offers a wide range of services to the amateur astronomer of any experience level, including nightly sky tours and observing with a large array of permanently installed telescopes. They also offer onsite and online rental of several imaging setups, as well as host remote-imaging telescopes.

While there were several North American hosting facilities available at the time, the allure of imaging objects completely unavailable from the Northern Hemisphere was too great to resist, so I approached Maury about hosting my equipment. Unfortunately, there were no spots available then, so I bided my time on an informal waiting list. In 2015, a spot opened up, and I began the transition to accomplishing truly remote astrophotography.

More than Just a Telescope

While I had acquired a lot of experience imaging from across my yard, truly remote-controlled astrophotography required several upgrades to my equipment for it to function semi-autonomously from thousands of kilometers away. If you decide to take the plunge, it's likely you'll have to consider new gear, too.

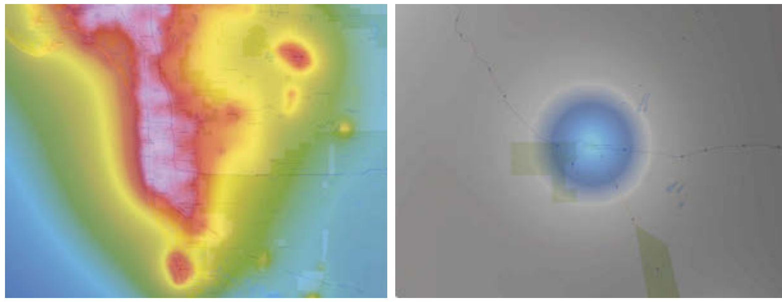
A reliable, heavy-duty telescope mount is without a doubt the number-one priority. Under a frequently clear sky, you're going to use your telescope far more than you ever did at home. As a result, you want to be sure your mount is very well built and can reliably point to your desired targets. Although I had a pretty good mount already (a Takahashi EM400), it didn't include encoders that read out exactly what coordinates the telescope is aiming at. Some mounts don't need encoders to do this, but with or without, the mount needs to include a "home" or "park" position. This is a repeatable starting position that the telescope returns to at the end of an imaging session. A horizontal home position is especially helpful when housing your instrument in a roll-off-roof observatory so that the roof doesn't collide with your telescope when shutting down for the night (or in the event of a weather emergency). Some mounts let you set the home position yourself.

Unless your mount is a fork version that can track across the entire sky unimpeded, or an alt-azimuth model with an integrated field de-rotator, it will need to be able to perform a *meridian flip*. This action is required when tracking objects as they cross the *meridian* — the imaginary line that divides the eastern and western halves of the sky. Your mount needs to rotate its payload to avoid crashing into the telescope pier or tripod while continuing to track your target.

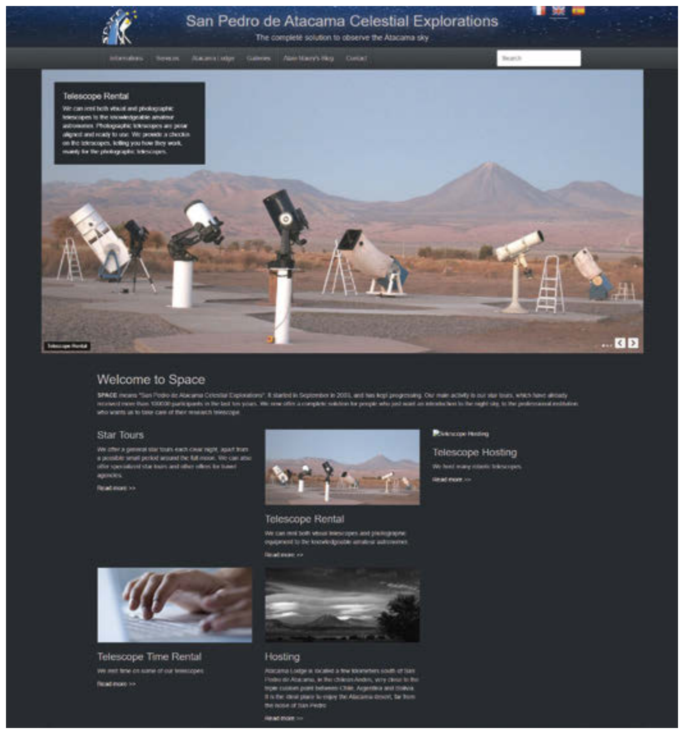
I upgraded my mount to an AstroSysteme Austria (ASA) DDM-85 direct-drive mount with high-resolution encoders, guaranteeing my control software always knows where my telescope is pointing with arcsecond accuracy. Other great alternatives are available from Astro-Physics (**astro-physics.com**), PlaneWave Instruments (**planewave.com**), Software Bisque (**bisque.com**), 10Micron (**10micron.eu**), and several others.

The next requirement is an optical tube assembly that needs minimal maintenance. That could mean a reflector or catadioptric that holds its collimation well and is easy to collimate in the field, or, even better, a refractor. While remote-imaging facilities typically employ site operators who can help you with equipment problems and minor maintenance tasks, they are responsible for a good number of telescopes and may not have the time to perform frequent or complex collimation adjustments. Keeping it simple will limit the problems that'll prevent you from taking advantage of clear nights. I currently use a PlaneWave CDK12.5 (12½-inch) corrected Dall-Kirkham optical tube as my primary imaging instrument. It holds its collimation reliably and rarely requires adjustments.

Another must-have piece in the remote-imaging puzzle is a computer-controlled, electronic focuser. If your scope doesn't have one, several manufacturers offer add-on units, including MoonLite Telescope Accessories (**focuser.com**), Starlight Instruments (**starlightinstruments.com**), and Optec (**optecinc.com**). I use an Optec Gemini Rotating focuser, which, in addition to permitting me to focus the camera quickly, can also rotate the camera to achieve the desired orientation of my SBIG STL-11000M CCD camera.



▲ **DARKER SKIES** The author relocated his telescope from the light pollution of Naples, Florida *(left)* to the extremely dark skies of San Pedro de Atacama *(right)*. The colors indicate the intensity of light pollution at both locations.



▲ **TELESCOPES** The San Pedro de Atacama Celestial Explorations (SPACE) facility offers nightly sky tours, onsite and remote telescope rental, and hosting services for your own imaging rig.

LIGHT POLLUTION: LIGHTPOLLUTIONMAP.INFO; SPACE WEBSITE: SPACEOBS.COM

The telescope, camera, and mount are the main pieces of a remote-imaging setup, but there are additional components that also need consideration. For example, while some telescope mounts (like the ASA DDM-85) are accurate enough to produce well-tracked, unguided, long exposures, I found that I get my best results with the assistance of an autoguiding setup. You can choose between an external guidescope or off-axis unit for this. I've tried both with my PlaneWave/ASA mount combination and get consistently good results with an off-axis guiding (OAG) system. While an OAG unit that can be rotated independently from the main imaging camera will allow you many more choices when it comes to choosing guide stars, in practice I haven't had any problems finding suitable guide stars without this option.

◀ **ROBOTIC SCOPE** The author visiting his telescope in mid-2019. It consisted at the time of a 12.5-inch PlaneWave CDK telescope, an SBIG STL11000M CCD camera with LRGB and Hα filters, and a guidescope with a ZWO guide camera. The instrument is mounted on an ASA DDM-85 direct drive German equatorial mount and controlled over the internet using the software *AnyDesk* and *Prism*.

Computing Considerations

Another remote-imaging necessity is a robust computer loaded with the required camera- and telescope-control software. Since the computer will reside onsite, there are two options depending on whether you'll be remotely connecting to the computer and reducing (calibrating, stacking, etc.) your images, or if you'll just be downloading your data through a file transfer service. If the former, then the computer needs to have a fairly powerful processor and lots of RAM, so that it performs like your home processing station. However, if you decide to choose the latter option, you can get by with a computer just powerful enough to run your control software.

No matter which direction you take with the control computer, it will need to have a large hard drive to store your data each night. Plan on investing in a 2-terabyte hard drive at the minimum — frequent clear skies mean you'll be accumulating a lot of images compared to what you're used to.

As for the telescope/camera control software, choose a program (or suite of programs) that permits you to plan and execute at least one full night of imaging and be able to control everything. After shopping around, I decided on *Prism* (**hyperion-astronomy.com**) as my one-stop control center. The professional version of the software is fairly inexpensive

▼ **OPEN SKIES** Conditions at the SPACE facility in the Atacama Desert are so dry that telescopes are typically stored outdoors and only covered in the rare threat of rain. Several domes and the large roll-off-roof observatory housing remote-imaging telescopes (where the author's telescope is located) are visible in the background.

AUTHOR AND SCOPE: ALAIN MAURY; SPACE ONSITE: SEAN WALKER / *S&T*

($349) and includes everything I need to point the telescope, focus the camera, calibrate the autoguider, and execute multiple imaging sessions from power up to shutdown. The software also has an automatic flat-fielding routine to record crucial calibration frames in the early evening or at dawn. It even includes a built-in planetarium to help me choose and point at targets. Once the data is acquired, I use *Prism* as a full-featured astro-image processing suite to calibrate all my images before I download them from the control computer.

Other remote-imaging hardware-control programs include *ACP* (**acpx.dc3.com**), *MaxIm DL Pro Suite* (**diffractionlimited.com**), *Sequence Generator Pro* (**sequencegeneratorpro.com**), *TheSkyX Imaging Edition* (**bisque.com**), and *Voyager* (**software.starkeeper.it**). In some cases, you may need two of these programs operating simultaneously.

Finally, you'll need some way to connect with your control computer, whether it's to simply download your images or, as in my case, to fire everything up for an evening of astrophotography. I subscribe to *AnyDesk* Remote Desktop Software (**anydesk.com**), which I use for this task, just as if I was there onsite. *TeamViewer* (**teamviewer.com**) is another, similar option. Some imagers instead prefer having their images

▲ **BARRED SPIRAL GALAXY** NGC 1365 in Fornax culminates at about 76° as seen from San Pedro de Atacama, making it an ideal target for the author's remote telescope. This image consists of almost 9 hours of exposure shot through LRGB filters.

▼ **SINUOUS OPACITY** Dark molecular clouds of the Aquila Rift fill the field in this deep image recorded with the PlaneWave telescope operating at f/5 using a focal reducer. Total exposure was 12 hours through LRGB filters.

TED WOLFE (2)

▲ **GALACTIC PRAWN** Located in southern Scorpius, IC 4628 passes directly overhead from Chile. It stands out well in this 6-hour exposure made with the telescope operating at f/5.

◀ **SILVER COIN** NGC 253, in Sculptor, is a nearby galaxy best seen from the Southern Hemisphere. Total exposure is 9 hours through LRGB filters.

TED WOLFE (2)

delivered directly to a subscription-based file transfer service like *Dropbox* (**dropbox.com**).

Once you've gathered all the required pieces, be sure to test it all together at home before shipping the equipment to your remote hosting facility. That way, you can identify and address any weak links in your system. Test your cable management to ensure nothing can get yanked out during a meridian flip, and that all adapters hold tight with your equipment pointed at any angle. When you're ready to ship it to its final destination, keep in mind that if you choose a hosting facility in a foreign country, you'll be charged import duties and fees. These can be as high as 40% of the cost of the equipment shipped.

Putting It All to Use

After everything arrives onsite and is set up, you'll need to work out any bugs that may have cropped up. It's a good idea to keep an operational journal to record any problems and their solutions to avoid having to re-learn how to solve the issue a year or two later. Sometimes an adapter loosens up or a cable becomes faulty. Fortunately, the hosting facility has at least one technician onsite who can help fix these problems as they crop up during the night.

Once everything is operating smoothly, imaging with a remote setup is a dream come true. The Atacama Desert, where San Pedro de Atacama is located, is one of the driest places on Earth. One client of SPACE who concentrates on variable star research recorded usable data on 345 nights in a single year.

Here's what a typical evening with my remote telescope looks like. I begin by booting up my home computer to check the local weather forecast for the site. If it's clear, I log on to my control computer using *AnyDesk*. An internet protocol camera provided by SPACE monitors the interior of each observatory and displays constantly updated still pictures showing the roof open and my scope in its park position. If all is as planned, I start up the mount and camera in *Prism* and begin cooling the camera. Next, I open the Automatic Observation form in *Prism* and enter my imaging script for the night. This is where I input my target, when to start the sequence, what filters to use, and how often to perform the autofocus command. I also adjust the autoguider parameters (if necessary) and designate a location to store the resulting files. I then do a short "Homefind" operation with the mount to ensure it's pointing accurately.

The entire startup process takes about 15 minutes. Once it's completed, I hit Go and watch as the telescope slews to my chosen target, acquires a guide star, and begins operations. I can then log out of *AnyDesk*, close my computer, and go on with the rest of my evening.

The next morning, I reconnect to the control system and confirm that the scope is parked and the camera's cooling system is turned off. If all is well, I activate *Prism*'s automatic data-reduction routine, which calibrates all the night's images with a single click. Once the reduced images have been downloaded onto my home computer, I power down the mount and camera, and log off *AnyDesk*. I then stack and process the results using *MaxIm DL, RegiStar,* and *Adobe Photoshop*.

Remote imaging can expand your astrophotography output by leaps and bounds. Although the initial costs for the necessary equipment and software can be substantial depending on the gear you choose, for me the investment was worth it. I get far more use out of my equipment than I could here at home.

■ **TED WOLFE** controls his imaging system in Chile from the comfort of his home in Naples, Florida. Visit **tedwolfe.com** to see more of his astrophotography.

Goodbye to All That

THE END OF EVERYTHING (ASTROPHYSICALLY SPEAKING)

Katie Mack
Scribner, 2020
240 pages, ISBN 9781982103545
$26, hardcover

IF THE UNIVERSE IS GOING TO END, you may as well have fun before it all goes down the tubes. Or gets sucked into a vacuum, burned up by a Heat Death, or pulled back from expansion to contraction like a macrocosm-size rubber band. The good news, according to Katie Mack, is that we probably have billions of years before any one of those doomsday scenarios comes to pass.

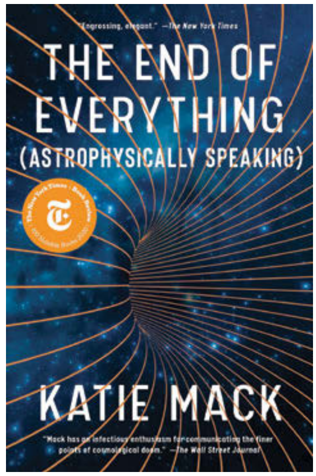
Well, maybe. It's astrophysics, so it's complicated.

The End of Everything (Astrophysically Speaking), Mack's sparkling popular-science-book debut, delivers on its promise to explain the tremendously difficult subject of cosmology to an audience that probably would rather not do all the math. Mack, an assistant professor of physics at North Carolina State University, deftly employs clever humor and first-rate explanatory science journalism to bring some of the most abstract astrophysics concepts to life.

> It's cheery Bill Bryson hanging with your scowling, pessimistic great-aunt who's convinced it's all going downhill.

It's all here: What differentiates special from general relativity. What the term "spacetime" really means. Why quantum mechanics breaks the Standard Model of particle physics. The implications of dark matter and dark energy for the eventual destruction of the universe, and the five leading theories of how that destruction is likely to happen. You may have to put the book down while your head stops spinning. As Mack puts it, "This is not easy to picture. Infinities are complicated that way."

One reason Mack and her fellow theoreticians can delve into the lifetime of the cosmos is that the Big Bang left fingerprints. The discovery of the cosmic microwave background suggested that the universe emerged from a moment of almost unimaginable heat and density before the traditional rules of physics could apply (*S&T:* July 2015, p. 28). Only in recent decades have we begun to build the instruments and the knowledge to fathom what will happen to the universe to which the Big Bang gave birth.



The bigger our telescopes get, the further back we can look, perhaps even to sense clues to our universe's eventual fate. And with theoretical physicists involved, it all gets a little nuts, because physics at an unimaginably large scale doesn't exactly obey a set of rules that we fully comprehend yet.

Mack is equal parts irreverent and informed, sly and yet sure of one thing: All that we are and all that we have ever been will someday be no more. It's cheery Bill Bryson hanging with your scowling, pessimistic great-aunt who's convinced it's all going downhill — with a gaggle of Nobel Prize winners making the occasional cameo.

This is a book for everyone fascinated by the questions that arise when we look at the sky and consider our place in the universe. If it's all going to end — if all life and other matter will someday be sucked into a true vacuum or vanish as the universe expands so much as to become a cold, dark cave of nothingness — what does that mean for the few decades most of us will have on this tiny rock orbiting an average star in a nondescript part of the Milky Way? Mack makes space for the most eschatological of conversations. She gives her readers room to consider what a life well lived truly means, how we make sense of what we can see, and what we do not yet grasp when we contemplate the vastness before us.

Mack's book has an even broader mandate. Our most recent history as a species teaches us the extreme importance of ordinary people understanding the foundations of scientific research. It bears noting that this book was partially funded with a grant from the Alfred P. Sloan Foundation's Public Understanding of Science program.

Altogether, *The End of Everything* presents astrophysics with an attitude, but the crackup one-liners and pop-culture references Mack employs to get her point across are really just window dressing. Fundamentally, this is a deeply researched gem of a book, a joy to read even when you know the end is nigh (or might be, anyway). And the fact that there's only a slim chance the universe could terminate without warning at any moment gives us a bit of comfort that we'll at least make it to the book's end.

■ Journalist **NICOLE NAZZARO** wrote a review of *The Last Stargazers* in the April 2021 issue.

Meade Series 5000 UHD Eyepieces

Do these eyepieces hit the sweet spot between performance and affordability?

◀ The Meade Series 5000 UHD eyepieces are very well made both optically and mechanically. The author used a variety of telescopes to test this set that fits 1¼-inch focusers and includes focal lengths of 24, 18, 15, and 10 mm (left to right).

ALL PHOTOS BY THE AUTHOR

Meade Series 5000 UHD Eyepieces

U.S. Price from: $120

Meade.com

What We Like

Excellent optical and mechanical construction

Nice star images across the entire field of view

Extremely low distortion

What We Don't Like

Bottom of 24-mm eyepiece can interfere with thumbscrew lock on some 1¼-inch focusers and star diagonals

THE AVAILABILITY OF MODERATELY priced, quality eyepieces in the marketplace continues to grow with the new Meade Instruments Series 5000 UHD eyepieces. Currently the line includes four models that fit 1¼-inch focusers and have focal lengths of 10 mm (priced at $120), 15 and 18 mm ($140 each), and 24 mm ($200). There's also a 30-mm model ($245) that's made for 2-inch focusers. The latter eyepiece wasn't available at the time we borrowed the other four for testing.

The UHD series features "flat-field" performance, which is a somewhat vague description for eyepieces, but most of us will translate that as an eyepiece showing quality star images across its entire field of view. And the UHDs do indeed deliver well on that front. But there's more to this flat-field performance that I'll get to in a bit.

The 10-mm model is listed as having a 60° apparent field, while others have 65° fields. Personal preferences vary, and while I certainly enjoy today's extraordinary wide-field eyepieces for some types of observing, I find apparent fields of around 65° extremely pleasant for general observing. The field is wide enough to avoid feeling restrictive but still shows a defined edge that you don't have to roll your eye around to see. I always know where I'm looking in the field and where the central sweet spot is.

On the test bench I measured the 10-mm as having an apparent field of 58°. The 15-mm has an exact 65° field, while the 18-mm was about 1° smaller. The 24-mm, on the other hand, has an apparent field of just 61°. Nevertheless, when I was at the telescope and switching rapidly between the 15- and 24-mm eyepieces, I perceived no appreciable difference in the diameters of their apparent fields. What's far more noteworthy, however, is the true field of view (the amount of sky actually seen) with the 24-mm eyepiece. It is virtually the same as that visible in my Tele Vue 24-mm Panoptic and 32-mm Plössl eyepieces — two eyepieces often highlighted for showing the maximum possible amount of sky visible with an eyepiece having a 1¼-inch barrel. (For further information on the apparent and true fields of eyepieces, see the article "Some Thoughts About Today's Eyepieces" on page 64 of the May 2021 issue.)

Those who observe without wearing eyeglasses should find the eye relief of these eyepieces more than adequate since it's 16 mm for the 10- and 15-mm eyepieces and 20 mm for the 18-mm model. And with 29 mm of eye relief, the 24-mm eyepiece should easily accommodate eyeglass wearers.

The UHD eyepieces are made with first-class construction that's right up there with the best I've seen. The precision-machined aluminum bodies are black anodized and have cranberry-red anodizing on the aluminum accent rings. Even the wide, textured rubber grip is a substantial 2½-mm-thick collar that will clearly stand up to years of use. The pliable rubber eye guard is also substantial but easily folds down when needed. Internally, the metal retaining rings for the lenses are precision machined and carefully blackened. The multi-coated lenses are blackened on their edges to reduce scattered light. And the eyepieces are said to be waterproof, which will certainly help prevent dust from getting onto internal lens surfaces even if you have no intention of dunking your eyepieces in water.

The only downside to the mechanical design I noted is that the wide base of the 24-mm eyepiece can interfere with the locking thumbscrew on some 1¼-inch focusers (see the images below). Since the maximum diameter of an eyepiece body defines the minimum interpupillary distance for a pair of eyepieces used in a binoviewer, only the 24-mm model (with a maximum body diameter of 66 mm) will possibly exceed the interpupillary spacing required by some adults (typically 55 to 74 mm).

During the first half of 2021, the four UHD eyepieces were my go-to set for general observing. I used them most of the time with a 6-inch f/10 refractor, but I also tested them on a Tele Vue-NP101 (4-inch f/5.4) refractor, an Orion 6-inch f/6 Maksutov-Newtonian, a Meade 12-inch f/5 Dobsonian, and a Celestron 5-inch f/10 Schmidt-Cassegrain.

As mentioned above, the eyepieces delivered nice, round star images across the entire field of view. The very flat focal plane of the 4-inch refractor provided a critical test of the eyepieces' performance and showed that there is a small shift in the focus point between the center and edge of the field. Stars sharply focused at the center of the field appeared a touch soft when moved to the edge. The only time it was obvious was when I was specifically looking

▲ The UHD eyepieces are all threaded to accept standard eyepiece filters.

for a difference. Furthermore, off-axis distortions due to aberrations inherent in the optics of many telescopes (and especially in the Dobsonian and SCT) degraded star images at the edge of the field much more than the slight focus shift of the eyepieces themselves.

Lateral color (the eyepiece aberration that turns stars into tiny colorful spectra at the edge of the field) is very well controlled in the UHD eyepieces. Only the 10-mm model showed a hint of color fringing due to lateral color as I swept brilliant Venus across the field of view in a daytime sky.

The four UHD models I tested are said to be parfocal and thus needing "little-to-no focus change when switching between eyepieces." The 15- and 18-mm eyepieces did have exactly the same focus point, while the 24-mm needed to have the focuser racked in about 2 mm, and the 10-mm needed to be racked out about 1½ mm. This is well within the limits of other eyepiece lines I've used that are marketed as parfocal.

Earlier I mentioned there was more to the flat-field aspect of the UHD eyepieces than just having a flat field with sharp star images. These eyepieces are notable for having no discernible distortion as objects are swept across the field of view. Planets remain round, and the shape of the lunar landscape is unchanged as you move it around the field. Other eyepieces I've used that have similar apparent fields as the UHDs display a significant amount of pincushion distortion. And while I'm not as troubled by this type of distortion as some observers, it's still nice not to be even aware of it when observing with the UHDs.

The Meade Series 5000 UHD eyepieces are very good. They provided sharp, contrasty views of the Sun (properly filtered), Moon, Venus (in the daytime), double stars, and deep-sky objects with a variety of telescopes. I can certainly recommend them for novice and experienced observers alike.

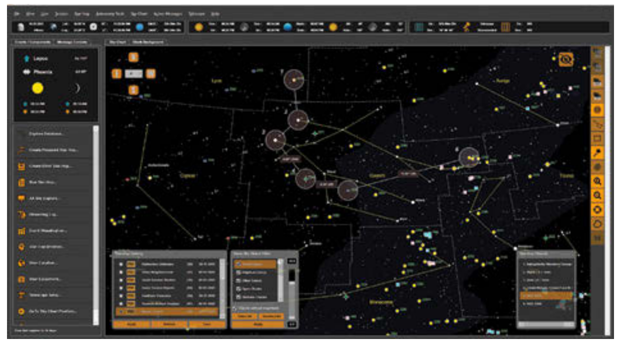
■ **DENNIS DI CICCO** was surprised by how few times he found himself reaching for some other eyepiece during the months he was observing with the four UHD eyepieces.

▲ The wide base of the 24-mm eyepiece can interfere with the locking thumbscrew on some 1¼-inch focusers and star diagonals. While awkward to reach, the thumbscrew on this Meade star diagonal (left) just clears the eyepiece base and allows the eyepiece to sit squarely in its holder. That's not the case for another diagonal (center) with a larger thumbscrew. The eyepiece base will not, however, interfere with the locking thumbscrews on most 2-to-1¼-inch adapters (right).

▲ WI-FI CONTROLLER

ZW Optical announces the latest version of its smart Wi-Fi controller for astrophotographers. The ASIAIR Plus ($279) lets you power and control your camera, focuser, autoguider, and Go To mount using your Android or iOS smart device. The ASIAIR Plus is a mini-computer with a 1.5 GHz CPU, 4GB of DDR4 memory, and 84GB of internal storage. Smaller and lighter than its predecessors, it's housed in a CNC-machined casing that attaches directly to your telescope or mount. It includes four female 5.5 × 2.1-mm, 12-volt DC outputs, two each of USB 2.0 and 3.0 ports, and a 2.5-mm DSLR shutter release port to control your Canon, Nikon, and ZWO imaging equipment. The unit connects to your smart device via a Wi-Fi antenna — with greater range and reliability than previous versions offered — and is controlled using the free *ASIAIR* app. It saves images to its internal memory or to a user-provided TF card, which you can later offload to your processing computer via a USB-C connection.

ZW Optical
astronomy-imaging-camera.com



▲ STAR-HOP MAKER

A new software program promises to make planning your observing sessions easier. *Star-Hop Maker* (€21, or about US$25) lets you create your own custom star-hopping maps that make hunting down your targets an easy and fun experience. This Windows-compatible program allows you generate star-hop routes for specific targets with just a few clicks. Simply choose your target and the program will determine the best star-hopping path from the brightest nearby object to your observing destination. Users can query the program's database to find new targets or create object-specific observing plans — for example, observing only barred spiral galaxies in Ursa Major. You can add or remove Hopping fields to create a continuous tour from one object to the next. To use your star-hop at the telescope, you can print it out or upload it to Google Drive and access it via the free Android *Star-Hop Maker Companion* app.

Star-Hop Maker
starhopmaker.com

◀ WIDE ADAPTER

Tele Vue Optics now offers a special wide T-mount adapter for Nikon cameras. The Nikon F-Mount Wide T Adapter with Bayonet (#NWT-2073, $57) is designed to take full advantage of the aperture potential in Nikon's bayonet-style camera adapter to minimize vignetting with Tele Vue imaging systems. The bayonet connects any Nikon camera to Tele Vue imaging systems that utilize its proprietary 2.4-inch-format accessories, and it provides 13% greater aperture than standard T-mount adapters. Nikon's Z-series mirrorless cameras require an additional F-to-Z adapter to achieve proper spacing.

Tele Vue Optics
32 Elkay Dr., Chester, NY 10918
845-469-4551; televue.com

NEW
CEM70N, CEM40N, GEM45N
NUC computer ready mounts
(Next Unit of Computing)
iOptron NUC series mounts mate seamlessly with Intel™ NUC mini computers* (model thickness of 38mm). NUC mounts feature a bracket positioned at the lower front area of the saddle to securely hold the minicomputer in place. They also include a USB connection to the mount near the NUC and a LAN pass though to the rear of the mount to connect the NUC to a standard computer or network. EC version mounts ready for NUC mini computers are available, see iOptron website for details.
CEM40N
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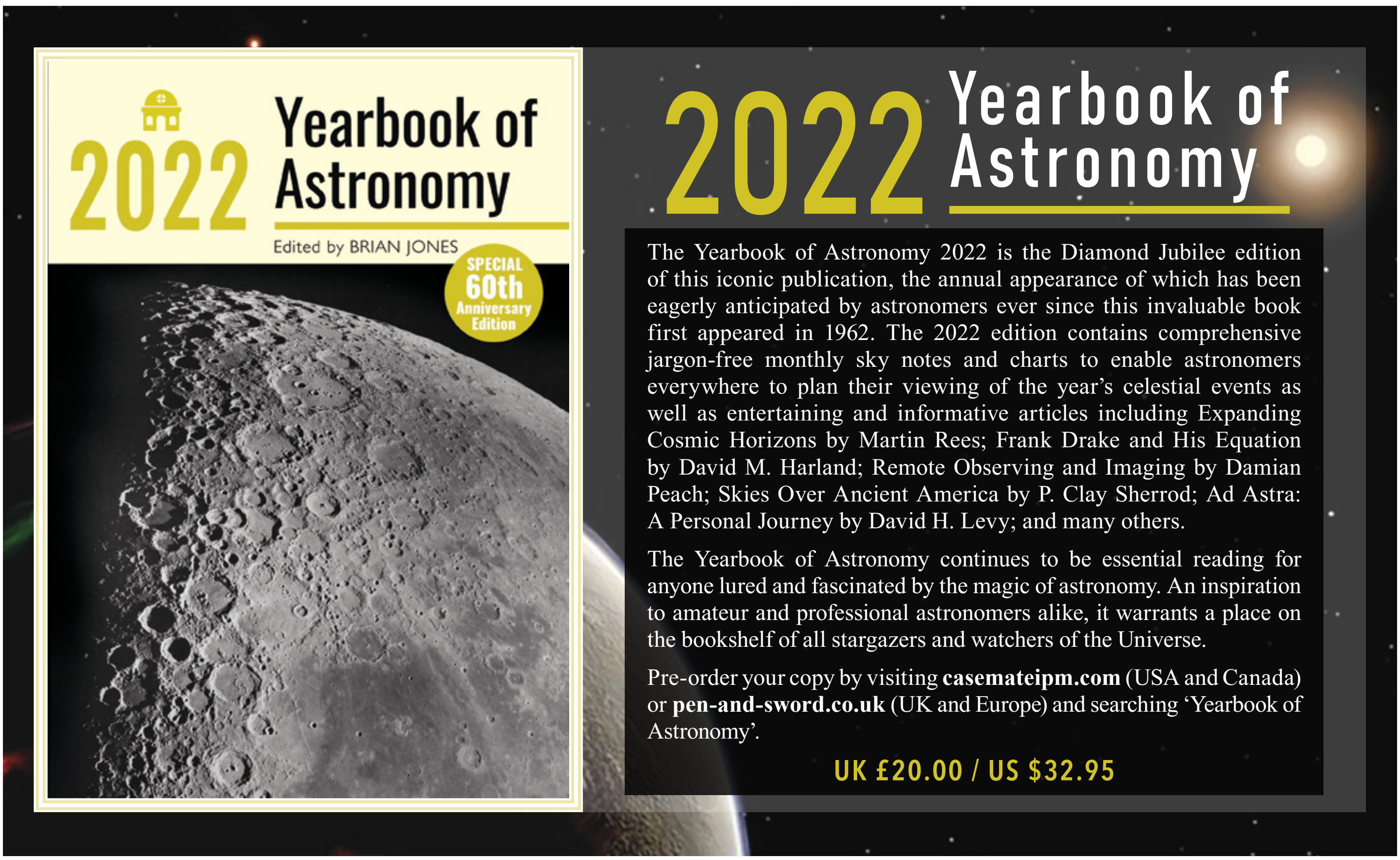

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A Mobile Scope Shelter

Stay set up and ready to observe for days at a time.

▲ Frank Siemsen's telescope shelter protects his 20″ Dobsonian from the elements and from his horse during the day.

OREGON AMATEUR ASTRONOMER Frank Siemsen has a beautiful place to set up a telescope. There's just one problem: The pasture is zoned for farm use only, which precludes building a permanent observatory there.

Like most of us who don't have a permanent structure, Frank would assemble his scope each evening and tear it down when he was done for the night, but that got old, especially during strings of clear nights when he would have to repeat the process over and over. He could have left the scope assembled and protected it with a Mylar shroud, but he also shares the pasture with his horse, Spirit, who would undoubtedly love the opportunity to rub up against it. Also, being in a wide-open agricultural area, there's a lot of dust and wind that can blow a telescope right over. Frank needed something sturdier, but not permanent.

The solution: a rigid but mobile telescope shelter. Frank built it in two parts — one to cover the bottom end of the scope and one to contain the upper end. He tilts the scope horizontally and rolls the two shelter halves together on wheels, then bolts the shelter together at the corners to make a single, sturdy unit.

To keep it light enough to move easily, Frank used 1″ × 3″ pine for the framework over the scope's upper end and covered only one side and the top with ¼″ plywood for stiffness. He covered the other side and bottom with marine vinyl, which is lighter and also withstands sunlight well.

The back end uses 2″ × 4″ pine for the framework and ¼″ plywood for the sides and top. The bottom is left open because the scope remains on its base on the ground when covered.

Frank's scope is a 20″ f/5 Dobsonian, so the shelter measures 9.5 feet long (4′ for the rear section and 5½′ for the front). The rear section is 4′ tall and 44″ wide, while the front section is 28″ high by 3′ wide. Since the two sections differ in shape, the front section has a flat flange around it to mate with the rear section, and the front section rests on legs that keep it horizontal.

The shelter provides room for the scope even when Frank puts it on an equatorial platform. Other times it holds his 8″ Dobsonian with room for an echo.

While the open bottom on the rear section could provide access for voles and other small creatures, Frank reports no problems with them so far. He

▼ *Left:* To cut down on weight, one side and the bottom of the shelter's front section are made of marine vinyl. *Right:* Quarter-inch plywood provides stiffness to withstand the weight of snow.

FRANK SIEMSEN (3)

suspects the neighbor's many barn cats help keep the area vermin-free.

Frank made one concession to permanence: He dug a hole and placed a wooden platform in it to support the scope so it wouldn't sink into the soft ground. The solid stand also helps keep vibration to a minimum.

When opened up for observing, the tops of the shelter sections make great work surfaces. Frank puts his binoculars, red light, charts, reading glasses, eyepieces, filters, etc. on top for easy access, and has lots of room to fully open out his copy of *Sky Atlas 2000*.

It's still a bit of a journey from Frank's house to the pasture, but now he only has to carry the scope out there once per dark phase. At the end of the night, he can close it up and go to bed, content in the knowledge that it'll be safe through the day and ready to go again the following night.

Frank is very happy with his scope shelter. "I wanted to avoid having to set up the big Dob all the time," he says. "It is so nice to not have to set it up and tear it down as often."

If you're in a similar situation, with a good area to leave your scope assembled and ready to observe but without a permanent observatory, Frank's scope shelter looks like a pretty neat solution to the problem.

For more information contact Frank at **siemsen@teleport.com**.

■ Contributing Editor **JERRY OLTION** still packs his scope in his car and drives an hour to his observing site.

▼ The shelter is designed for Frank's 20″ Dobsonian, but it works well for his 8″ scope, too.

FRANK SIEMSEN

SUMMER MOON

Arman Mohammadi

The first full Moon of summer in the Northern Hemisphere glows a brilliant orange color over the plains and mountains of Markazi Province, Iran. **DETAILS:** *Canon EOS Ra mirrorless camera with Canon EF 100-to-400-mm IS II USM zoom lens at 400 mm. Total exposure: 1/160 second at ISO 2500.*

◁ IRIDESCENT CLOUD

Melissa Lee

Like their namesake, rainbow clouds occur when the water droplets or ice crystals inside scatter sunlight. They are often seen within 40° of the Sun.

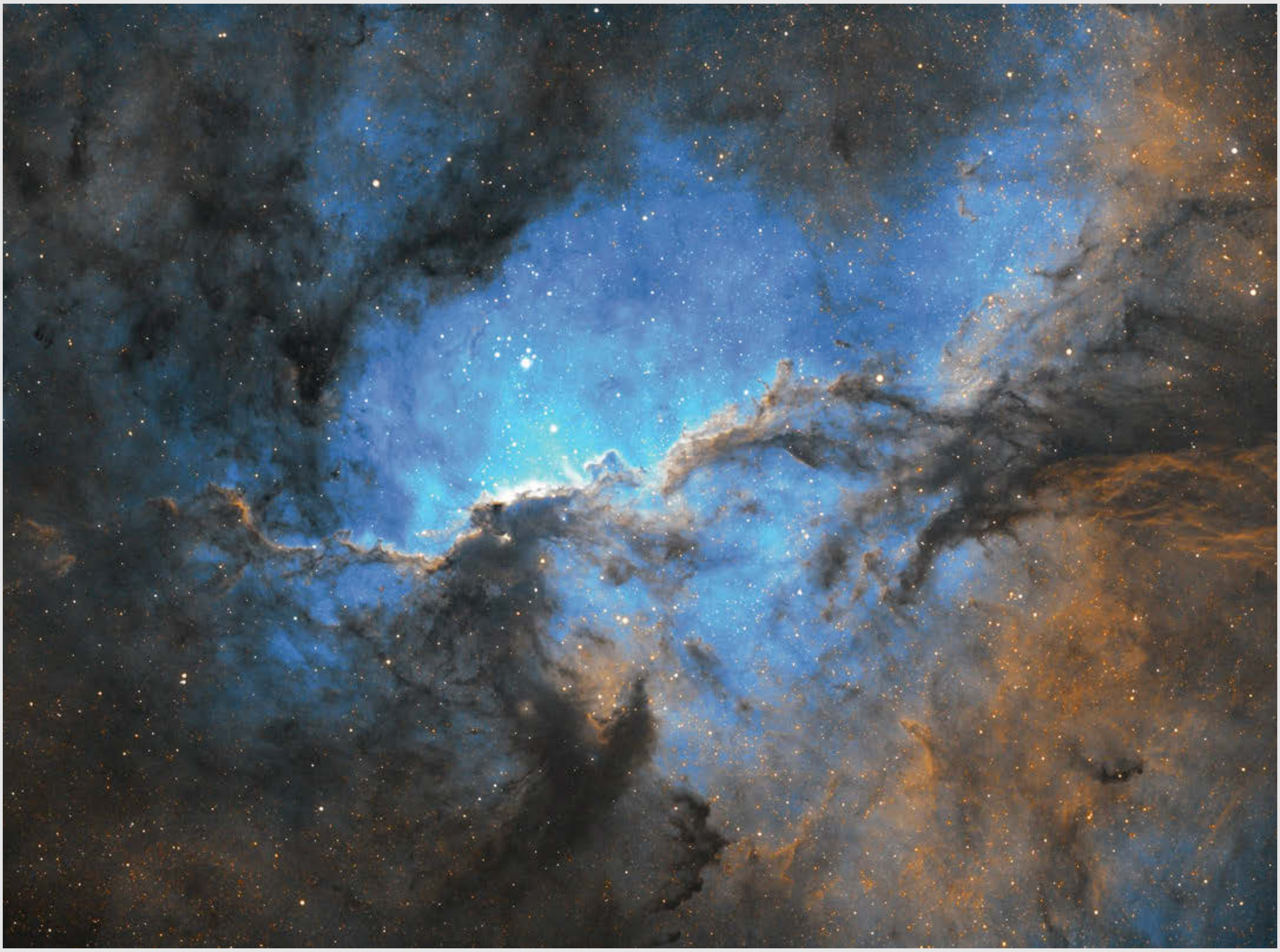
DETAILS: *Motorola Droid Turbo smartphone. Total exposure: 1/6400 second at f/2, ISO 64.*

▽ A DRACONIC BATTLE IN ARA

Mary Toki

The dark tendrils that bisect NGC 6188 lead many observers to dub this emission nebula the Fighting Dragons of Ara. Radiation from the young open cluster NGC 6193 (left of center) illuminates the epic battle.

DETAILS: *Sky-Watcher Esprit 100-mm ED Triplet APO refractor with ZWO ASI294MM Pro camera. Total exposure: 9 hours through narrowband filters.*



◁ NEEDLE GALAXY

Dave Doctor

Edge-on spiral galaxy NGC 4565 in Coma Berenices displays slightly warped outer spiral arms caused by interactions with another massive galaxy in the past. North is at left.

DETAILS: *Officina Stellare RiDK 400 Riccardi Dall-Kirkham telescope with SBIG STX-16803 CCD camera. Total exposure: 23 hours through LRGB filters.*

▽ WISHING WELL CLUSTER

Fernando Oliveira de Menezes

The bright open cluster NGC 3532 lies some 1,300 light-years away in the constellation Carina. It gets its nickname from its resemblance to scattered coins dropped into a well. North is at right.

DETAILS: *Sky-Watcher Esprit 150 ED Triplet APO refractor with ZWO ASI6200MC Pro CMOS camera. Total exposure: 2 hours and 55 minutes.*

THE SNAKE NEBULA
Gerald Rhemann
Several dense clouds of dark gas and dust blot the area around the star 44 Ophiuchi at the bottom right, including the Snake Nebula (left) and Barnard 68 at the top.
DETAILS: *ASA 12-inch f/3.6 Newtonian astrograph with FLI ML16200 CCD camera. Total exposure: 3 hours through LRGB filters.*

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A Night of Extremes

Breaking down in tears isn't a typical occurrence while stargazing, but this night 20 years ago called for it.

BACKYARD ASTRONOMY AFFORDS us many fascinating, beautiful, and sometimes surprising experiences. One evening in 2000, for example, I was treated to the most remarkable auroral display, an event rarely seen from my location 50 kilometers (30 miles) northwest of New York City. Another time I was scared out of my seat when a nearby tree came crashing down with a thundering boom, simply due to old age.

The evening of September 11, 2001, held its own unexpected experiences, though of a wholly different character.

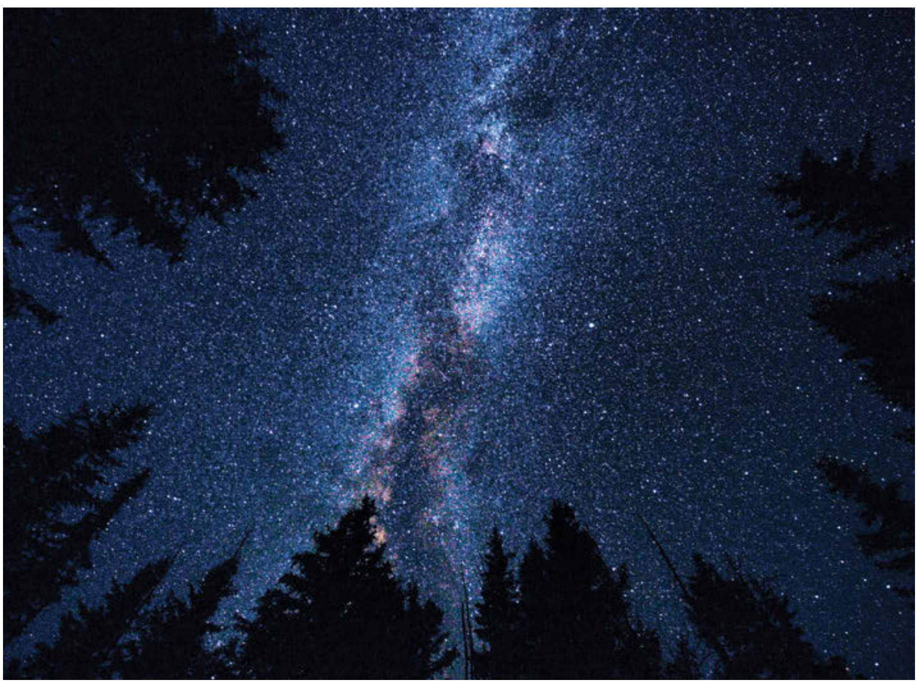
That morning broke crisp and fresh. The sky was dark blue and promised an evening of good viewing. I was anxious to try out a new eyepiece I'd just received as a gift. As always, I planned to linger in one constellation at a time to admire double stars and my favorite carbon stars.

Like millions of other Americans, I felt overwhelmed by the horrific tragedies of that morning, so I left work early and, feeling helpless, watched the Twin Towers crumble over and over again on TV. Living not far from the city, I knew people who might be victims, and I wouldn't learn their fate for days.

At dusk, eager to calm my nerves, I set up my simple observing booth comprised of six 4-by-8-foot plywood panels fastened together with door hinges. They form a hexagon with a narrow doorway that provides an effective barrier against both the wind and a nearby streetlight. Outside the booth, I also mounted my binoculars on a tripod.

All air traffic was prohibited that night, so the sky was deserted. There was a breeze, but it was otherwise a decent scoping night, all things considered. I was trying to enjoy my new eyepiece and the peaceful solitude that distant stars evoke.

Suddenly I was startled by the unmistakable sound of a jet approaching from the north. *How is this possible?* I wondered. *Is this another terrorist attack?* The nuclear power plant 30 kilometers from me would make a ripe target. My adrenaline surged, and my heart began to race.



I darted out of my booth and scanned the skies. The ominous sound got louder and louder, then *Shhhrrr-roarrrrr* . . . a jet roared past overhead. Flying a few hundred feet above me, it took my breath away. It was a U.S. Air Force fighter jet following the Hudson River southward on its way to patrol the skies above New York City.

I collapsed into my chair, leaned forward, and began to weep into my palms. Why was I crying for the first time in decades? I cried to release the sadness and anger boiling inside me. I cried for the victims and their families, while also crying with relief that my family and I were safe in our home. I cried with gratitude for that heroic pilot. And I cried because I felt proud to be an American.

Exhausted, I dragged my equipment into the garage, leaving the tripods and booth behind. Later, as I tiptoed quietly through the kitchen door, I heard the jet again. That's when I had an epiphany: I didn't feel terrorized. The terrorists had failed. That night, I'd argue, we Americans were shocked and saddened, but not terrorized, not lastingly anyway. In fact, overnight we became more united toward a single purpose than at any time since World War II (and, sadly, any time since).

After a long day, I climbed into bed feeling safe and secure, and I slept well.

■ **BOB MEEHAN** was a remodeling contractor in New City, New York, before retiring to Bradenton, Florida. Reach him at **robjmee@msn.com**.

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