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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

MAY 2022

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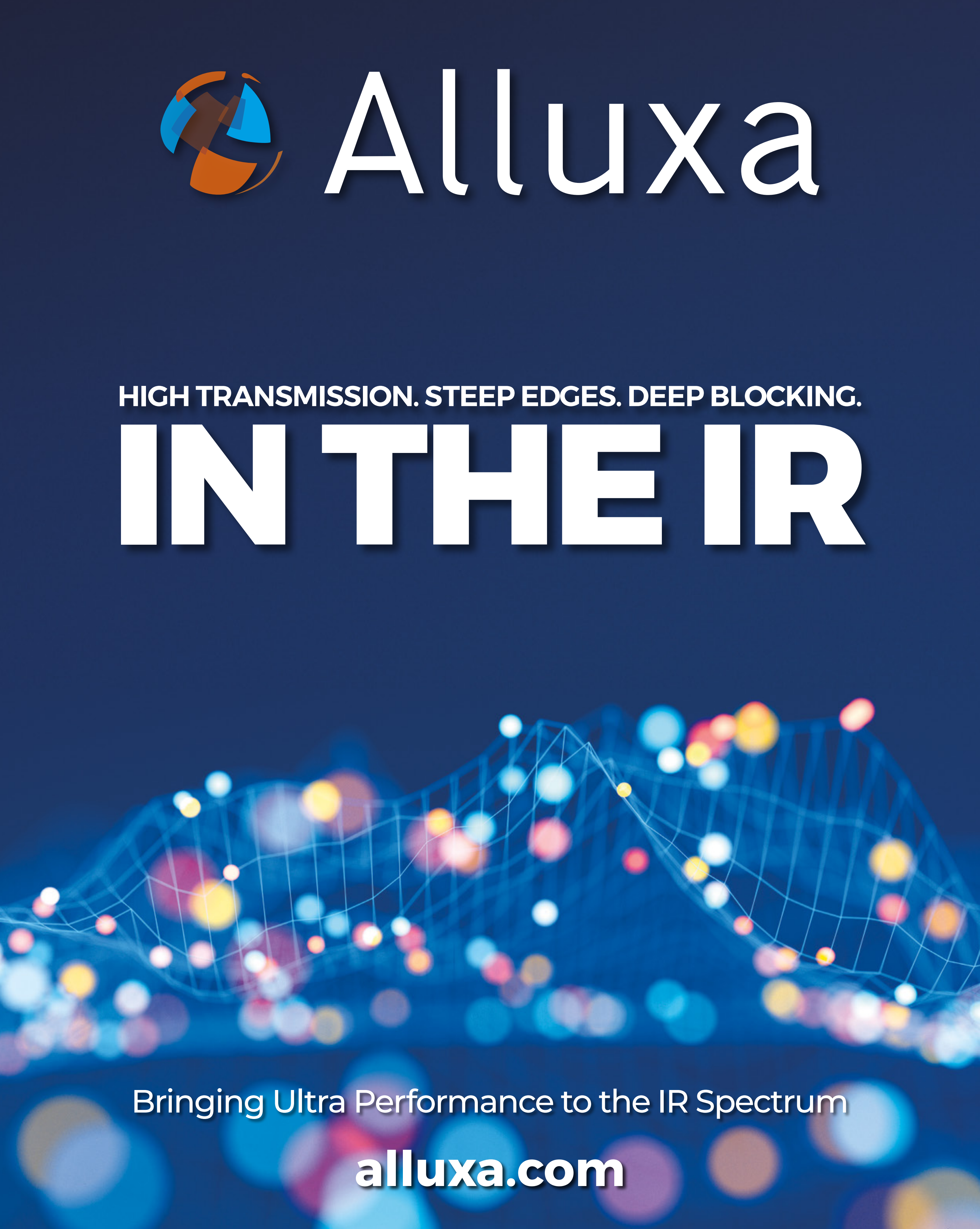
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ON THE COVER

Thirty-image stacked mosaic of Comet Leonard's majesty

BLAKE ESTES

ONLINE

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Find out what the sky looks like for your time and place. You can also print the chart as a handout.
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Who Knew?

ASTRONOMY IS FULL OF SURPRISES, and this issue is, too.

Some developments are not completely unexpected but still thrill when they occur. Take Comet Leonard. When first detected in early 2021, it was 19th magnitude, and astronomers didn't expect it to get much brighter than 4th mag. Yet as Sean Walker relates in his follow-up on page 58, by year's end Comet Leonard had reached mag 3 or better in several outbursts. These brightenings left photographers like Blake Estes, who shot our cover image, tripping over themselves to capture shots.

Another in this category is NASA's planned return to Venus. The last time the agency sent a mission there was in 1989, when it dispatched the Magellan probe from the Space Shuttle *Atlantis*. A new mission was long overdue, yet NASA pleasantly surprised Venus scientists and aficionados by approving not one but two new probes. See Emily Lakdawalla's feature on these two missions — plus the European Space Agency's upcoming Venus orbiter — on page 12.

Other kinds of surprises in astronomy might make you raise your eyebrows and think, *Cool.* One such revelation is that we might have a brand-new meteor shower this month. We're all familiar with annuals like August's Perseids and December's Geminids, but May's Boötids? As Joe Rao discusses on page 34, the breakup of Comet 73P could result in a new shower whose radiant lies in the constellation Boötes.

▲ Surprises sometimes come in enormous packages (above, Comet Leonard)

BLAKE ESTES

Another in this realm might be the discovery that the oldest stars have only a third as much lithium as scientists thought, as Ken Croswell explains on page 20. The finding has forced astrophysicists to wonder whether our understanding of the Big Bang is correct or if, to explain the discrepancy, we might need new laws of physics.

Other surprises might dazzle a bit more, eliciting a "Wow! Who knew?" Take Scott Harrington's realization of just how many galaxies he could pick out at night with an old pair of 7×35 binoculars. Ten? Twenty? No — 86. See his inspiring story on page 26.

Another "Wow! Who knew?" moment: learning that Mercury has a tail. Comets have tails, but planets? Indeed, Mercury sports a train of sodium atoms that extends millions of kilometers into space. And, as Tom Dobbins describes on page 52, amateurs can photograph it with even modest equipment.

I've saved the best for last: Dutch optical engineer Rik ter Horst has crafted an entire, working telescope out of a single piece of glass that would fit snugly into the palm of your hand. For the eye-opening details, read Jerry Oltion's gobsmacked reaction on page 74.

Peter

Editor in Chief

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The Essential Guide to Astronomy

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

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Remembering the Shoemakers

Carolyn Shoemaker's passing is sad, but judging by David Levy's moving tribute "Carolyn Shoemaker (1929–2021)" (*S&T:* Dec. 2021, p. 11), she had a wonderful long life. As it happens, I met her briefly on February 1, 1996, when Gene Shoemaker visited Yale University to give a talk on the possible connection between comet showers and the solar system's passage through the plane of the Milky Way galaxy.

When I saw that Carolyn Shoemaker was present, I succumbed to a moment of hero worship and asked her to autograph a copy of *Sky & Telescope* I had on hand! Al Washburn captured the moment in the photograph at left.

Joel Marks • Milford, Connecticut

◀ Carolyn Shoemaker and members of the Astronomical Society of New Haven meet during Gene Shoemaker's lecture at Yale University.

JOEL MARKS

Henrietta Swan Leavitt

In her excellent article "Remembering Henrietta Swan Leavitt" (*S&T:* Dec. 2021, p. 12), Dava Sobel notes Cecilia Payne's lament that Director Pickering's decision to assign Leavitt to fundamental photometry might have "set back the study of variable stars for several decades." It is perhaps worth remembering, however, that some of the next important steps in understanding Cepheid variable stars depended upon theorists catching up with the progress of Leavitt and other observers of those stars.

When Leavitt published her studies of Cepheids in the Small Magellanic Cloud in 1907 and 1912, most astronomers believed Cepheids were ill-understood binary stars. In 1914, Harlow Shapley championed the idea that the variability of Cepheids was instead due to pulsation in a single star. Over the next decade, astronomers such as Arthur Stanley Eddington gradually elaborated the theoretical framework of stellar pulsation. By the late 1920s, the general view had shifted, and most astronomers accepted pulsation as the cause of Cepheid variability. Leavitt was more of an observer than a theorist, but the Leavitt Law guided this progress in the theoretical understanding of Cepheids. Although Leavitt's life was short, she lived long enough to see the beginnings of this change in the understanding of Cepheid variables.

Horace A. Smith
East Lansing, Michigan

I very much enjoyed reading Dava Sobel's marvelous article, but I would like to address a minor point in her discussion of Harlow Shapley's work. Shapley did indeed determine the distances to the Milky Way's globular clusters and used that information to infer that the center of the Milly Way was more than 60,000 light-years away in the direction of Sagittarius. (We now know it to be about 26,000 light-years away.) But Shapley did not use Cepheid variables for his distance measurements. In his time, scientists didn't understand the differences between the classes of variable stars very well, but astronomers today call the stars he observed RR Lyrae variables.

The difference is that Cepheids are brilliant, massive stars, generally between 5 and 20 solar masses, and bright enough to be seen across intergalactic distances, whereas RR Lyrae variables are smaller stars, typically a fraction of a solar mass, and are so common in globular clusters that they were once called "cluster variables." They are too dim to detect easily across intergalactic distances but are well suited to measuring distances inside and around a galaxy. And they have their own period-luminosity relationship.

Doug Robertson
Longmont, Colorado

Gary Seronik replies: *A fellow* S&T *editor and I discussed your letter at length, and the most succinct account of Shapley's use of RR Lyrae variables we found was on page 258 of* The Physical Universe: An Introduction to Astronomy *by Frank Shu, which says, "Shapley had proposed correctly that pulsation lay behind the variability of these stars. Pulsating stars, the RR Lyrae variables, were known to exist in globular clusters, and Shapley proceeded to apply the Cepheid period-luminosity relationship to the RR Lyrae stars to calculate the distances to the globular clusters in which they were found. Shapley did not know of interstellar dust, nor that RR Lyrae stars differ from classical Cepheids . . ." So, although Shapley did indeed use RR Lyrae stars, it seems he was applying Leavitt's period-luminosity law. I would argue on that basis that Dava Sobel's wording is correct but doesn't cover all the nuances of the situation. (It would have been a serious side road to go down to get to this level of detail in Sobel's article.)*

Reading Peter Tyson's "Swan Song" about Henrietta Swan Leavitt (*S&T:* Dec. 2021, p. 4) made my day. I wish more people like him would seek parity for women.

Thank you, Peter.

Colleen Ansley
Toronto, Ontario

Thanks so much for your excellent article about Henrietta Swan Leavitt. Such a nice tribute to an unsung hero in her day. Your Spectrum column was also much appreciated.

As an amateur astronomer with the Southwest Florida Astronomical Society in Fort Myers, Florida, I gave a presentation several years ago about women astronomers. I'm happy to report that the current astronomer for Fort Myers's Calusa Nature Center & Planetarium is female.

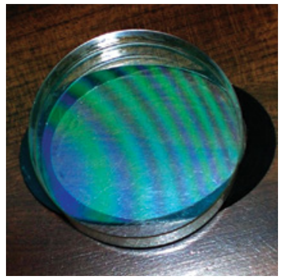
Originally, I was concerned about joining the Society, thinking it might be an all-boys club, but it turned out to be a band of brothers with a few sisters. On several occasions, I've been outside in the middle of the night observing with mostly men and a few women. They were always very helpful, and I later served as secretary and then vice president of the club before an injury precluded further action. I still get their excellent newsletter at **theeyepiece.org**. Thanks again for remembering the ladies.

Alice Mack
Fort Myers, Florida

Problematic Mirrors

I enjoyed reading "To Build or Buy?" by Jerry Oltion (*S&T:* Nov. 2021, p. 66). In the early part of the article, it mentioned that mirrors from the Coulter Optical Company tended to be "hit-and-miss." Every Coulter mirror I received for refiguring was undercorrected. Some were as bad as ½ wave, which isn't very good for seeing lunar and planetary details. I have no idea how they were testing these mirrors, but it probably wasn't with a Foucault test. A lot of this glass (not all) wasn't properly annealed and had strain in it, which became visible with polarized light. Maybe they didn't know this, but I felt bad whenever I had to tell people I couldn't work on their glass.

The only good secondary mirrors are made in the United States and possibly Europe. I bought one from Antares Optical, and it's really first-class. Another company I like is ProtoStar. These secondary mirrors aren't cheap, but they're worth it. Once, I bought a 1-inch 1⁄20-wave elliptical diagonal mirror from a private owner. After I installed it in a modest 4.5-inch (114-mm) Newtonian and threw the original in the trash, the difference truly was like day and night.



◀ The easiest way to test a flat is to compare it with another of known quality under diffused monochromatic light. A good diagonal should reflect straight lines. This one isn't very good, but it might be useable.

Alan Raycraft
Peyton, Colorado

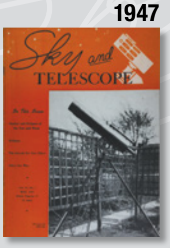
FOR THE RECORD

● Recent studies have shown that Comet Leonard (C/2021 A1) is on an outbound hyperbolic orbit and will not return to the inner solar system, unlike what was stated in "Comet Leonard Races Across the Sky" (*S&T:* Dec. 2021, p. 48).

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

1947



1972

1997

ALAN RAYCRAFT

◖ May 1947

Stellar Rotation "[Horace Babcock selected] a star, 78 Virginis, whose spectrum has very narrow lines, indicative of no rotational component in the line of sight, but belonging to the class of stars for which rapid rotation is common. If this star does rotate, its axis must be pointing almost directly toward us.

"Employing a quarter-wave plate of mica and a plane-parallel crystal of calcite, the Mount Wilson astronomer analyzed the spectrum of 78 Virginis to detect the polarized components of its light caused by the Zeeman effect. He found a field strength of 1,500 gauss, corresponding to the expected rotational velocity of 60 kilometers per second. [His] work is of high significance in establishing this method for investigation of problems in stellar rotation."

Until this work, Zeeman line splitting had been observed only in laboratories and the Sun.

◖ May 1972

Sharper Images "Accurate angular diameters of four bright stars are among the first results from the powerful new method of speckle interferometry, employed by D. Y. Gezari, A. Labeyrie, and R. V. Stachnik, State University of New York at Stony Brook. . . . It involves star photography with the 200-inch Hale reflector plus a special camera that provides a very large scale, short exposure, and narrow wavelength interval. From a large number of images of a star, optical processing in the laboratory yields a reconstructed, diffraction-limited image . . .

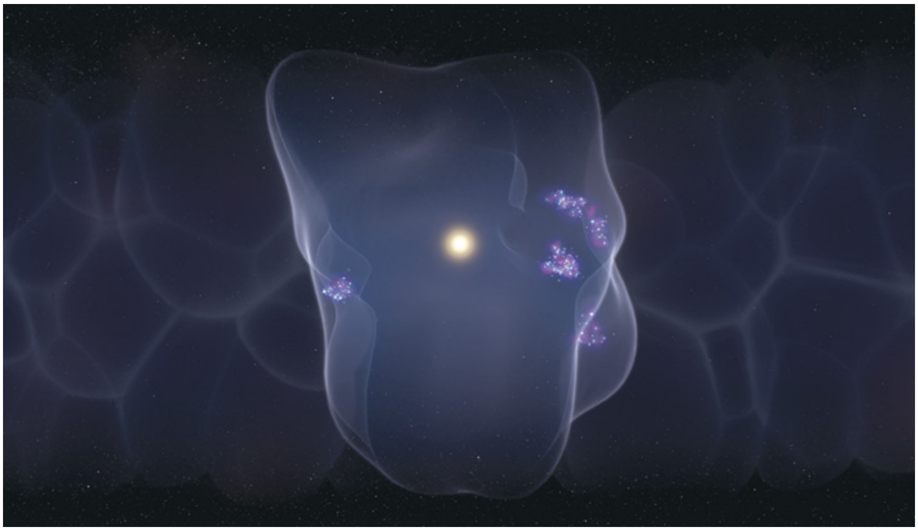
"Dr. Gezari's group has also used the new technique to discover a previously unsuspected companion of Beta Cephei, 0.255 second distant and five magnitudes fainter. [This] new companion is perhaps too difficult for visual recognition in any existing instrument."

This method to correct bad seeing achieved success a few years before that of adaptive optics.

◖ May 1997

Lonely Stars "Central to our mental map of the cosmos is the notion that stars reside solely in galaxies. But evidence is now in hand that trillions of stars in the Virgo Cluster of galaxies lie beyond the gravitational embrace of that grouping's individual members.

"As Henry C. Ferguson (Space Telescope Science Institute) explained . . . astronomers have long posited that tidal interactions between galaxies might draw stars out of the 'cities' of their birth. [His group] has actually resolved individual stars in a 2.3-arcminute-wide field 50 arcminutes east of M87, the giant elliptical galaxy at the center of the Virgo Cluster. . . . Ferguson notes that if the interlopers are indeed at the Virgo Cluster's distance [their separation equals] half the distance between our Milky Way and the Andromeda Galaxy . . . The researchers conclude that at least 11 percent, or several *trillion*, of the Virgo Cluster's stars lie between, rather than within, galaxies."



▲ This artist's illustration shows the Local Bubble surrounding the Sun, with star formation occurring along the bubble's surface.

STARS

1,000-light-year "Bubble" Is the Source of All Nearby New Stars

BEGINNING 14 MILLION years ago, more than a dozen stars near the Sun have ended their lives as spectacular supernovae. These ongoing blasts have swept up intervening gas, creating nurseries for stellar newborns along the edges of an expanding shell, now 1,000 light-years wide.

This is the picture Catherine Zucker (Center for Astrophysics, Harvard & Smithsonian) and colleagues have painted in the January 12th *Nature*.

They're expanding on a decades-old explanation for the Local Bubble, a cavity of sparse, hot gas around the Sun likely blown out by supernovae. Zucker's team used data from the European Space Agency's Gaia satellite to map the exact positions, shapes, and motions of gas and stars within 650 light-years of the Sun and discovered that almost all the stellar nurseries near the solar system lie on the hilly surface of the Local Bubble. There are older stars within the bubble, but essentially none younger than 50 million years, Zucker says.

"The data and their interpretation give strong support to the idea of triggered star formation in the Local Bubble shell," says Dieter Breitschwerdt (Berlin Institute of Technology), who was not involved in this study.

By tracing the star clusters' motions backward, Zucker and colleagues identified two of them, Upper Centaurus Lupus and Lower Centaurus Crux, as the likely source of the initial supernovae, which occurred between 13.6 million and 15.1 million years ago. The supernovae are ongoing, though, with some occurring as recently as a couple million years ago, Zucker explains.

This inferred history is consistent with the abundance of a radioactive iron isotope found on ocean floors, says Breitschwerdt. He and colleagues pinned a 2 million-year-old iron-60 signature on two nearby supernovae.

But other bumps in the iron-60 record, including activity between 7 million and 9 million years ago, are harder to explain, he notes, because the Sun only entered the Local Bubble 5 million years ago.

Speaking at an American Astronomical Society press conference, Zucker agreed that supernovae within the Local Bubble can't explain the entire iron-60 record. But the fact that the Sun just happens to sit near the center of a bubble means structures like this one probably litter the Milky Way. The Sun and Earth may have passed from one supernova-blown bubble to another.

"Now the Sun just sits by chance in the center of the bubble," Zucker adds, "and we get this front-row seat to star formation happening all around us."

■ **MONICA YOUNG**

See the data: https://is.gd/3Dstars

EXOPLANETS

New Exomoon Candidate Found

ASTRONOMERS HAVE NOT yet confirmed the discovery of a single exomoon, even though a dozen candidates have been put forward. On January 13th David Kipping (Columbia University) and colleagues announced another potential exomoon in *Nature Astronomy*. But just as with previous candidates, they urge caution.

The putative moon, designated Kepler-1708 b-i, orbits a Jupiter-size planet on a Mars-like orbit around a Sun-like star 5,600 light-years away. The moon orbits its planet at about 12 planetary radii, much like Jupiter's moon Europa. But Kepler-1708 b-i (if real) is huge, with about 2.6 times Earth's girth.

Kipping's team found the lunar candidate by surveying cool gas giants detected by NASA's Kepler mission. Out of 70 such planets that passed in front of their stars at least twice, only the transits of Kepler-1708 b showed a moon-like signal.

"There's a 1% chance that this is just the data fluctuating in a really evil way that conspires to trick us," Kipping says. "It's both a small number and uncomfortably large." The team needs more data to confirm Kepler-1708 b-i's status as an exomoon, he adds.

Laura Kreidberg (Max Planck Institute for Astronomy, Germany), whose follow-up studies called into question the very first exomoon candidate (also

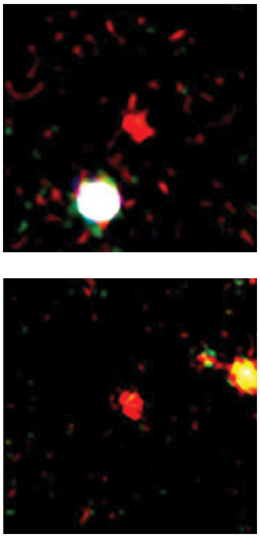
LEAH HUSTAK (STSCI)

GALAXIES

The Most Distant Galaxies Yet Seen?

IN TWO STUDIES posted to the arXiv preprint server, Yuichi Harikane (University of Tokyo) and his colleagues report the detection of two sources that appear to blaze at us from a mere 330 million years after the Big Bang (corresponding to a redshift of 13).

The current record-holder with a secure distance measurement is GN-z11; its redshift is about 11, meaning we see it as it was 420 million years after the Big Bang.



◀ These composite near-infrared images show HD1 and HD2 (red objects), two galaxies in the early universe.

Other observations have suggested that stars lit up within the universe's first 300 million years. But even if the two new galaxies prove to lie as far away (and thus, as early) as they appear to, they're probably not first-generation objects, Harikane says. Estimates show they're similar in mass to the Magellanic Clouds, the Milky Way's largest dwarf galaxies, and thus likely evolved from still smaller galaxies.

Harikane's team found the galaxy candidates, dubbed HD1 and HD2, in archival images covering visible and infrared wavelengths. They were looking for galaxies detected at the longest, reddest wavelengths but invisible at shorter ones, which would indicate that their light had come from a great distance.

A follow-up spectrum of HD1 with the Atacama Large Millimeter/submillimeter Array (ALMA) showed a hint of strongly redshifted emission from ionized oxygen. If the line is real, it puts HD1 at a redshift of 13.27 — and bingo, we have the earliest galaxy yet seen. But if not, then HD1 and HD2 might lie more than a billion years later in cosmic history. Harikane and collaborators have secured time on the James Webb Space Telescope to confirm the galaxies' distance.

HD1 and HD2 are brighter than astronomers usually expect star-forming galaxies to be, as are GN-z11 and other candidates found in this early era. In a companion paper to the one announcing the discovery, Fabio Pacucci (Center for Astrophysics, Harvard & Smithsonian), Harikane, and colleagues suggest that these early galaxies might be so bright due to a combination of rampant starbirth and a madly gobbling black hole.

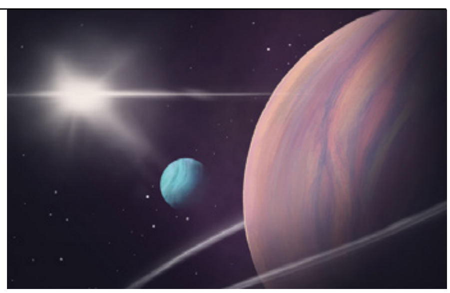
■ CAMILLE M. CARLISLE

discovered by Kipping's team, *S&T:* Sept. 2020, p. 34), says that Kepler-1708 b-i is one of the most promising candidates yet identified.

But Kreidberg agrees that the discovery needs more observations: "We would need to see another transit observation that shows two dips in brightness: one caused by the planet blocking light from the star, and one from the moon blocking the light."

Although Kepler has retired, several telescopes coming online in the next decade or so may provide the opportunity for follow-up observations.

■ BEN SKUSE



▲ An illustration of a large, blue-green exomoon orbiting a gas giant planet

EXOMOON: HELENA VALENZUELA WIDERSTRÖM; DISTANT GALAXIES: Y. HARIKANE ET AL.

IN BRIEF

Starlinks Don't Impact Science (Yet)

A new study of SpaceX's Starlink satellites' impact on astronomy, in the January 10th *Astrophysical Journal Letters*, gives cause for both relief and concern. Przemek Mróz (University of Warsaw, Poland) and colleagues monitored satellite trails in images taken by the Zwicky Transient Facility (ZTF), which scans the entire northern sky every two days, between November 2019 and September 2021. They found that twilight images (often taken to search for near-Earth objects) contain an increasing number of streaks, escalating from less than 0.5% in 2019 to 18% in 2021. Eventually, nearly all twilight images will contain a Starlink trail, Mróz says. However, single trails are faint enough that they don't saturate the detector, so the automatic pipeline can mask the streak. Only 0.04% of the detector area is lost, and the image remains useful. But the "VisorSat" model of Starlink satellites is not yet faint enough to avoid saturating pixels of, for example, the Vera Rubin Observatory. Dimming satellites below 7th magnitude will be key to mitigate the negative consequences for astronomy.

■ MONICA YOUNG

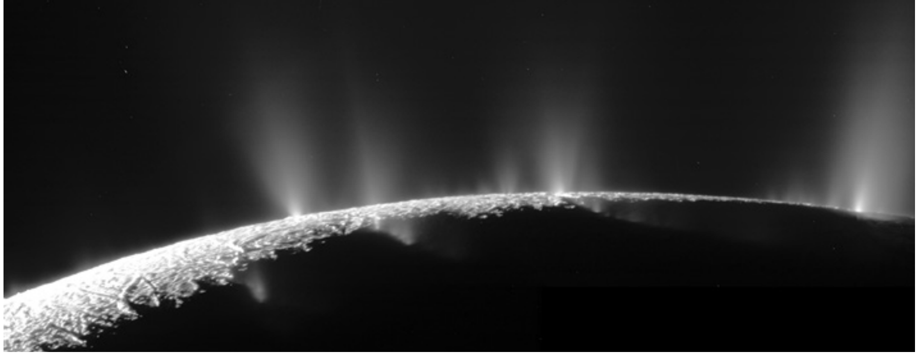
Largest 3D Map of the Cosmos

Only seven months into a five-year survey, the Dark Energy Spectroscopic Instrument (DESI) has already surpassed all cosmic surveys to date, creating the largest and most detailed map of the universe. DESI scientists presented preliminary results at January's CosmoPalooza conference. The instrument is installed on the Mayall 4-meter telescope at Kitt Peak National Observatory in Arizona, its operations aided by 5,000 fiber-optic-positioning robots. Though DESI saw first light in late 2019, the official sky survey didn't begin until May 2021 due to pandemic-related isuses. Like the long-running and transformative Sloan Digital Sky Survey, DESI is also a full-sky survey but with the ability to measure more precise distances to farther-away objects. DESI should amass spectra of 35 million galaxies and quasars by 2026 and has already collected 7.5 million to date. The primary goal is nothing less than a reconstruction of the last 12 billion years of the universe's expansion, to shed light on the mysterious dark energy that makes up 68% of the universe's content.

■ MONICA YOUNG

SOLAR SYSTEM

Do the Plumes from Saturn's Icy Moon Reach Down to Its Ocean?



▲ The Cassini spacecraft imaged dramatic plumes erupting from Saturn's moon Enceladus.

ASTRONOMERS long thought that the watery plumes erupting from the surface of Saturn's icy moon Enceladus might provide access to its subsurface ocean. But computer models designed for studying sea ice on Earth suggest that the plumes might have a different chemistry than the waters below.

NASA's Cassini spacecraft first imaged and later even sampled the geyser-like plumes of water vapor and particles escaping from rifts in the icy crust of Enceladus's south polar region. Scientists interpreted the presence of salts (sodium chloride and sodium carbonate) and traces of biologically interesting organic compounds as evidence that the plumes were erupting from pipe-like fissures that extended all the way from the surface of the thick, icy crust to a salty subsurface sea.

However, hopes that the plumes would provide easy access to the subsurface layers were called into question at December's meeting of the American Geophysical Union. Colin Meyer (Dartmouth College) and colleagues applied computer models developed for terrestrial sea ice to Enceladus. They found that pockets of slushy brine, produced by the localized heating of tidal stress and shear, should be present within Enceladus's icy shell. That brine can percolate through porous ices to the surface, where it erupts into the vacuum. The concentration of salts in this meltwater should increase as the water vaporizes and escapes into space.

While Meyer doesn't doubt that Enceladus has a global subsurface ocean, he cautions that the plume's measured saltiness "may not be representative of the ocean chemistry or the chemistry of the shell but actually of concentrated interstitial liquid."

Sampling Enceladus's hidden ocean may be more difficult than many have imagined, but Meyer notes that pockets of slushy brine in the icy crust could be habitable zones in their own right.

■ THOMAS A. DOBBINS

MILKY WAY

Celestial Ruins on Our Galaxy's Edge

LONG AGO, the Milky Way's gravity rent a globular cluster and crumbled its thousands of stars across 15 degrees of sky. Now, new measurements of some of those stars show that they used to belong to the oldest stellar association in or around our galaxy.

The Milky Way itself formed some 200 million years after the Big Bang. Eons of star formation have rendered it anew, but hints of its past remain in its 150 or so globular clusters, each of which is crowded with stars typically billions of years old.

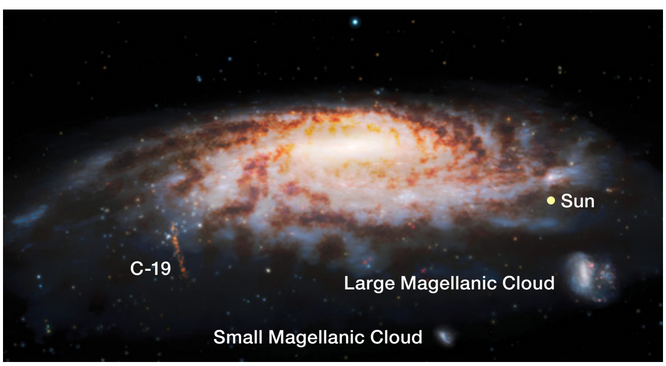
While the Milky Way's globular clusters are undeniably ancient, none of them seems to have survived from the earliest days. Their abundance of heavy elements, a proxy for their age, bottoms out at 0.2% that of the Sun.

A study of a celestial ruin may shed light on ancient globulars' disappearance. In the January 6th *Nature*, Nicolas Martin (University of Strasbourg, France) and colleagues report a detailed study of a collection of stars in the Milky Way halo dubbed C-19. Based on their data, the researchers conclude these stars were once a globular cluster. Now they're a stellar stream that's orbiting the Milky Way on a relatively close polar orbit, currently 60,000 light-years from the Sun.

Team member Rodrigo Ibata (also University of Strasbourg) helped discover this stream from the massive data set that the Gaia satellite has collected. The team then followed up with ground-based spectroscopy, which confirmed that stars selected from this disintegrated cluster have extremely low amounts of heavy elements: less than 0.05% that of the Sun. "Such a low global metallicity has so far never been observed for any stellar system in the Milky Way, in its surroundings, or beyond," the researchers write.

C-19's ancient remains suggest that globular clusters *could* form early on; it's just that the ones from our galaxy's earliest years generally didn't survive the tumultuous gravitational environment. Or, adds John Norris (Australian National University), who wasn't involved in the study, it's still possible that back then, relatively few such clusters were forming in general.

■ MONICA YOUNG



◀ This illustration shows the location of the C-19 stellar stream, recently discovered at the edge of our Milky Way Galaxy. (The Sun and the Magellanic Clouds are labeled for reference.)

PLUMES FROM ENCELADUS: KEVIN M. GILL / JPL-CALTECH / NASA / SSI; C-19 STELLAR STREAM: INTERNATIONAL GEMINI OBSERVATORY / NOIRLAB / NSF / AURA / J. DA SILVA / SPACEENGINE; ACKNOWLEDGMENT: M. ZAMANI

Grave Expectations

We can try to devise rules for how detecting alien life should unfold, but E.T. might not play along.

LEAH TISCIONE / S&T

WE ARE A LONG WAY from having a *Star Trek* tricorder to scan for "life signs." On several occasions, the peer-reviewed literature has reported indications of past and present life beyond Earth that further study found to be unsubstantiated. The scientific enterprise has survived these false starts; our error-correction processes have worked well. But in the time between an initial report of a possible biosignature and a later nonbiological explanation, the mass media and the public often let their imaginations run wild.

Another of the sexiest perennial space-science stories after possible hints of alien life are asteroids threatening Earth. In 1999, worried that their credibility might suffer if the public saw them as crying wolf, astronomers devised the Torino scale to categorize possible impact threats, ranging from "0" (no danger) all the way up to "10" (near-certain global catastrophe).

Last October a group of scientists, including leading astrobiology officials at NASA, proposed in *Nature* an analogous scale to rate reports of possible alien life detection (**https://is.gd/CoLDscale**). In the Confidence of Life Detection, or CoLD, scale, a "1" could possibly be caused by life. A "2" means sources of contamination are ruled out.

> Life may not follow our script, and its discovery may not cleanly fit into a linear numbered scale.

It's a "4" if non-biological sources are shown to be implausible. And so on, up to the highest level, a "7," when independent follow-up observations confirm the life hypothesis and we can finally declare to all the world (and whoever else is listening), "It's life, Jim!"

This effort toward a unified approach arose after astrobiology leaders at NASA grew unhappy with the attention given to the reported discovery of phosphine on Venus (*S&T:* Jan. 2021, p. 15). The media widely focused on the finding as being a possible sign of life, even though the phosphine authors were very careful to stress that they regarded life as an interpretation that should only be accepted if all others were ruled out.

So, what were the NASA authors really so upset about? Maybe they were disturbed by a possible discovery that was not where and what we expected. NASA is heavily invested in searching for habitability on Mars, Europa, and elsewhere, including exoplanets. We hold workshops and design instruments to detect life in these places. We know that the first signs — an isotopic anomaly among organic deposits on Mars, or a disequilibrium mixture of gases on an exoplanet — will be ambiguous, and we know how we'll follow up to rule out other explanations.

But life may not follow our script, and its discovery may not cleanly fit into a linear numbered scale. Ambiguity and disagreement might make us uncomfortable, but we're talking life, not a rock hurtling through space following well-known laws of motion. We might well find a biosignature where we don't expect it.

To me the CoLD scale reads almost as a science-fiction story in which the authors have agreed on how they expect the discovery of life will unfold. It's fine to run through scenarios and hold provisional expectations, but when these become officially recognized by those running the programs that hand out funding, we may fall into "groupthink" and miss something important. The history of planetary exploration suggests that some of the most important discoveries will arrive in surprising ways that were not in the proposals used to justify our missions.

■ Astrobiologist and Contributing Editor **DAVID GRINSPOON** is author, among other books, of *Lonely Planets: The Natural Philosophy of Alien Life.*

 by Emily Lakdawalla

VENUS RENAIS

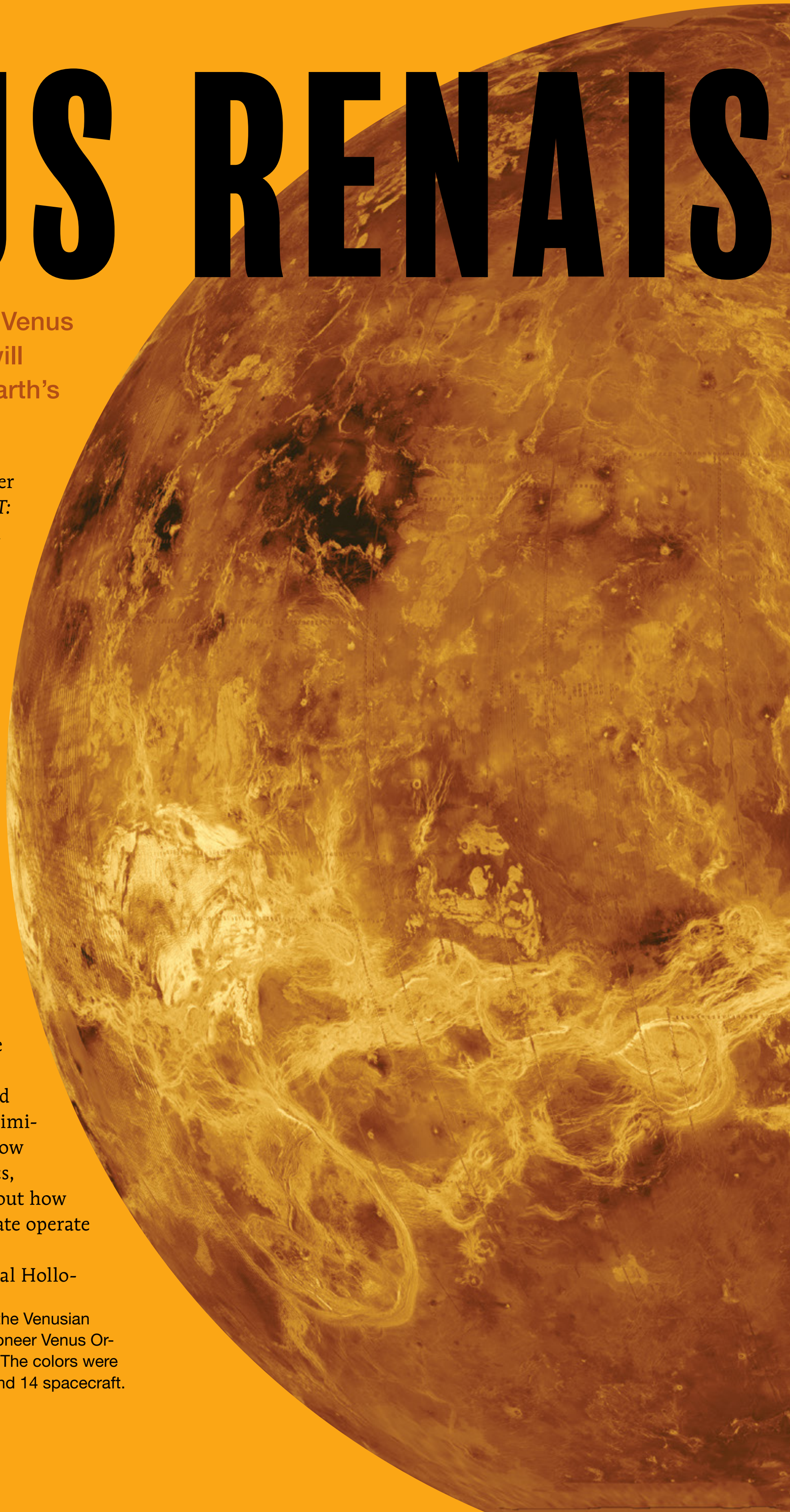
Only two spacecraft have orbited Venus since 1994. Three new missions will transform our understanding of Earth's evil twin in the 2030s.

This is the dawn of a new Age of Venus. After a dry spell lasting more than 25 years (*S&T:* Sep 2018, p. 14), NASA has finally selected not one but two missions to our neighboring planet: the VERITAS orbiter, launching as soon as 2027, and the DAVINCI flyby and atmospheric probe, launching in 2029. The European Space Agency will follow with the EnVision orbiter in the early 2030s.

What broke the drought? "To some degree, it had just been so long that it was becoming kind of an embarrassment," says David Grinspoon (Planetary Science Institute), a co-investigator on DAVINCI. Just as important, however, was that exoplanet researchers had started advocating for Venus missions. "They're already starting to find exo-Venuses. What hope do we have of figuring things out that many light-years away if we haven't really looked at Venus?"

Suzanne Smrekar (Jet Propulsion Laboratory), principal investigator on VERITAS, gives additional credit to Earth scientists. "There are a lot of open questions about plate tectonics," she explains — questions that are best answered by comparing our planet with another one of similar size, age, and composition. But we don't know enough about Venus to understand its tectonics, much less to use that understanding to figure out how Earth's dynamic tectonism, weather, and climate operate in the present, past, and future.

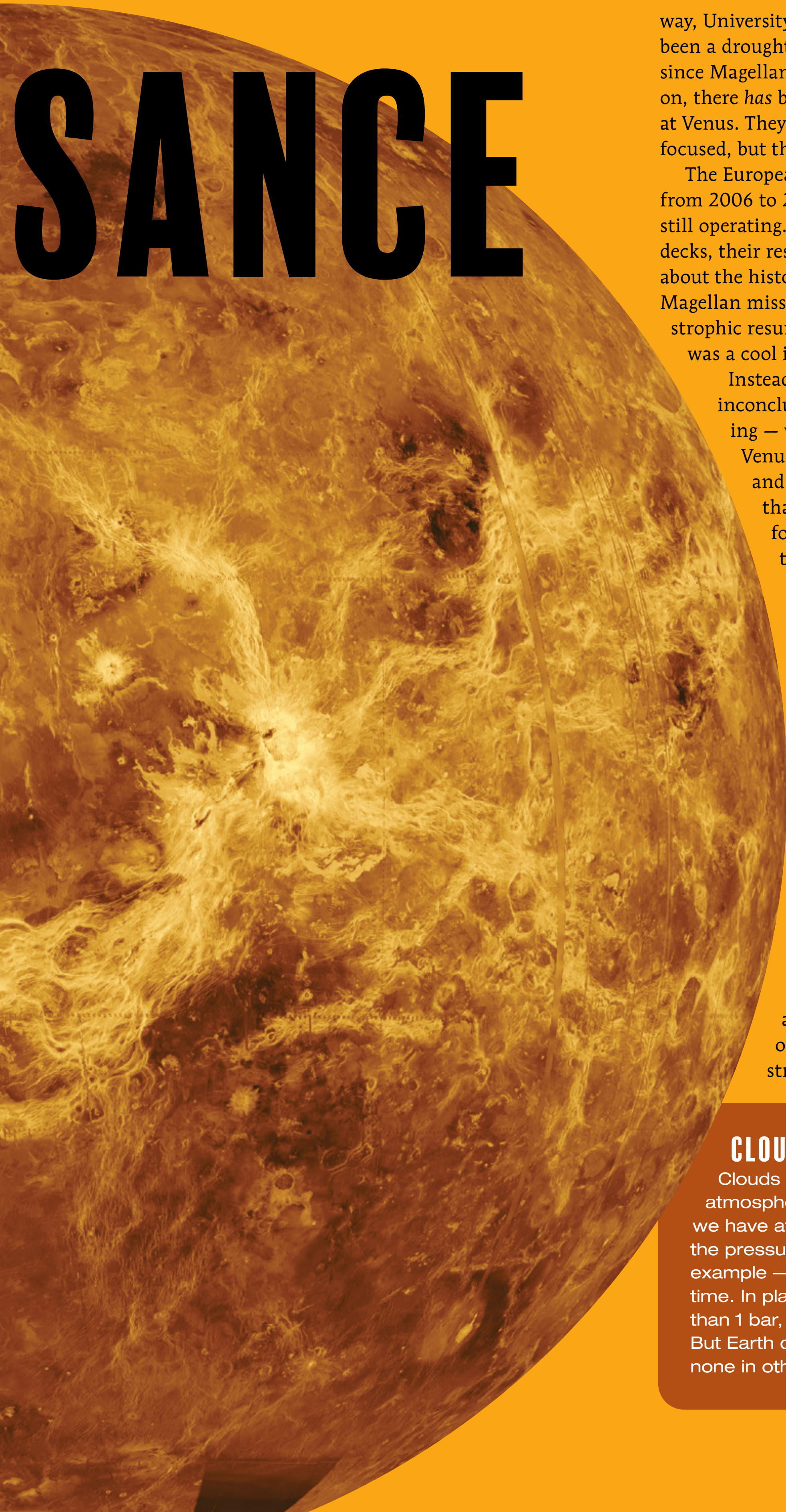
If you talk to EnVision's Richard Ghail (Royal Hollo-



▶ **VENUS AS WE KNOW IT** This simulated mosaic of the Venusian surface combines radar data from the Magellan and Pioneer Venus Orbiter spacecraft colorized to enhance surface features. The colors were inspired by images recorded by the Soviet Venera 13 and 14 spacecraft. The hemisphere is centered at 180° east longitude.

NASA / JPL

SANCE



way, University of London), though, there hasn't actually been a drought. "The attitude is: 'We haven't had a mission since Magellan, nothing's happened,'" he says. "Like, hang on, there *has* been Venus Express, there *has* been Akatsuki at Venus. They were atmosphere-focused and not surface-focused, but they have been doing surface science."

The European Space Agency's Venus Express studied Venus from 2006 to 2014; Japan's Akatsuki arrived in 2015 and is still operating. Despite being devoted to the planet's cloud decks, their results have overturned prevailing attitudes about the history of Venus's barren landscape. "Out of the Magellan mission came this paradigm that Venus had catastrophic resurfacing and then quiescence," says Smrekar. "It was a cool idea, but I think it's wrong."

Instead, Venus Express produced abundant (though inconclusive) evidence for recent — and even continuing — volcanism. Both it and Akatsuki have shown Venus's atmosphere to be much more dynamic, and much more connected to the rocky surface, than we realized. Those discoveries have laid the foundation for thrilling new Venus missions in the 2030s.

Hot Wind, Acid Clouds

We've known the fundamental facts about Venus's atmosphere since Mariner 2 performed the first-ever planetary flyby in 1962; probes, balloons, and landers from the Soviet and American space agencies filled in much of the rest. Very nearly the same size as Earth and only a little closer to the Sun, Venus rotates backwards, but slowly. The retrograde rotation counteracts its orbital motion, so its sidereal days (243 Earth days long) are longer than its years (225 Earth days).

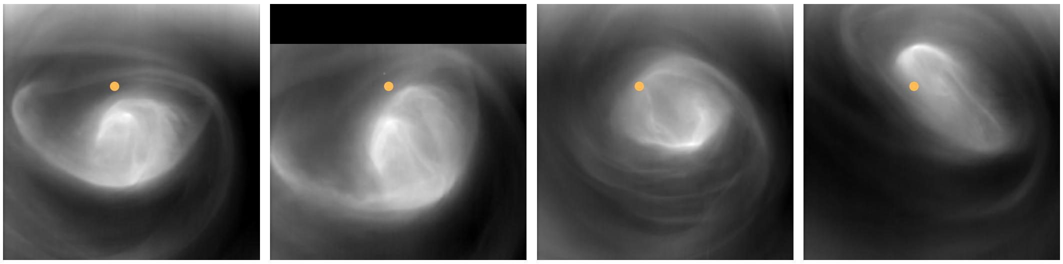
Venus's surface is shrouded by an utterly opaque layer of clouds, more than 20 kilometers thick. The clouds are 75% pure sulfuric acid droplets, but they also contain a mysterious "ultraviolet absorber" that creates dark streaks in ultraviolet-filter images. Fortuitously,

CLOUDS

Clouds most commonly form at or above an atmospheric pressure of around 1 bar, or what we have at sea level on Earth. On worlds where the pressure is much higher than that — Venus, for example — clouds cover the entire planet, all the time. In places where the pressure is much lower than 1 bar, such as Mars, clouds are rare and thin. But Earth can have thick clouds in some places and none in other places.

CLOUD ICONS: KUSDARTI / THE NOUN PROJECT

▶ **EYE OF THE STORM** Venus Express caught rapid changes in the vortex over the planet's southern pole (yellow dot). From left to right, the infrared images show changes over the course of two days. The vortex hovers about 60 km above the Venusian surface.



those dark streaks enable scientists to track cloud motions and measure wind speeds.

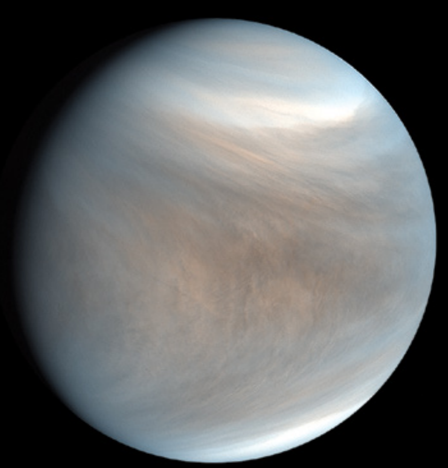
The temperature and altitude of the top of the troposphere are constant almost everywhere on the planet, except near the poles. Wind speed is oddly constant, too. Except near the poles, the entire atmosphere moves westward at 100 meters per second (more than 200 mph), traveling completely around the planet once every four days. There's nothing quite like this atmospheric "super-rotation" anywhere else in the solar system.

Probes showed that the winds weaken closer to the surface, but the speed never drops to zero; the lowermost 10 kilometers of Venus's atmosphere always experience a breeze of 1 to 3 meters per second.

The surface roasts at a temperature of 740K (470°C, 870°F) and bears a crushing atmospheric pressure 92 times that of Earth's. The air is almost all carbon dioxide. In fact, it appears that Venus has about the same proportion of carbon that Earth does, but whereas Earth's carbon is mostly locked into rocks like limestone and marble as carbonate minerals, Venus's carbon is all in the air.

There's also a high proportion of heavy hydrogen relative to regular hydrogen in Venus's atmosphere, which has led scientists to hypothesize that Venus has lost most of its primordial water. Without much water, geologists reasoned, Venus's rocky interior would be much less mobile than Earth's, making Earth-style plate tectonics impossible.

VENUS IN UV This synthesized image combines Akatsuki observations at two different ultraviolet wavelengths to show mesmerizing detail in Venus's atmosphere. Dark blue streaks mark the presence of an unidentified chemical substance.



Europe Goes to Venus

The Soviet Union and the United States initiated the first phase of Venus exploration at the same time that they were rushing to land on the Moon and bring home lunar rocks. Scientifically speaking, Soviet and American planetary science therefore grew out of geology. At Venus, both countries focused on penetrating Venus's clouds to see the rocky surface for comparison with Earth, the Moon, and Mars.

Europe's planetary science community, on the other hand, has stronger roots in a different aspect of Earth science: "We accepted climate change long before the United States did," Ghail says. Trying to explain Venus's hellish climate had inspired the idea of a runaway greenhouse. But what triggered the runaway greenhouse, and could the same thing happen on our rapidly warming Earth? ESA's Venus Express mission sought to better understand climate change on both Venus and Earth. Similar goals motivated Akatsuki.

Venus Express immediately gave us improved views of weird features at both of Venus's poles. The poles are surrounded by a *cold collar*, where both the temperature and altitude of the top of the troposphere drop, and with them the top of the visible clouds, by about 5 kilometers.

With longer-wavelength infrared imaging, Venus Express could easily see down to the middle cloud layer (approximately 55 km above the surface), where gigantic vortices of relatively warm air spin and wobble drunkenly around both poles once every two to three days. They most commonly look like wispy figures of eight, described as a double vortex, but are sometimes oval and sometimes triple. They never looked quite the same from one Venus Express orbit to the next. How these persistent storms connect to the upper or lower polar atmosphere, or to the global rotation of the rest of the atmosphere, remains a mystery.

A long mission followed these early discoveries, and the longevity generated unique science, Grinspoon explains. "What was great about Venus Express, and is great about Akatsuki, is the sustained presence of these orbiters with first-rate instrumentation, because there's a lot of complexity and variability."

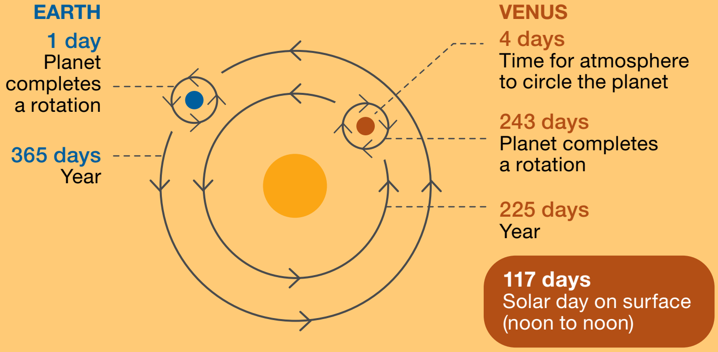
Wind speeds changed and cloud brightness varied from one Venus Express orbit to the next. As Venus Express watched between 2006 and 2010, the superrotational wind sped up from 100 to 120 meters per second. At much smaller scales, both Venus Express and Akatsuki have seen turbulent, bubbly motions in the lower clouds.

POLAR VORTEX IMAGES: ESA / VIRTIS / INAF-IASF / OBS. DE PARIS-LESIA / UNIV. OF OXFORD; VENUS IN UV: PLANET-C (AKATSUKI) PROJECT TEAM

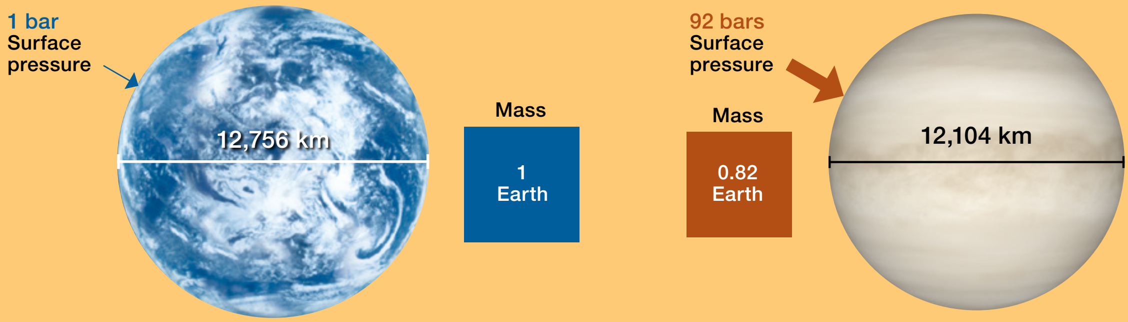
VENUS VS. EARTH

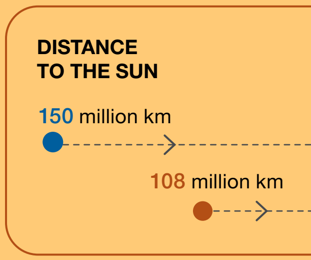
Venus and Earth share similar sizes, masses, densities, and even distances from the Sun. But Venus's atmosphere and rotation make it dramatically different from our planet.

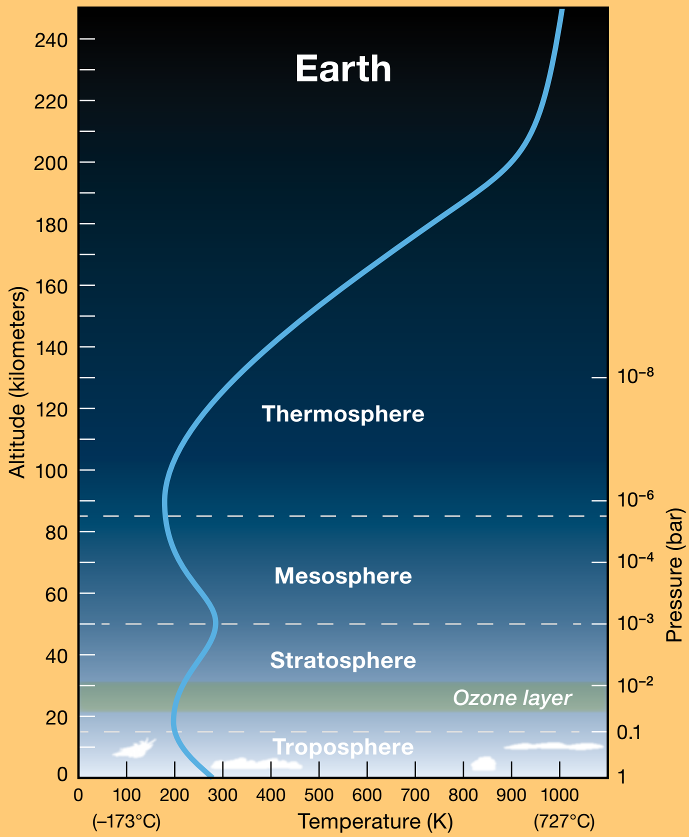
▶ Venus rotates slowly clockwise (unlike Earth), but it orbits the Sun counterclockwise (as all the planets do). So although it takes 243 Earth days to rotate once about its axis — called its *sidereal* day — it takes 117 Earth days for the Sun to travel from noon to noon at Venus's equator (its solar day). Complicating matters, Venus's cloud deck circles the planet in about four Earth days, for reasons unknown. *(Not to scale)*

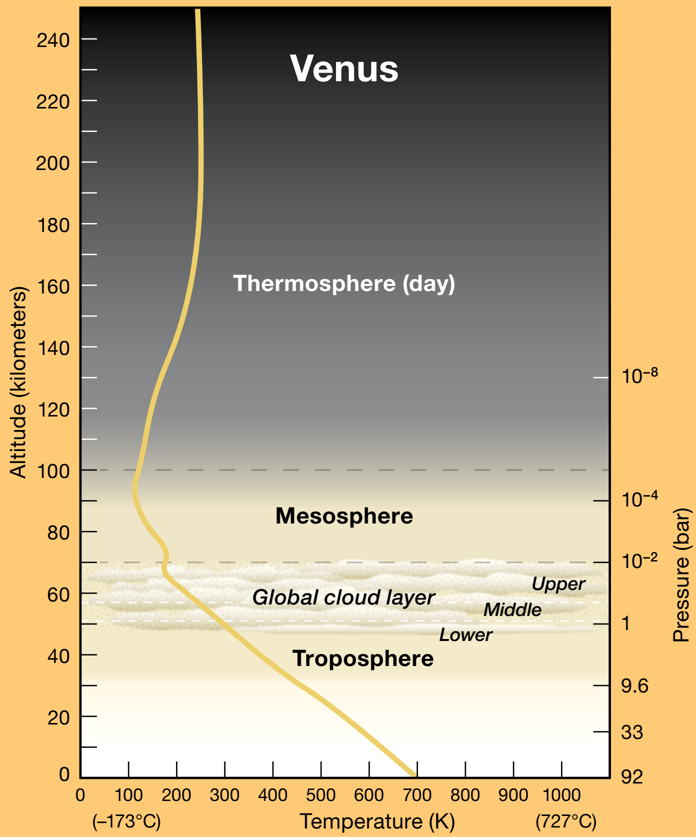


SIMILAR, BUT DIFFERENT



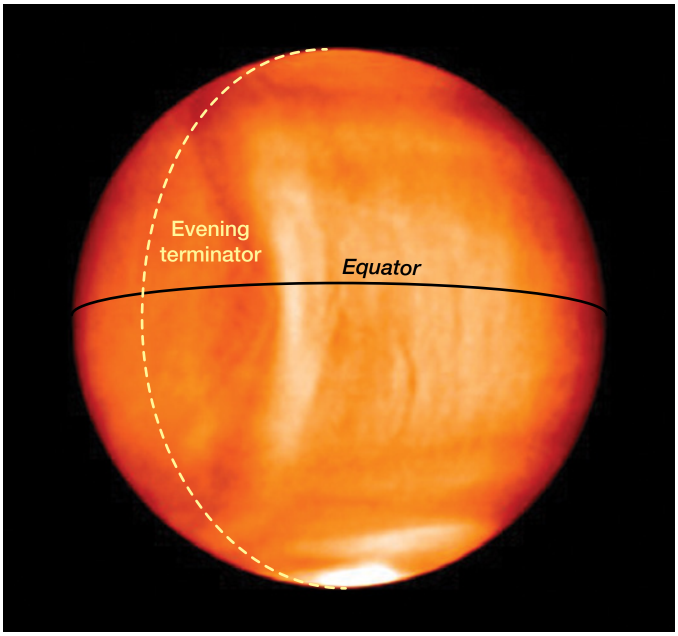






▲ **ATMOSPHERES AT A GLANCE** Atmospheric pressure, ground heating, solar heating, and chemistry combine to create unique conditions on Venus and Earth. The troposphere is where weather happens: Molecules that exist as gases near the warm ground cool and condense to cloud-forming droplets as they rise in altitude. Clouds rarely go above the troposphere, because above it, temperature increases and pressure decreases, and a cloud's molecules change to gas again. Conditions don't permit Venusian clouds to form until roughly 50 km up — about three times higher than Earth's clouds ever reach. At this altitude on Venus, temperature and pressure are Earth-like.

INFOGRAPHIC: TERRI DUBÉ / *S&T*; VENUS: NASA / GSFC SCIENTIFIC VISUALIZATION STUDIO; EARTH: *S&T* ILLUSTRATION; ATMOSPHERES OF VENUS AND EARTH: GREGG DINDERMAN / *S&T*



▲ **PLANET-SIZE CLOUD** Upon arrival at Venus in 2015, the Akatsuki spacecraft spotted this persistent, bow-shaped feature in the planet's clouds. It sits above Aphrodite Terra, the largest continent-like highland region. Image is a false-color infrared view.

The composition of the atmosphere is variable, too. For example, Venus Express found sulfur dioxide above the clouds to be "random" and "patchy," with huge variations from one place to another and from one orbit to another. One way to puff sulfur oxides high into the atmosphere in patchy and random ways is to spew it out of volcanoes.

Akatsuki: Surface to Air Connections

Earth's variable weather is driven by interactions between the air and ground — think of rain shadows behind mountain ranges — but scientists thought Venus's atmosphere was too thick to "feel" the ground below it. However, right after arrival, Akatsuki's cameras spotted a planet-spanning, stationary, bow-shaped cloud. This enormous atmospheric feature permanently sits directly over some of the highest-elevation crust of Venus, Aphrodite Terra.

"I think the most striking result from Akatsuki is this weird connection between the surface topography and massive structures in the clouds," Grinspoon says.

Venus Express scientists found local changes in atmospheric composition in the same location. Climatologists now believe the cloud feature to be a *gravity wave*, a vertical displacement that's the result of the interaction of the moving, buoyant atmosphere and the high topography.

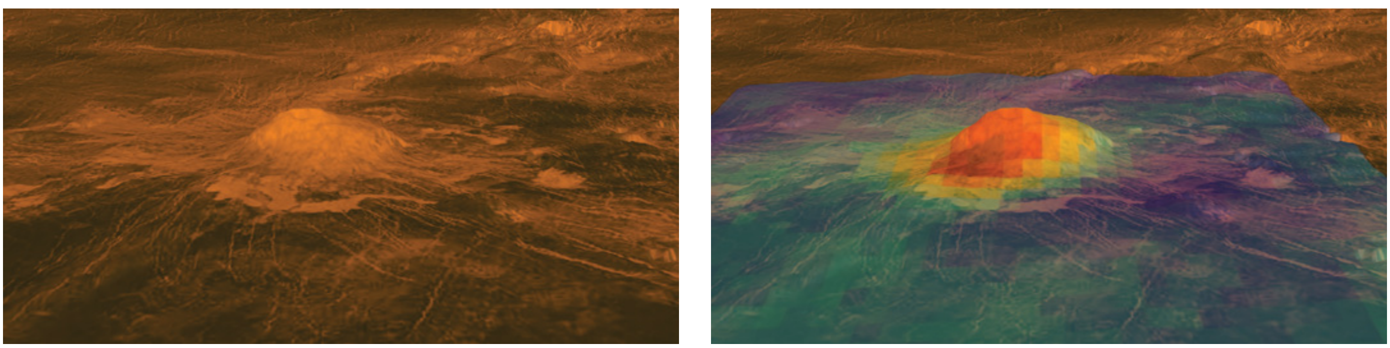
"The atmosphere is much more dynamic than anybody had expected," Ghail says. "And those dynamics must be driven by something."

There are two ways to put energy into an atmosphere: The Sun delivers heat from the top down, and a planet's internal heat puts in energy from the bottom up. Geologic activity — particularly surface volcanism — can shunt a lot of heat into an atmosphere. Venus has lots of volcanoes, but are they active today? Neither orbiter could see the surface clearly enough to tell us for sure what might be happening there, though Venus Express provided enticing glimpses.

For instance, some of Venus's volcanic flows might be fresh. Venus Express saw hints of the heat signature from fresh lava flows that bloomed and then vanished. Volcanism might also explain the short-lived sulfur dioxide clouds the spacecraft detected. The extra heat and volcanic gases could cause rapid chemical weathering on Venus's surface. On Earth, water attacks fresh lava to alter its minerals, but on Venus, sulfur compounds probably connect the chemistry of air and rocks, and sulfur oxides might be the ones to react with minerals.

Any one of these bits of evidence isn't enough to say that Venus is presently volcanically active, but taken together, they at least "demand further investigation," Ghail says. "That's what really justified going back. To understand all those really big surprises in Venus Express data, we need to understand the geology, because Venus Express said: 'Venus isn't anything like you think it is from Magellan. It's active, it's dynamic, it's got things going on.'"

▼ **ACTIVE VOLCANISM?** *Left:* The volcanic peak Idunn Mons lies in the southern Imdr Regio and rises about 2.5 km above the surrounding volcanic plains (vertical extent is exaggerated 30 times in this image, simulated from Magellan data). Bright areas in the radar data indicate rough or steep terrain; dark areas are smooth. *Right:* Heat patterns (colors, red-orange is warmest) observed by Venus Express indicate the summit is warmer than the surrounding terrain, perhaps due to recent lava flows.



GRAVITY WAVE IN VENUS'S ATMOSPHERE: PLANET-C PROJECT TEAM; HOT SPOT ON VENUS: ESA / NASA / JPL-CALTECH

Exoplanet Next Door

What Venus Express and Akatsuki have taught us about Venus's climate has reinforced the idea that the planet may have looked quite Earth-like — watery and temperate — for much of its history (*S&T:* Oct 2021, p. 12). Other missions, like Rosetta, have demonstrated that Earth's water didn't come from comets but may have been part of the planet from the start (*S&T:* May 2017, p. 14).

Smrekar points out that as far back as Magellan, argon isotopic data suggested that if Earth and Venus started out with the same amount of water and other lighter constituents, today's Venus may actually retain more water, deeply buried in mantle rocks, than Earth does.

"We've seen all these low-density planets squashed right up against their suns," Smrekar says. "The idea that your position in the solar system determines how much volatiles you got dealt is wrong. We can't just say, 'Oh, Venus is close to the Sun, so it doesn't have much water.'"

Clearly, to understand exoplanets, it would help if we understood our nearer neighbors better. In a way, exoplanet science has merged with Venus science to produce the current list of highest-priority questions for future missions.

A NASA science advisory body called the Venus Exploration Analysis Group (inevitably abbreviated VEXAG) provides opportunities for Venus scientists to discuss and agree on the most important goals for future Venus exploration. VEXAG members presented the latest version of their consensus at a meeting in November 2021. There are three overarching goals.

The first goal is to figure out what Venus looked like early on and whether it was habitable, in order to better understand the evolution of Venus-size exoplanets. Was Venus once watery like Earth? Is its present state representative of the way that Venus-size planets evolve, or is it unusual?

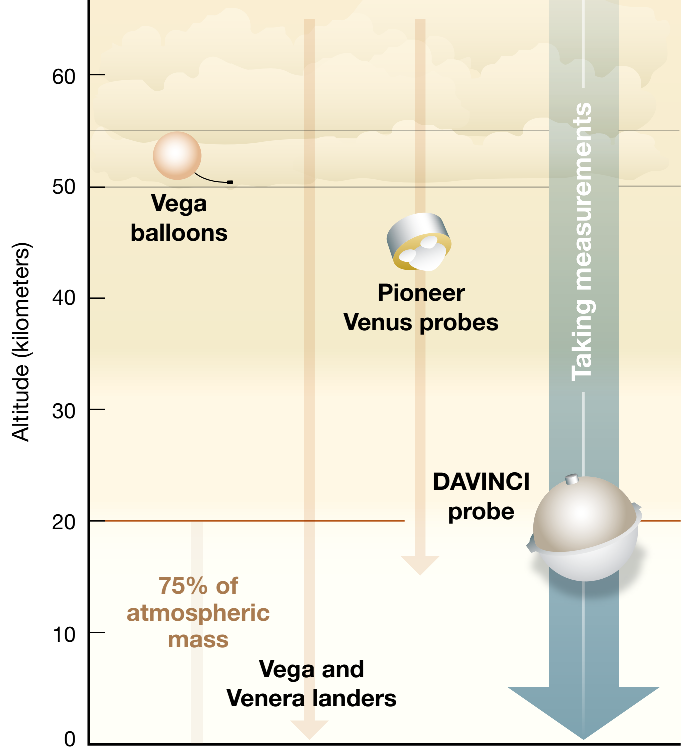
The second is to understand the composition and motions of the atmosphere. What drives all that variable behavior? How are the different parts of the atmosphere connected to one another? What the heck is that ultraviolet absorber?

The third goal is to understand the surface's geologic history and how the surface and atmosphere interact today. What stories are preserved in Venus's rocks? What can we learn from their composition and the landforms they build? What processes shape and modify the surface today? What is the structure of the interior? How do the atmosphere and surface interact chemically?

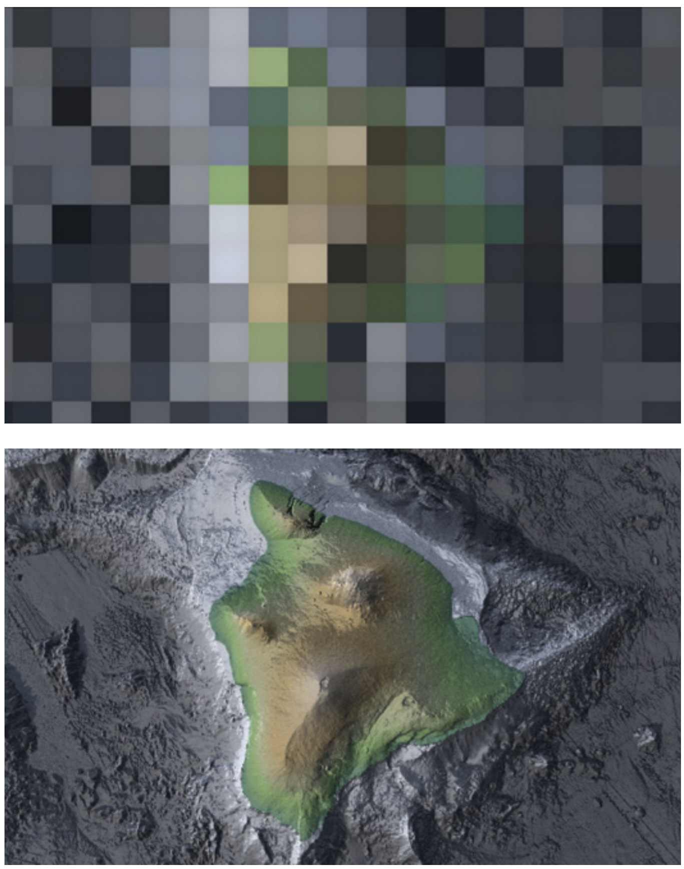
The three missions that will explore Venus in the 2030s will address all of the VEXAG goals. And they will do it cooperatively, building on one another to produce a body of scientific data that is much more than the sum of its parts.

The New Venus Fleet

The study of Venus's geology now is in a similar state to Martian science at the turn of the millennium. (Thanks to Venus Express and Akatsuki, Venusian climate science is more advanced than that.) Following the end of the Mariner and



▲ **A UNIQUE VIEW** Previous missions gave us limited information about the structure of Venus's atmosphere (thin arrows), but DAVINCI will take a wide range of measurements throughout its descent to the surface.



▲ **EYE-OPENING** VERITAS's radar instrument, VISAR, will deliver topographic measurements roughly 100 times sharper than Magellan did. Based on U.S. Geological Survey data, these images show how the island of Hawai‘i would look to Magellan *(top)* and to VERITAS *(bottom)*.

DAVINCI'S DESCENT: GREGG DINDERMAN / *S&T*; RESOLUTION COMPARISON: VERITAS TEAM

WHICH WAY IS SUNRISE?

If you could see the Sun from Venus's surface, it would rise in the west and set in the east.

Viking missions to Mars in the 1970s, geologists lacked new data for the Red Planet until the 1990s. Venus has likewise experienced a long hiatus: The Pioneer Venus, Venera, VeGa, and Magellan missions produced global data sets on surface geology and near-surface atmospheric chemistry, but the only dedicated visitors Venus has had since 1994 are Venus Express and Akatsuki.

VERITAS, DAVINCI, and EnVision stand to kick off a renaissance at Venus like the one that happened on Mars after Pathfinder landed in 1997 and was followed within a decade by four orbiters and two rovers, bringing Mars science into the digital age.

The Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS) orbiter will launch first, late in 2027. It has a narrow but extremely important focus: establishing a foundational, global data set of Venusian topography and radar images using 21st-century technology. It's directly analogous to the Mars Global Surveyor mission, whose laser altimeter MOLA produced the first good topographic map of Mars. Topographic maps are good for science on their own, but their lasting value is as a geodetic base map, which will tie all other past and future data sets to a single model of the planet's geometric shape, enabling data-rich connections among missions. Its first global maps should be available in mid-2031.

VERITAS will also produce a global radar map at a resolution of 30 meters per pixel, similar to early Earth maps from the Landsat satellites or to one of the best current global Mars maps, the one from Mars Odyssey's thermal imager. As with VERITAS's topography data, there will be exciting science revealed in the radar map, but its lasting contribution will be as a geographic reference that will unite all other data.

Finally, VERITAS carries an infrared imaging system that will peer through narrow "windows" in the atmosphere where carbon dioxide is moderately transparent. The resulting maps will be a little fuzzy, because the thick atmosphere scatters light, limiting the resolving power to a pretty low 10 kilometers per pixel.

The images will likely not provide conclusive answers about how Venus's rock composition varies from place to place, but they should provide clear evidence for anomalous spots worth further investigation. And they could even spot telltale emissions from an active eruption, Smrekar hopes. "I would be thrilled if we actually see water coming out of a volcano," she says. "That would be the best day ever."

Following VERITAS is the Deep Atmosphere Venus Investigation of Noble Gases, Chemistry, and Imaging (DAVINCI) mission. Nearly 50 years after the last time we obtained in-situ data from Venus's deep atmosphere, DAVINCI's probe will descend through the clouds to make direct measurements of atmospheric temperature, pressure, and composition.

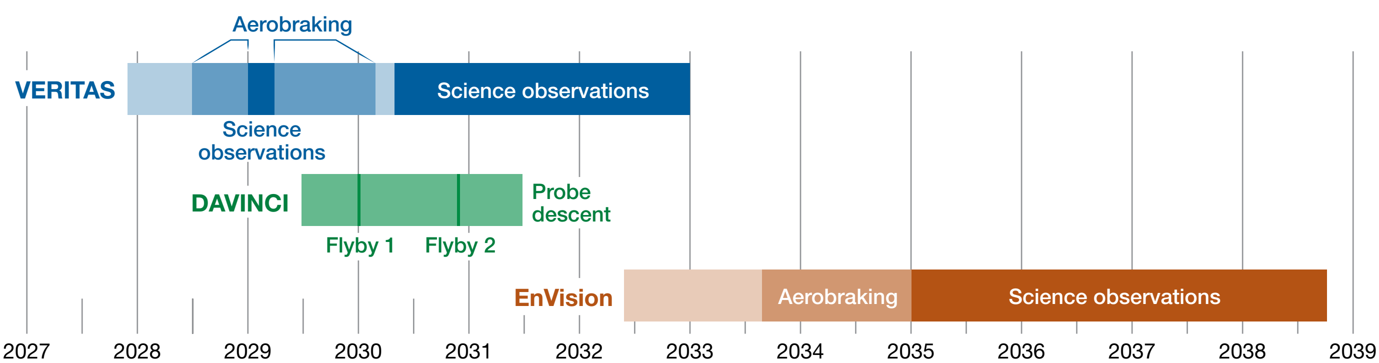
"DAVINCI can measure things that we can't measure from orbit," Grinspoon says. "The rare gases and isotopes have never been decently measured on Venus. And they're just so key to formation and evolution theories." It'll be a "reprint the textbooks" moment when the data come in.

The DAVINCI probe's science payload is heavily based on the miniaturized analytical laboratory instruments in the Curiosity rover that are currently sampling Mars's atmosphere. The probe's descent will take about an hour; for about half of that time, it will be below the bottom of the cloud deck. Unlike any previous Venus descent probe, DAVINCI will shoot images on the way down, like both Curiosity and Perseverance did on Mars, using a similar camera. DAVINCI will serve the same role for Venus as the Huygens probe did for Titan science, connecting Cassini's orbital measurements through Titan's haze to directly measured properties of the atmosphere and surface.

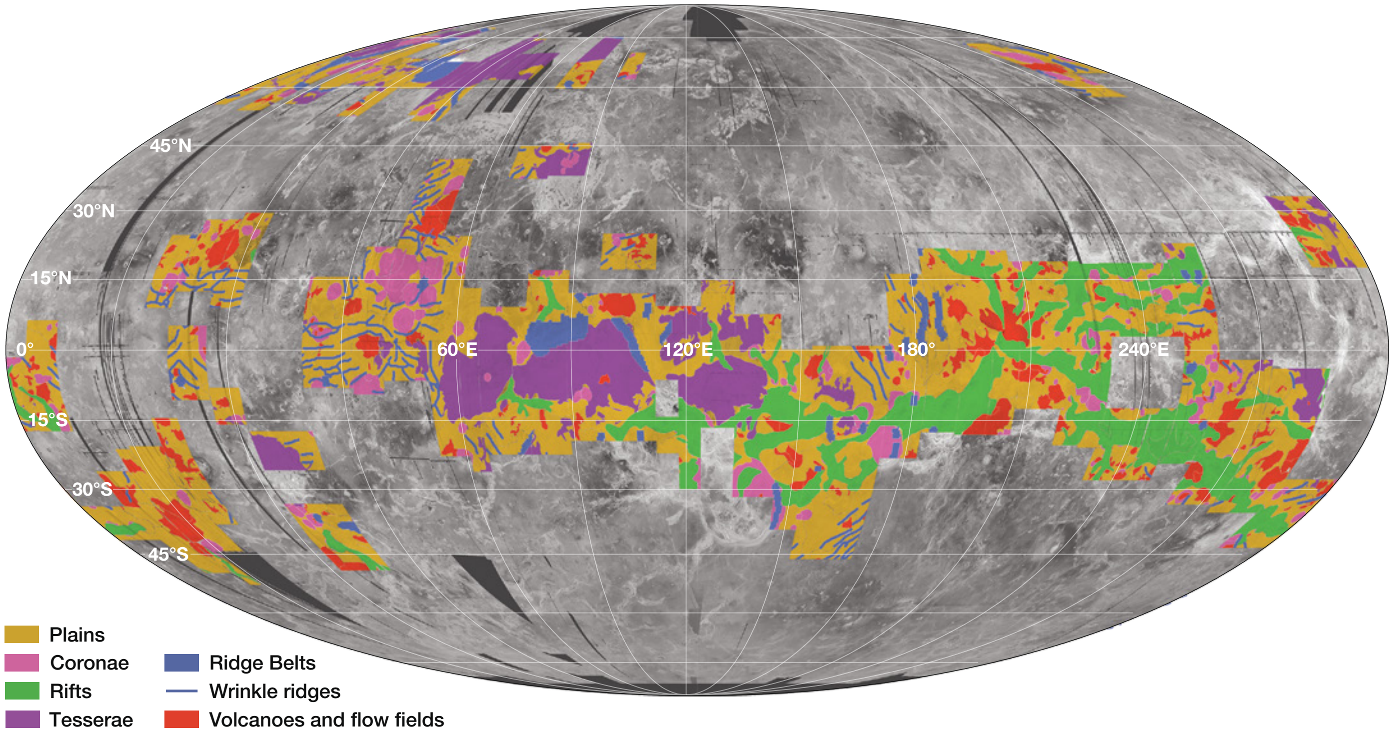
For the best photos, DAVINCI needs to land with the Sun as high overhead as possible. Setting that up requires two flybys, and DAVINCI's carrier spacecraft will make use of those flybys to record long series of images watching the roiling motions of clouds at different levels in the atmosphere.

Both of the NASA missions may be over before the European Space Agency's EnVision arrives at Venus, though we can

TENTATIVE MISSION TIMELINES



SUN ICON: YELENA POLYAKOV / THE NOUN PROJECT; TIMELINE: GREGG DINDERMAN / S&T



▲ **WHAT ENVISION MIGHT SEE** EnVision's radar will penetrate Venus's clouds, mapping key geological features such as volcanoes and continent-like tesserae at a resolution of about 10 km. This map shows one example of the targets the mission could study.

M. PRICE AND J. SUPPE / *EARTH, MOON, AND PLANETS* 1995, ESA, NASA

hope that VERITAS will last longer than its primary planned mission, and that DAVINCI can continue performing flybys. In fact, according to DAVINCI principal investigator Jim Garvin (NASA Goddard Space Flight Center), DAVINCI could go into Venus orbit on its next flyby after dropping the probe.

With VERITAS's global maps and DAVINCI's in-situ measurements already available, EnVision will be able to reach its full potential. If NASA had not selected its two missions for development, EnVision would have had many more mapping responsibilities, Ghail explains. "VERITAS is a global geophysics mission. It's about getting topography and gravity globally, at high resolution. And it's very good at that, better than EnVision would be."

EnVision's radar mapper won't get VERITAS's global coverage, but it will see parts of the surface at higher resolution, focusing on especially compelling geologic features to elucidate the present and past of Venus. EnVision will therefore be able to function like ESA's Sentinel Earth orbiters or the HiRISE camera on NASA's Mars Reconnaissance Orbiter, monitoring Venus's atmosphere and surface for changes over time. EnVision's radar sounder will also draw profiles of the subsurface structure across Venus craters, cracks, volcanoes, and crumpled mountains, just as Mars Express and Mars Reconnaissance Orbiter have done, helping to tell the story of Venus's geologic history.

Finally, EnVision carries a suite of spectrometers that will see to many levels of the atmosphere as well as to the surface. In fact, one of EnVision's spectrometers will be a near-duplicate of the one on VERITAS. Flying a nearly identical instrument twice is not something that happens often in planetary science, but it's very common on Earth orbiters, and it will enable scientists to establish a continuous record of weather and surface changes from VERITAS through EnVision, spanning a decade and possibly more.

The Decade of Venus

To say that Venus scientists are thrilled about the selection of three new missions is understating things. But there are reasons to be happy besides the new data. "It's been a big tension between all the [proposed] missions," Smrekar says. "It's been very fracturing to be so competitive all the time. It's really a pleasure to be cooperating instead of competing."

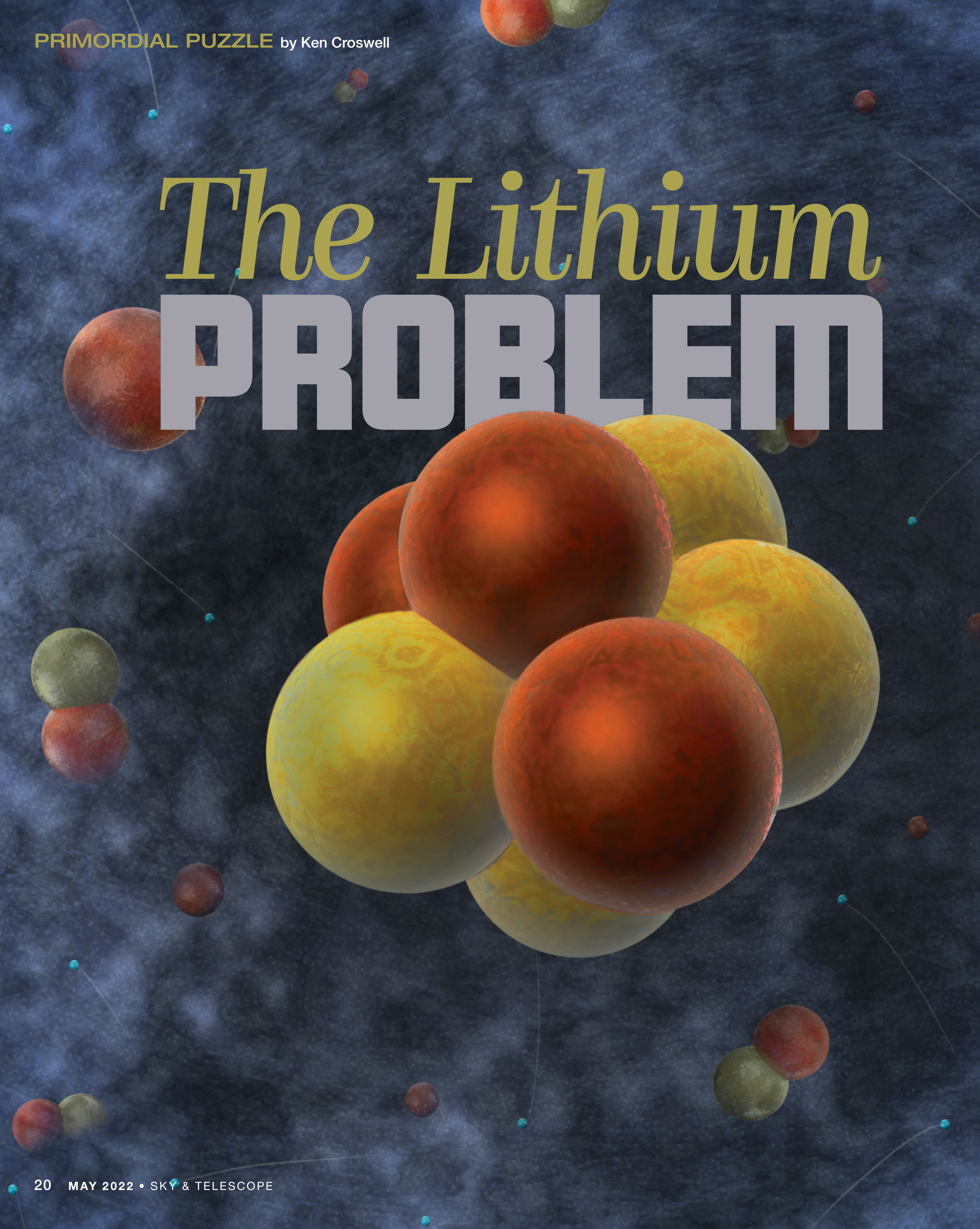
Grinspoon agrees. "There was this wonderful moment after the selection when we realized, 'Oh, now we can all be friends again,' because until then we'd been so in competition against each other."

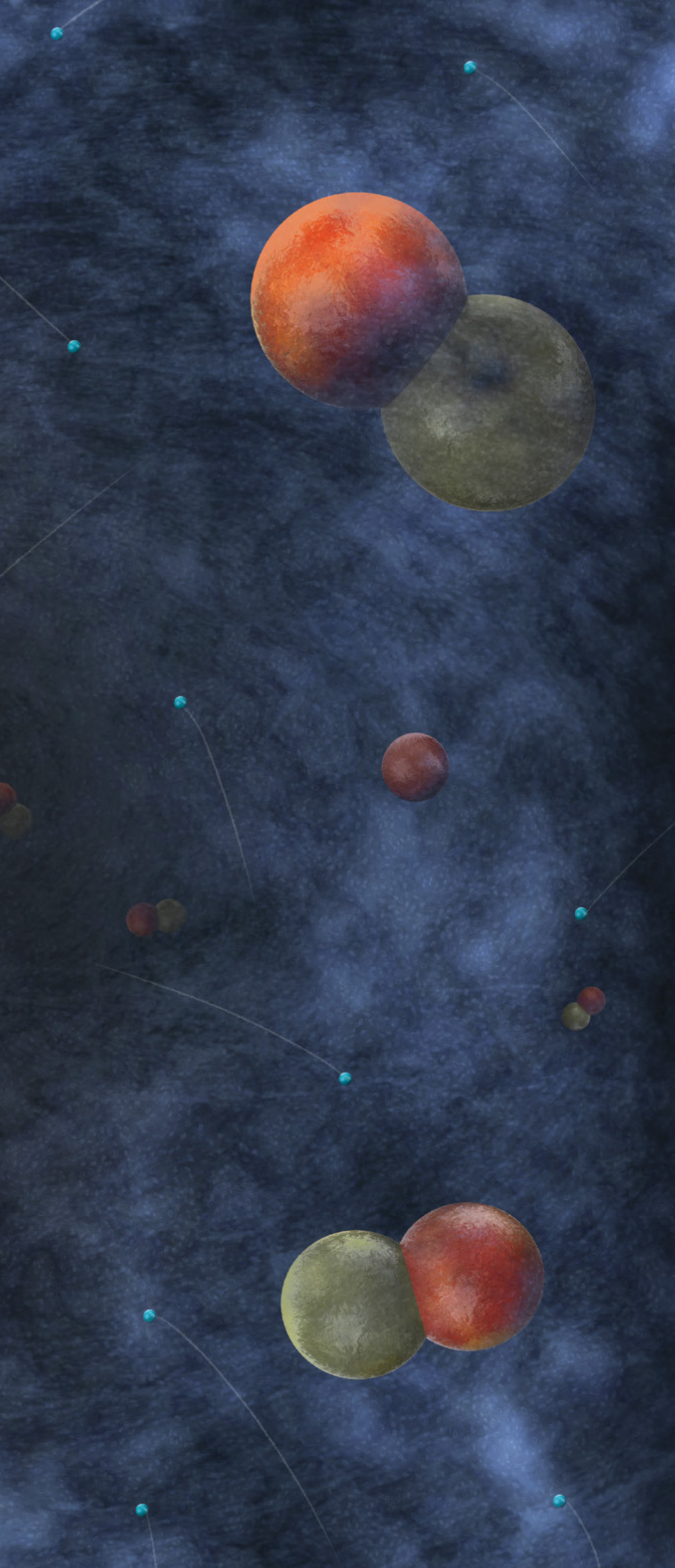
Europe and the United States aren't the only ones planning new missions to Venus. The next decade could also see missions launched by India and even from a private company, Rocket Lab, based in New Zealand. A spacecraft from the United Arab Emirates will also swing by Venus en route to the asteroid belt. Underappreciated and poorly understood for so long, Venus will finally enjoy the kind of scientific boom that Mars has experienced for 25 years. May that boom last at least as long as the Age of Mars has.

■ Contributing Editor **EMILY LAKDAWALLA** is a freelance space writer and artist. Her second book, *Curiosity and Its Science Mission: A Mars Rover Goes to Work*, is forthcoming from Springer-Praxis in 2023.

PRIMORDIAL PUZZLE by Ken Croswell

The Lithium PROBLEM





Why do the oldest stars have only a third as much lithium as Big Bang predictions say they should?

The creation of the universe may seem an impossible subject to study. After all, according to the Planck spacecraft, the Big Bang — the brilliant event that gave birth to our cosmos — occurred 13.8 billion years ago.

Nevertheless, we do see signs of this primeval fireworks display today, in the nearby universe. For one thing, most galaxies rush away from ours. For another, the Big Bang's afterglow pervades space: Microwaves carry news from an era just 380,000 years after the Big Bang, long before stars shone.

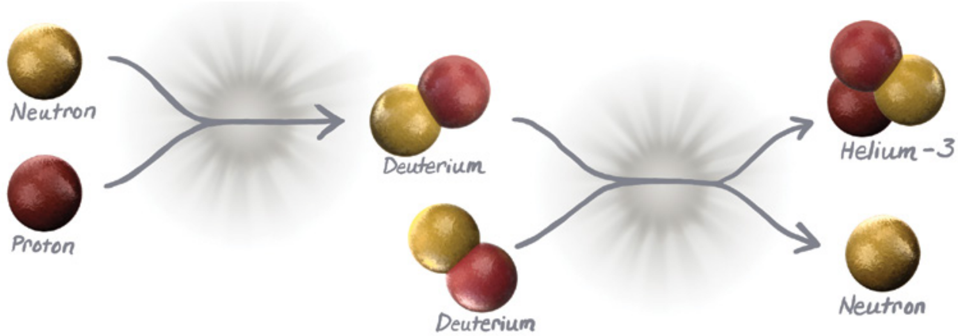
Amazingly, we even have clues from a much earlier epoch. Mere minutes after the Big Bang, the extreme temperature of the plasma filling the universe triggered nuclear reactions, creating elements that survive to this day. The universe at that time was not dense by terrestrial standards: Just 1 second after the Big Bang, the universe's *baryonic*, or normal, matter was fluffier than cotton candy. The nuclear reactions were therefore so simple that cosmologists can work out what happened. The inferno forged lots of hydrogen and helium, the two light elements that still dominate the universe today.

But a third chemical element is currently causing a cosmic conundrum: lithium, which has three protons in its nucleus and is therefore atomic number 3. Nowadays lithium is in certain batteries and antidepressant drugs; it was once in 7UP, perhaps inspiring the "Up" in the drink's name.

In 1981 French astronomers François and Monique Spite (Paris Observatory) accidentally discovered the element in ancient stars, whose chemical composition should largely reflect what the Big Bang produced. These stars, though nearby, were visitors from the stellar halo, the population of old stars that surrounds and penetrates the Milky Way's disk (*S&T:* June 2020, p. 58). Astronomers can recognize nearby halo stars from both their kinematics and also their low iron abundances. Iron originates in supernovae, and halo stars are so old that they formed before many of these explosions had occurred.

NICOLLE R. FULLER, SAYOSTUDIO

▶ **CHAIN REACTIONS** Several key reactions occurred in the primordial universe as particles rapidly collided and created elements heavier than simple hydrogen (whose nucleus is just a proton). Among the earliest were the production of deuterium and helium.



The Spites were actually looking for another chemical element, aluminum, when they saw a spectral line in the red part of the spectrum from lithium. Even though the halo stars had a wide variety of iron abundances, with iron-to-hydrogen ratios ranging from 0.4% to 8% solar, most of the stars had similar amounts of lithium, much less than the Sun was born with. This uniform lithium level, now called the *Spite plateau*, suggested the lithium came straight from the Big Bang instead of building up over cosmic time as generation after generation of stars died and enriched their surroundings.

As if that weren't enough, the quantity of lithium the Spites saw was compatible with the amount that Big Bang calculations had predicted, a result that the theory's proponents trumpeted. "This is a field, in the '80s and '90s, that was afflicted with a bit of triumphalism," said Robert Scherrer (Vanderbilt University) during a recent lecture. "You know, people back then said 'Big Bang nucleosynthesis works, and anyone who disagrees with us is obviously an idiot.'"

Today, however, astronomers instead confront what they call *the lithium problem*. Improved measurements of cosmological constraints have ruined the agreement between theory and observation: Halo stars in the Spite plateau have only a third as much lithium as Big Bang calculations now say they should.

Primordial Prediction and Predicament

In order to predict how much lithium emerged from the Big Bang fireball, cosmologists must know how dense the universe was back then. The denser the universe, the faster the nuclear reactions proceeded, producing more of some isotopes and fewer of others. What counts is the density of baryons participating in nuclear reactions.

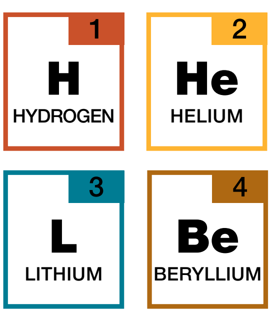
In the 1980s, the universe's baryonic density was poorly determined. "Everything was okay because we didn't know enough," says Keith Olive (University of Minnesota). That's why the predicted lithium level overlapped with the Spites' measurement.

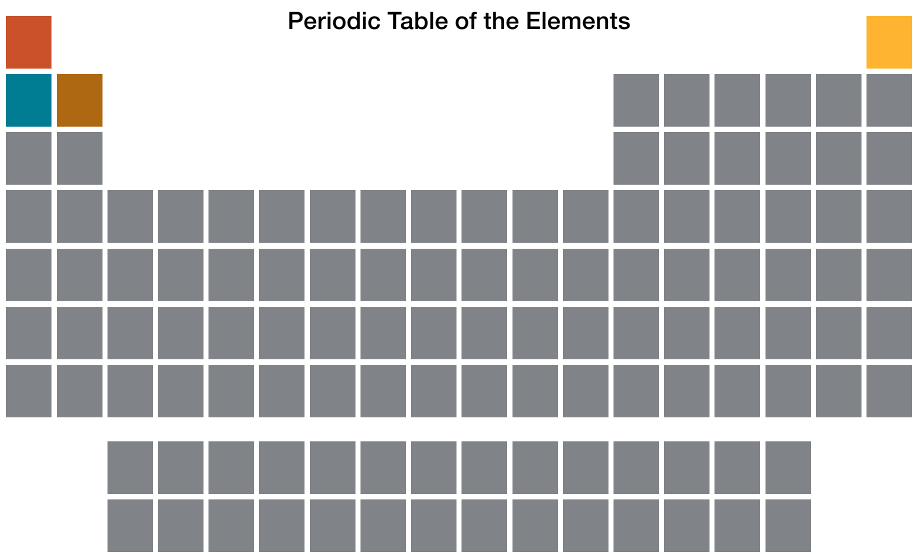
Things aren't okay today. In 2003, the Wilkinson Microwave Anisotropy Probe determined the universe's baryonic density from the tiny temperature fluctuations in the cosmic microwave background. Later the Planck spacecraft pinned this number down to an incredible accuracy of better than 1%. Today we know that baryons constitute just under 5% of the matter needed to halt the universe's expansion.

Now that cosmologists know the exact baryonic density, they can calculate how much lithium the Big Bang initially created: almost none. Protons bombarded the lithium that arose, splitting it into helium-4 nuclei.

Instead, as we now know, the three most common ele-

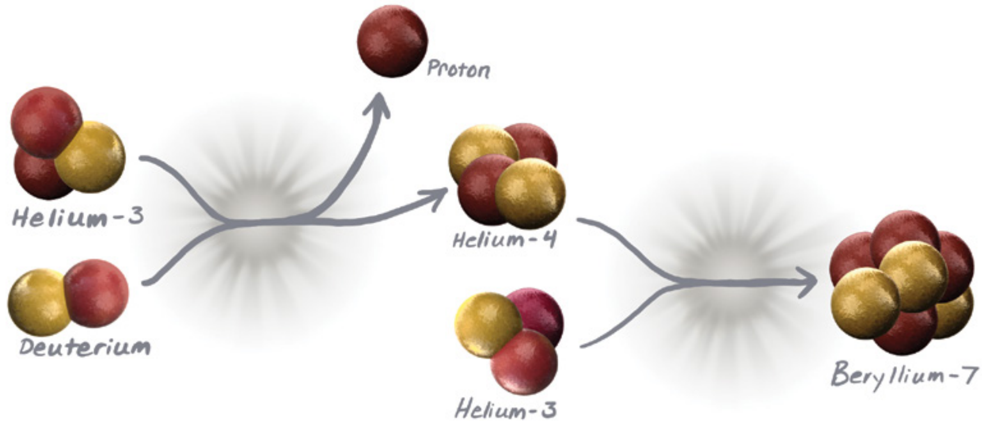
EARLY ELEMENTS Nuclear reactions in the primordial universe involved isotopes of the four lightest elements: hydrogen, helium, lithium, and beryllium. The earliest lithium created was rapidly destroyed by proton collisions, however — almost all of the lithium from the primordial universe instead is a byproduct of later beryllium decay.



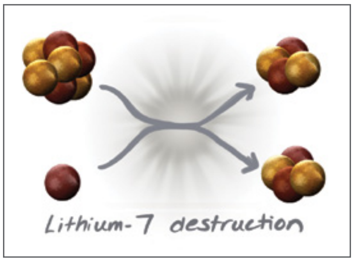


ALL NUCLEAR REACTIONS: NICOLLE R. FULLER, SAYOSTUDIO; PERIODIC TABLE: TERRI DUBÉ

▶ **HEAVIER NUCLEI** As reactions continued in the primordial universe, nuclei combined into larger and larger forms. Hydrogen and helium isotopes interacted with each other and other particles, ultimately creating beryllium mere minutes after the Big Bang.



ments that existed minutes after the Big Bang were hydrogen, helium, and a bit of beryllium, the element with atomic number 4 that's present in emeralds on Earth as well as in the mirrors of the James Webb Space Telescope. Beryllium arose when helium-4 nuclei hit helium-3 to make beryllium-7, whose nucleus has four protons and three neutrons.



On Earth beryllium-7 is radioactive. It decays when one of its four electrons falls into the atom's nucleus and merges with a proton, which becomes a neutron. The atom thereby changes into lithium-7, the dominant lithium isotope.

For many centuries after the Big Bang, however, this decay didn't happen, because all nuclei were naked: They had no electrons at all. If they had, high-energy photons would have torn the electrons away. Beryllium-7 therefore had no electrons to capture.

As space expanded, though, the cosmos cooled, and about 800 years after the Big Bang the temperature fell to some 80,000 kelvin. Beryllium-7 could then acquire electrons, some of which soon fell into the nuclei and turned all of the beryllium into lithium.

This lithium survived. By now the cooler cosmic temperature had tamed the protons; they no longer had enough energy to zap the lithium and split it apart. This is how about 95% of primordial lithium was minted. The rest dates back to the first few minutes of the universe's life — the lucky lithium that evaded the voracious protons.

The problem: These nuclear reactions created three times more lithium than exists in halo stars.

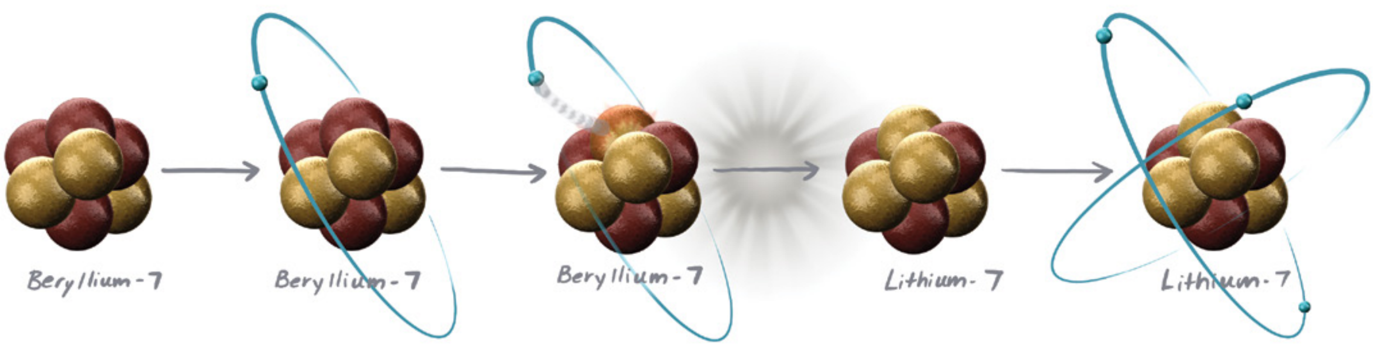
Perhaps, then, the solution to the lithium problem is that we don't fully understand those nuclear reactions. Nuclear physicist Alain Coc (University of Paris, Saclay) had once thought this might indeed be the answer. He and other scientists have spent years studying these nuclear reactions, by theory and experiment, hoping to find a mismatch between the assumed nuclear reaction rates and the actual rates.

The upshot of all this effort? "There is no way to solve this problem by nuclear physics," Coc says. The nuclear reaction rates are now known so well that the predictions are solid — and they confirm that the Big Bang produced three times more lithium than halo stars harbor.

Deuterium Detour

What if something disrupted most of the beryllium nuclei early on, before they could find electrons and make lithium? Neutrons destroy beryllium just as protons destroy lithium. If there were enough neutrons in the early universe, they could have prevented the later formation of lithium, thereby solving the problem.

Not so fast. The early universe had far more protons than neutrons. If it had more neutrons than we thought, those neutrons would have made too much of another primordial product: deuterium.



▲ **LITHIUM'S LATE ARRIVAL** About 800 years after the Big Bang, beryllium nuclei grabbed an electron, but the electron soon fell into the nucleus, converting a proton into a neutron and changing the beryllium into lithium. Much later, the lithium nucleus acquired its usual three electrons.

Deuterium is hydrogen-2, a heavy isotope of the lightest element. Deuterium's nucleus has one proton and one neutron. Although less common than hydrogen-1, deuterium is hardly rare; it's almost as abundant as iron, which is the ninth most common element in the modern cosmos. Every time you drink water, you're ingesting not just H_2O but also HDO and even D_2O.

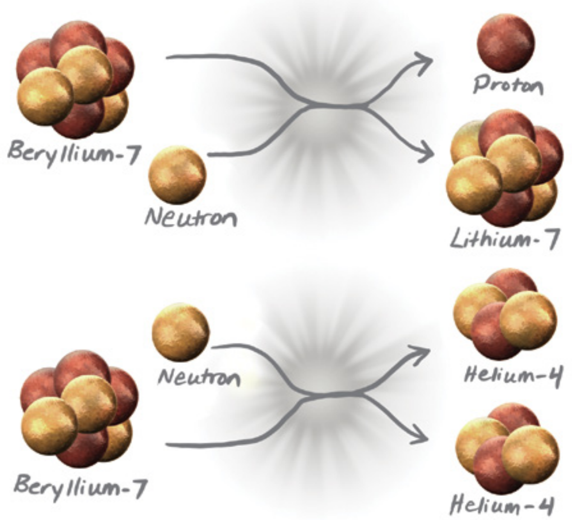
But deuterium is delicate. The Sun creates the isotope every second but annihilates it a second later by turning it into helium-3. Nearly all the deuterium on Earth and in space arose right after the Big Bang when protons smashed into neutrons. The isotope survived the primordial inferno only because the universe expanded and cooled, shutting off the nuclear reactions before they could destroy the deuterium.

10 BILLION KELVIN Universe's temperature when it was 1 second old

1 BILLION KELVIN Universe's temperature at 100 seconds

The primordial deuterium abundance reveals the universe's baryonic density: The denser the universe, the less deuterium there is, because the nuclear reactions would have eliminated more of the isotope. Thus, astronomers were motivated to find deuterium in space, which they first did in the 1970s.

But those early measurements didn't necessarily represent the universe's original quantity of deuterium. To know that, astronomers had to observe a pristine environment. The obvious choice — halo stars — won't work, because they have annihilated the easily burned isotope. But in the 1990s, astronomers began reporting deuterium in pristine gas clouds that lie between us and distant quasars, whose light shines through the clouds and reveals the clouds' compositions. Although the first published result proved incorrect, by the early 21st century a primordial deuterium level was emerging that agreed with the baryonic density derived from observations of the cosmic microwave background with the Wilkinson Microwave Anisotropy Probe.



▲ **BERYLLIUM'S NEMESIS** Interactions with neutrons in the early universe could easily convert beryllium into lithium or break it into two helium nuclei. But almost all the lithium made this way didn't survive, and most neutrons were busy being part of deuterium and helium anyway.

Today the primordial deuterium abundance is known with an accuracy of just 1%. In 2018 a team led by Ryan Cooke (Durham University, UK) reported a deuterium-to-hydrogen ratio of 2.5×10^{-5}. That means the Big Bang generated one deuterium nucleus for every 40,000 hydrogen-1 nuclei. Moreover, this number requires a baryonic density that agrees with the value the Planck spacecraft measured.

So we know the primordial deuterium abundance. We know the universe's density, which agrees with the deuterium abundance. And deuterium has neutrons. Therefore, if the early universe really had enough neutrons to get rid of beryllium, thereby solving the lithium problem, those neutrons should also have created too much deuterium, leading to a deuterium problem.

There's also another problem with invoking neutrons. Most of the universe's neutrons are in helium, whose primordial value we know by observing oxygen-poor galaxies such as I Zwicky 18 (*S&T:* Apr. 2018, p. 22). If the early universe had too many neutrons, these primitive galaxies should have more helium than they actually do.

New Physics

Perhaps the solution to the lithium problem requires something more daring: new laws of physics. After all, if we don't grasp the laws of physics, some unknown phenomenon at the dawn of time could have altered the amount of lithium.

Although this idea may sound crazy, new physics did solve another long-standing puzzle, the solar neutrino problem. Scientists had detected only about a third of the expected number of neutrinos from the Sun. At that time, the standard wisdom held that these ghostly particles had no mass. We now know that neutrinos do have mass, which lets them oscillate from one type to another. There are three types of neutrinos, and the experiments were sensitive to only one, explaining the factor-of-three shortfall.

To solve the lithium problem, some scientists have proposed that a "Particle X" arose soon after the Big Bang. Particle X lived just a short time, so it broke up, emitting neutrons that obliterated two-thirds of the beryllium-7 but managed to leave the deuterium and helium alone.

Even wilder ideas exist. Perhaps some of the fundamental constants of nature, such as the speed of light or the charge of an electron, differed during the universe's earliest moments. Or — most extreme of all — perhaps the disagreement between theory and observation means the whole theory is wrong: The Big Bang never happened.

The Fault in Our Stars

Given the extraordinary amount of evidence in favor of the Big Bang, few astronomers embrace such a radical solution to the lithium problem. In fact, many are now leaning toward an idea that comes not from invoking new physics but instead from refuting old English literature. Contrary to the words of

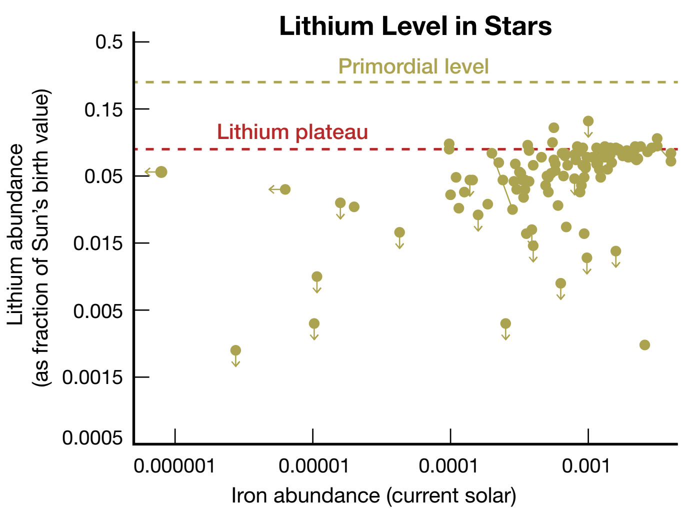
William Shakespeare, the fault really does lie in our stars — specifically, in our halo stars.

Stars usually destroy lithium, because the element is fragile. Protons split it apart once the temperature exceeds 2.5 million K. The Sun has annihilated nearly all of its lithium. Although the solar surface is too cool to harm the element, the outer parts of the Sun are convective. That means they bubble and boil, dragging surface material down into the hot interior, where protons destroy the lithium.

In part because of their low level of heavy elements, or *metals*, halo stars have thinner convective zones, so lithium stays near the surface and survives. But did all of it survive? "To me, it's unfathomable that nature doesn't find a way" to eliminate most of the lithium, says Grant Mathews (University of Notre Dame). After all, halo stars have been around for more than 10 billion years, during which time the lithium could have sunk beneath the thin outer layer and been consumed by the hot interior. If so, that solves the lithium problem. "Which is too bad, because it's also the most boring explanation," says Mathews.

One argument against this explanation is the Spite plateau: All its stars have nearly the same amount of lithium. How could stars with different masses, rotation periods, magnetic fields, and metal abundances have all removed the same fraction of their lithium? It's like standing in a forest in mid-autumn and seeing that every tree has shed exactly the same fraction of its leaves.

In recent years, though, astronomers have found evidence that some halo stars *do* destroy their lithium. In particular, astronomers have discovered that the rare halo stars with



▲ **SPITE PLATEAU** When astronomers measure the lithium levels of ancient stars, they find a maximum value called the Spite plateau. Astronomers thought the plateau value revealed how much lithium Big Bang nucleosynthesis created, but the plateau is inexplicably lower than updated primordial calculations. Old, extremely metal-poor stars (shown here) often have values far below the plateau, which potentially means the stars have destroyed their lithium with time. Such destruction might be the ultimate explanation for the lithium problem. (The Sun's current lithium level is 0.5% of its birth value.)

D. S. AGUADO / *ASTROPHYSICAL JOURNAL LETTERS* 2019

Some Halo Stars Observed by the Spites

Object	Mag(v)	RA	Dec.	Constellation
HD 76932	5.9	$08^{h}\,58.7^{m}$	–16° 07′	Hydra
HD 84937	8.3	$09^{h}\,48.9^{m}$	+13° 44′	Leo
HD 94028	8.2	$10^{h}\,51.5^{m}$	+20° 16′	Leo
HD 134169	7.7	$15^{h}\,08.3^{m}$	+03° 55′	Virgo
HD 140283	7.2	$15^{h}\,43.1^{m}$	–10° 56′	Libra
HD 194598	8.3	$20^{h}\,26.2^{m}$	+09° 27′	Delphinus
HD 201891	7.4	$21^{h}\,12.0^{m}$	+17° 43′	Pegasus

Right ascension and declination are for equinox 2000.0.

exceptionally low iron abundances — so pristine in their makeup that researchers would expect them to best reflect the Big Bang's composition — often have lithium levels far below that of the Spite plateau. Astronomers have called this phenomenon the "meltdown" of the plateau. These extreme halo stars have clearly found a way to erase most of their lithium. If they have, then so, too, might all halo stars, which means we cannot assume that the Spite plateau is an imprint from Big Bang nuclear reactions.

To gauge opinions about these developments, scientists at a 2019 conference in Italy voted on their preferred answer to the lithium problem. The winning solution? The Big Bang nucleosynthesis calculations are fine; halo stars have destroyed two-thirds of their lithium.

If so, then we currently have no direct measurement of how much lithium the primordial universe produced. Someday decades hence, with advanced telescopes, astronomers may discern this crucial number.

This will be extremely difficult, though, and not just because lithium is much rarer than deuterium. The best targets will probably be metal-poor clouds of cold gas, either in or between galaxies. The clouds must be metal-poor so that their composition is primordial; they must be cold because otherwise lithium atoms lose an electron, which leads to spectral lines that get swamped by those of hydrogen. Finally, the clouds must lie in front of stars or quasars. Then the lithium can signal its presence by absorbing some of the background light.

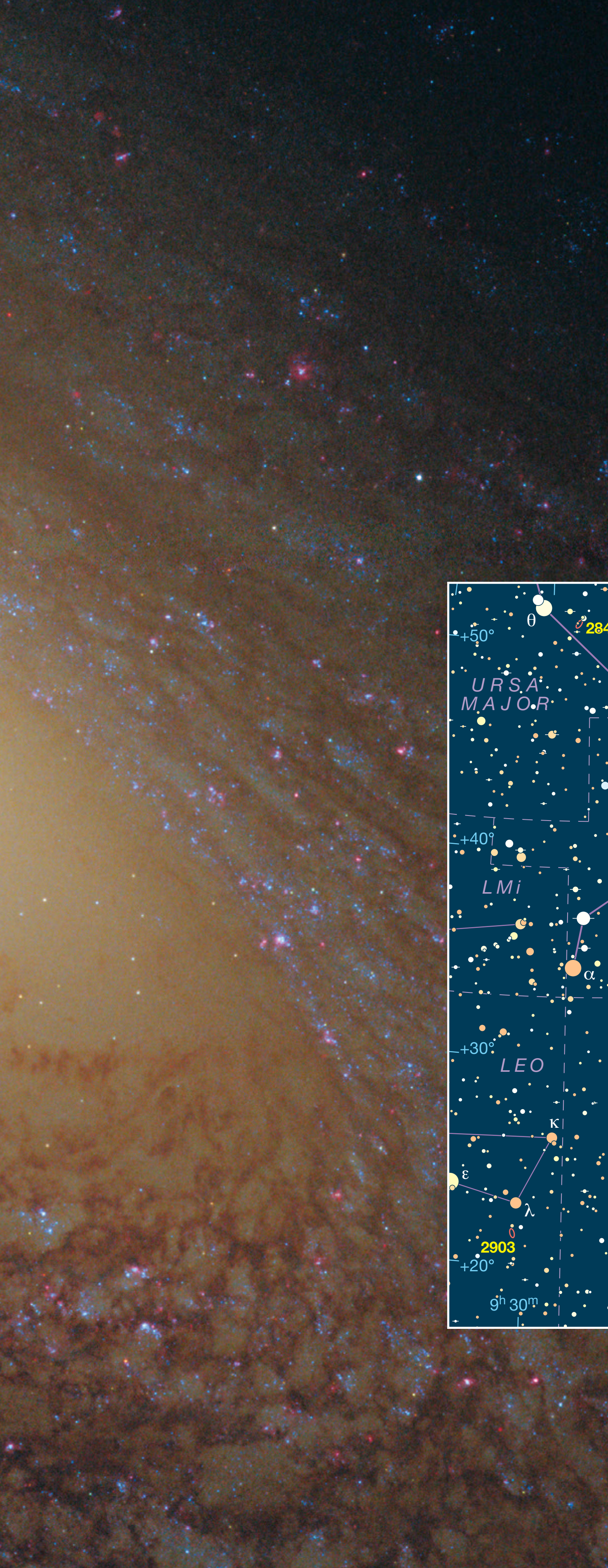
If such measurements someday succeed and show a high primordial lithium level that agrees with Big Bang theory, the result will affirm the standard cosmology. On the other hand, if the two numbers still disagree, astronomers will need to seek another solution to the lithium problem. And who knows: There's even an outside chance that Big Bang skeptics such as the late Fred Hoyle — who coined "Big Bang" without believing in it — will have the last laugh.

■ **KEN CROSWELL** earned his PhD from Harvard University for observing halo stars in the Milky Way. He has written about Big Bang nucleosynthesis in his books *The Alchemy of the Heavens* and *The Universe at Midnight*.

 by Scott Harrington

Springtime's *Neglected* Binocular Galaxies

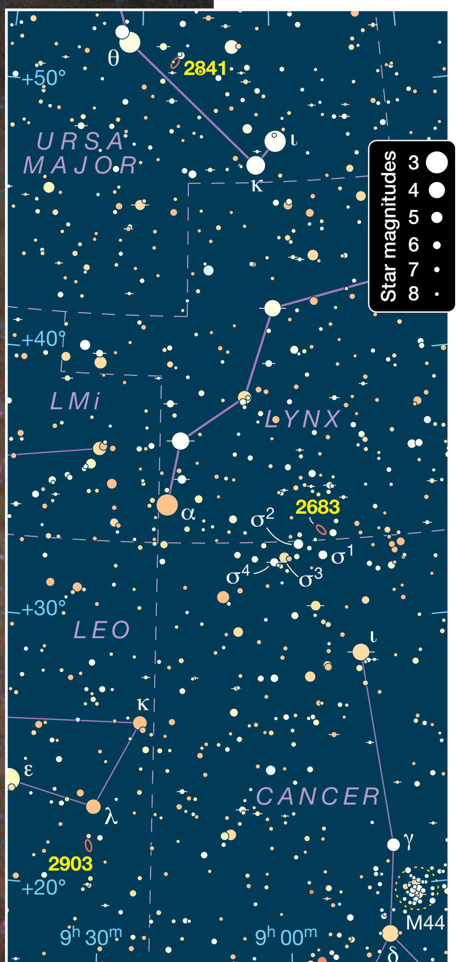
BY THE BEAR'S PAW Lying at a distance of some 46 million light-years in Ursa Major, NGC 2841 is the prototype of objects known as *flocculent spiral galaxies*. These galaxies are characterized by disjointed, fragmented spiral arms that appear patchy in images — the patchiness is likely due to star formation. North is up in all images unless otherwise noted.



Crack out your binos and see how many distant island universes you can spot during mild May evenings.

Less than 15 years ago, when I first started stargazing, all I had to aid my observing was an old pair of 7×35 binoculars. I had no idea what they might reveal, so every new deep-sky object I saw thrilled me — especially galaxies. I concentrated on the Messier catalog during those early years and let it be my guide to what I thought were all the brightest galaxies in the sky.

As I became a better observer, however, I glimpsed a few bright galaxies that weren't in Charles Messier's famous list. This was simultaneously shocking and exhilarating because it meant there might be many more visible of which I was unaware. I then became obsessed with seeing all the galaxies I could in those little 7×35s and, after many years of dedicated searching, reached a grand total of 87 galaxies!



▲ **GALAXY TOUR** Hop down from Ursa Major through Lynx down to Leo to find three targets for your binoculars.

In the end, I'd seen 38 galaxies brighter than magnitude 10.0 not listed in the Messier catalog. It's a stunning number because there are only 37 Messier galaxies that meet this threshold! This revealed just how many galaxies binocular observers are missing if they only stick to Messier's list. So, on this tour, I'll be visiting 14 of those 38 "neglected" galaxies using mostly my 8×56 and 12×60 binoculars (with true fields of view of 5.9° and 5.0°, respectively).

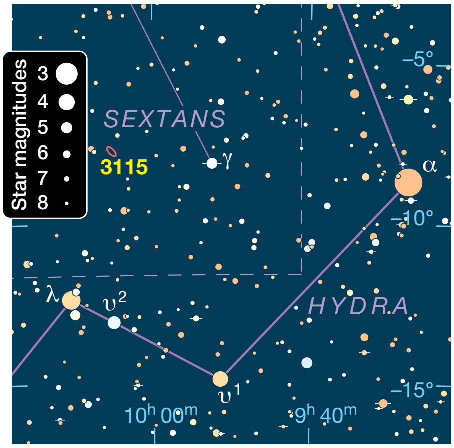
North by Northwest

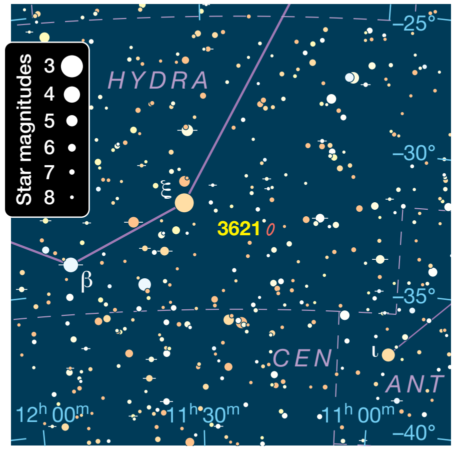
Let's start with the bright but oft-overlooked **NGC 2841**, which resides near the front paw of Ursa Major. To find the 9.2-magnitude galaxy (which is tilted 25° from edge-on), simply look 1.8° southwest of 3rd-magnitude Theta (θ) Ursae Majoris. In my 8×56 binos, it's immediately visible 5′ southwest of an 8.5-magnitude star as an elongated glow running northwest to southeast. With my 12×60s, the galaxy's entire glow is 6.5′ long and appears mottled. However, my 5.1-inch (130-mm) reflector at 27× reveals that what I'm actually seeing is the galaxy's bright little core, along with an 11.2-magnitude star involved in the northern end. When looking at this intermediate-type spiral, try to keep in mind that it's comparable in size to our very own Milky Way!

NASA / ESA / HUBBLE HERITAGE (STSCI / AURA) / ESA / HUBBLE COLLABORATION / ACKNOWLEDGEMENT: M. CROCKETT AND S. KAVIRAJ (OXFORD UNIVERSITY) / R. O'CONNELL (UNIVERSITY OF VIRGINIA) / B. WHITMORE (STSCI) / WFC3 SCIENTIFIC OVERSIGHT COMMITTEE

Our next target is 9.8-magnitude **NGC 2683**, which lies nearly 20° farther south in Lynx right along the border with Cancer. To get to it, I like to start by finding 3rd-magnitude Alpha (α) Lyncis with my naked eye. This can be easily accomplished by drawing a line from Regulus, or Alpha Leonis, northwest up to 3rd-magnitude Epsilon (ε) Leonis and continuing about the same distance again. With Alpha Lyncis now in your binoculars, sliding 6° a bit south of due west will bring the sought-after galaxy into view, along with a loose gathering of 5th- and 6th-magnitude stars that carry the Bayer designation Sigma (σ) Cancri.

With both binos, a small clump of four faint stars is the first thing that catches my eyes in the target location. NGC 2683, tilted about 10° from edge-on, is fainter and takes more effort to spot just 0.2° north of the stellar quartet. With the 8×56s, the galaxy is a faint smudge and only with averted vision can I see it as a streak. The view doesn't improve much with my 12×60s except that I can discern the galaxy's length to be about 3′.



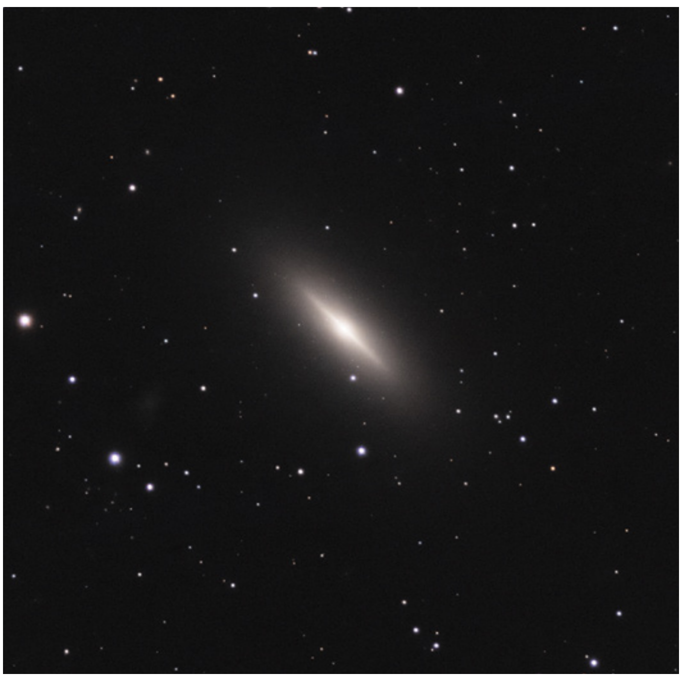


To find the well-known telescope target **NGC 2903**, drop southeast to 4th-magnitude Lambda (λ) Leonis in the Sickle of Leo. This 9th-magnitude galaxy lies only 1.5° south of the star and is easy to see in my 8×56s. It's physically similar in size to the Milky Way and in images appears as a magnificent, barred spiral tilted about 26° from edge-on. With my 12×60s I can see a small disk with direct vision, while it swells to about 6′ long with averted vision. It's also mildly elongated north-south, and I can glimpse an 11.5-magnitude star off to its south-southeast.

Below the Lion

The Polish astronomer and cartographer Johannes Hevelius established the constellation Sextans in the 17th century (as he did Lynx). And just like NGC 2683, the 8.9-magnitude galaxy **NGC 3115** is the brightest in its respective constellation by more than a full magnitude.

To locate it, simply slide 6.2° east-northeast of yellow, 2nd-magnitude Alpha Hydrae until you reach Gamma (γ) Sextantis. Continuing in



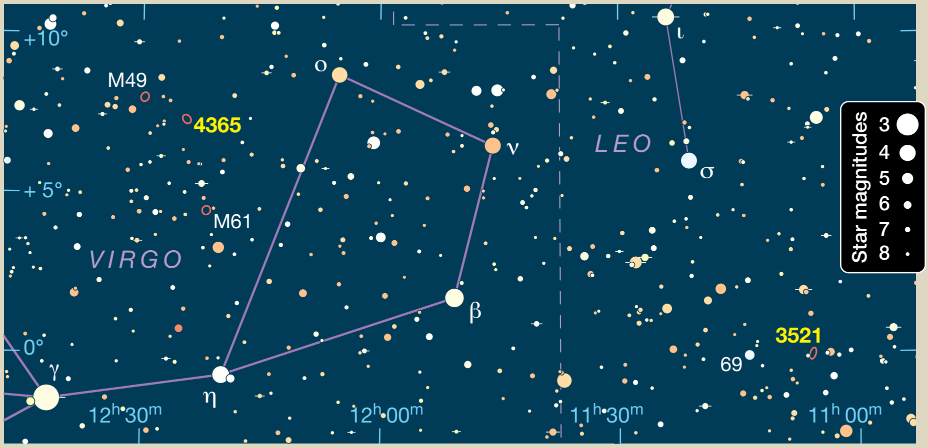
▲ **THE SPINDLE** The only galaxy on this tour in Sextans is the lenticular NGC 3115. Of the first six galaxies visited here, it's the only one that isn't a member of a sparsely populated group of galaxies dubbed the "Leo Spur." The image is the view with a 5.1-inch (130-mm) scope.

▲ **MESMERISING SPIRAL** NGC 3521 in Leo is a beauty in big instruments such as the European Southern Observatory's 8-m Very Large Telescope in Chile where this image was taken. But you can nevertheless enjoy the sight in your binoculars.

NGC 3115: GARY IMM; NGC 3521: ESO / O. MALIY; NGC 4365: JIM THOMMES; SKETCH: SCOTT HARRINGTON

▶ **EITHER SIDE OF THE BORDER** You'll find the galaxies NGC 4365 and NGC 3521 in the adjacent constellations of Virgo and Leo.

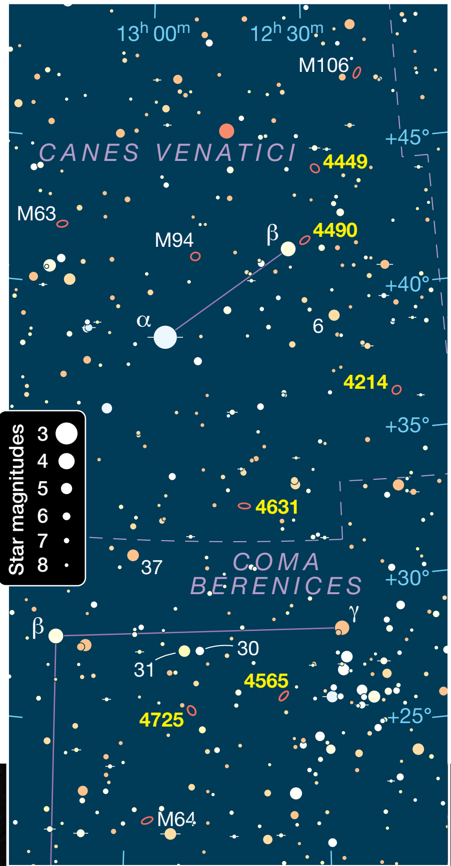
▼ **ANCIENT LIGHT** NGC 4365 is the most distant object in this sampling of springtime galaxies, lying 74 million light-years away in the constellation Virgo. The sketch shows the 4° binocular field of view, with M49 above center and NGC 4365 toward the right edge of the circle, as well as NGC 4526 and NGC 4535 toward the left edge. The image below, taken with a 6-inch (152-mm) Newtonian at f/4.8, zooms into the area around NGC 4365 and spans some 1.3°. Asteroid 535 Montague serendipitously visited the field in 2019 and appears as a short streak above NGC 4365.



the same direction for another 3.2° will bring you to the brightest (confirmed) lenticular galaxy in the sky, which immediately looks like an out-of-focus star in my 8×56 binos. Upon closer inspection, I can see two faint stars of magnitudes 10.5 and 11.1 east of the galaxy.

With my 12×60s the famous Spindle Galaxy, as it's also known, has a high-surface-brightness core that appears out-of-round. It's here that the nearest billion-solar-mass black hole to Earth lurks. I see diffuse extensions protruding to the northeast and southwest, making it appear a good 4′ long. This galaxy really looks like a brighter version of NGC 2683.

Each object we've visited so far has been farther south than the previous one, and our next target continues this trend. In fact, 9.7-magnitude **NGC 3621** in Hydra was the most southerly object ever discovered by William Herschel. To see it, though, you'll need to be able to reach down to the 4th-magnitude stars Xi (ξ) and Beta (β) Hydrae at the very bottom of the Water Snake's belly.



◀ **TRICKLE OF TARGETS** A sextet of galaxies awaits you in your exploration from Coma to Canes.

NGC 3621 lies 3¼° west-southwest of Xi Hydrae. It's noticeable in my 8×56s thanks to its relatively large disk, which is a smooth glow elongated north-south. With my 12×60s, the galaxy spans nearly 12′ and has a 10.3-magnitude star off its southwestern edge. NGC 3621 is about 80,000 light-years across and in photographs appears as a loosely wound spiral galaxy tilted 23° from edge-on.

Among the galaxies on our tour, **NGC 3521** in Leo was actually the first one discovered — by William Herschel

▲ **ONE-ARMED BEAUTY** NGC 4725 is a rare example of a one-armed spiral galaxy that we see tilted halfway from edge-on to face-on. Two spirals bracket it: NGC 4747 (also known as Arp 159) sits above left, while NGC 4712 floats below right. The image was taken with a 14-inch f/9.5 telescope.

ALSON WONG

all the way back in February 1784. To find this 9th-magnitude object, you'll need to star-hop down the hind leg of the Lion until you reach 4th-magnitude Sigma Leonis, then continue south-southwestward another 6.4° before reaching 5.4-magnitude 69 Leonis. The galaxy lies exactly 2° due west and in my 8×56 binos looks like an out-of-focus star about 10′ northwest of a 7.9-magnitude star.

In images like the one on page 28, NGC 3521 is a mesmerizing spiral galaxy tilted only about 24° from edge-on. With my 12×60s, it has a bright little center that gradually fades out and a barely detectable north-south elongation to its disk.

Skipping *Over* the Cluster

The area of sky shared by Virgo and Leo harbors numerous galaxies bright enough for binoculars. Most are members of the well-known Virgo Cluster, but a few aren't — and **NGC 4365**, at magnitude 9.6, is the brightest of those. Luckily, it's not too hard to find since it lies just 1.5° southwest of 8th-magnitude M49 and has 10th-magnitude stars on either side of it, at equal separations of 14′.

Interestingly, NGC 4365 and M49 are both giant elliptical galaxies comparable in size and mass to each other. However, NGC 4365 lies 20 million light-years *behind* M49. Yet even at that distance the galaxy is still visible in my 8×56s as a distinctly nonstellar glow! Turning my 12×60s towards it only reveals a bright core. NGC 4365 is very simple looking and reminds me of countless other galaxies I've seen in binoculars.

Like most of the constellations on this tour, Coma Berenices has plenty of galaxies bright enough for binoculars. But unbeknownst to many (including Charles Messier and his contemporaries), the galaxy tied for third brightest in the constellation is the 9.4-magnitude beauty **NGC 4725**. To find it, start at the naked-eye "corner" star Beta Comae Berenices before sliding west nearly 5° to the ½°-wide pair of faint, naked-eye stars 30 and 31 Comae Berenices. You should spot the galaxy 2° south from there and just west of a nearly vertical isosceles triangle of mostly 9th- and 10th-magnitude stars.

In my 8×56s, NGC 4725 appears bright and distinctly nonstellar. With my 12×60 binos I can see that the galaxy's halo is gently elongated northeast to southwest and measures 6′ long. It has a smooth gradient all the way down to a stellar core. I can glimpse an 11.6-magnitude star 6′ to the northwest and an 11.5-magnitude star 10′ to the southwest. NGC 4725 is possibly larger than our own Milky Way and a transition galaxy between a normal and a barred spiral.

Not far outside the naked-eye Coma Cluster (this open star cluster is also known as Melotte 111) is one of the most difficult spiral galaxies I've ever seen in 7×35 binoculars. Cataloged as **NGC 4565** but popularly known as the Needle Galaxy, it lies a mere 3.2° west-northwest of our last target.

Even with the extra aperture of my 8×56 binos, the almost perfectly edge-on, magnitude-9.6 spiral isn't an easy catch. It lies 0.2° north-northwest of 9.1-magnitude HD 109718 and is just a dim, extremely thin sliver of light. In the 12×60s, I can detect the Needle stretching out to an impressive 9′ in length. What's truly incredible is that the extent of NGC 4565's disk stretches 50% *beyond* that of the Milky Way's.

JOE RENZETTI

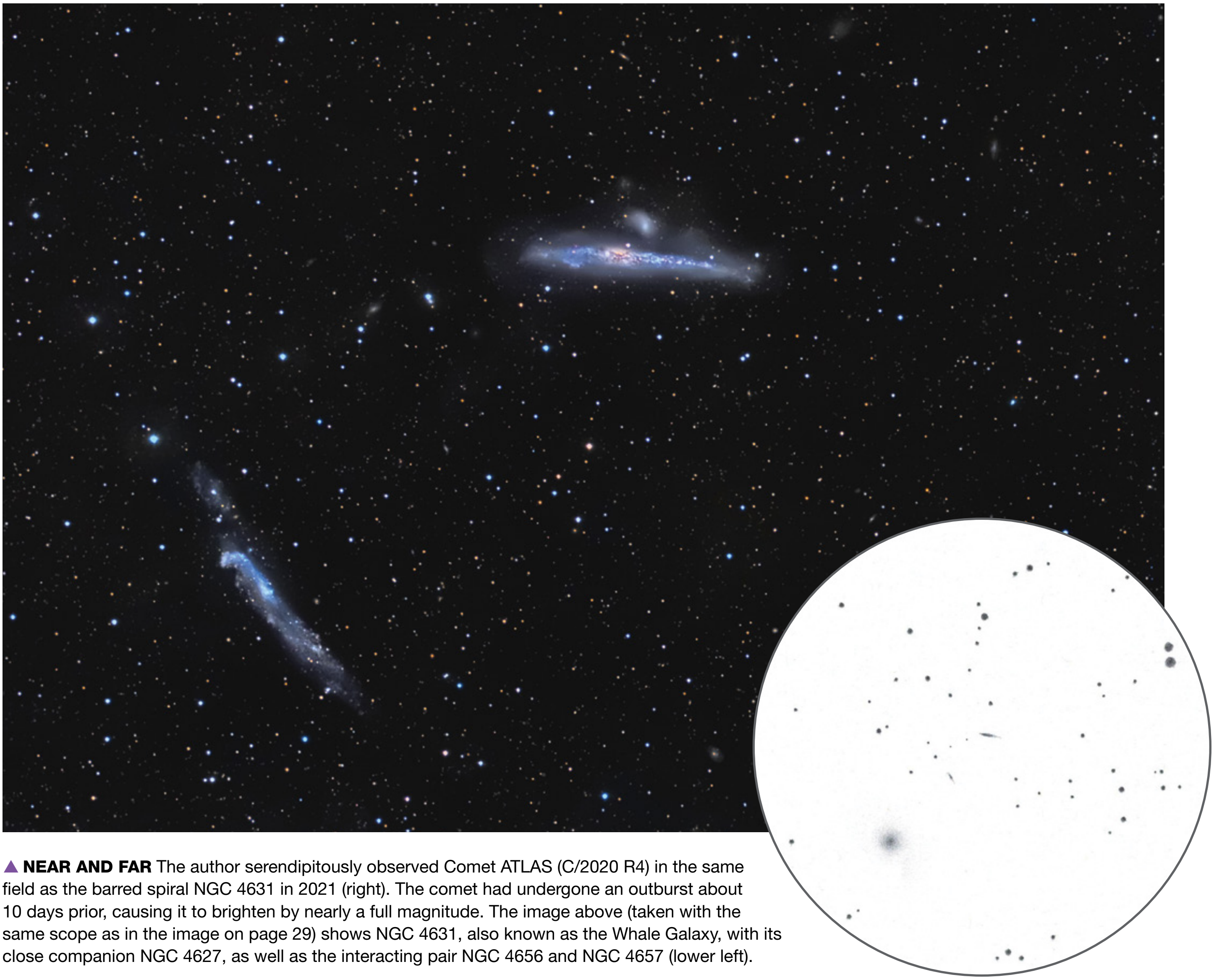
▲ **THE NEEDLE** Edge-on spiral NGC 4565 is only one of more than two dozen galaxies bright enough for binoculars in Coma Berenices.

The Dog House

Our next galaxy is an arresting sight in any size binoculars and way more impressive than the previous object. **NGC 4631** lies along the southern border of Canes Venatici. To find it go back to Beta Comae then slide a bit less than 4° northwest to 4.9-magnitude 37 Comae before continuing in roughly the same direction for another 4.2°.

In my 8×56s, NGC 4631 is a bright and distinct slash running east to west with the dimmer slash of NGC 4656 only ½° southeast. In the 12×60s, NGC 4631 spans an impressive 12′, with the western end slightly brighter and broader. In fact, this broadening has led many telescope users to see it as a gray whale swimming eastward. Despite its unusual appearance, it's actually just an edge-on barred spiral galaxy that's a little smaller than our Milky Way.

The second-brightest star in Canes Venatici is 4th-magnitude Beta Canum Venaticorum, and it will be our jumping-off point for the next three targets. The first is 9.8-magnitude **NGC 4490**, which couldn't be easier to locate as it lies



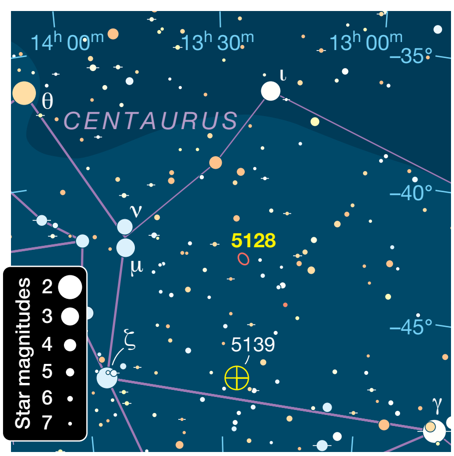
▲ **NEAR AND FAR** The author serendipitously observed Comet ATLAS (C/2020 R4) in the same field as the barred spiral NGC 4631 in 2021 (right). The comet had undergone an outburst about 10 days prior, causing it to brighten by nearly a full magnitude. The image above (taken with the same scope as in the image on page 29) shows NGC 4631, also known as the Whale Galaxy, with its close companion NGC 4627, as well as the interacting pair NGC 4656 and NGC 4657 (lower left).

NGC 4631: JIM THOMMES; SKETCH: SCOTT HARRINGTON

a mere ½° northwest of the star. It's a barely nonstellar glow in my 8×56 binos with an 11.2-magnitude star just south of it. With the extra magnification of my 12×60s, I see a tiny triangle of 11th-magnitude stars 12′ north of the galaxy. Those binoculars also reveal the galaxy's east-to-west elongation and a uniformly high surface brightness.

To get to our next object, **NGC 4214** (also magnitude 9.8), find Beta Canum Venaticorum again and drop about 3° south-southwest to 5th-magnitude 6 Canum Venaticorum. Continuing in that same direction for another 3½° will bring the galaxy into view.

With my 8×56s, NGC 4214 is tough to spot as it lies in a field devoid of any stars brighter than 9th magnitude. Once found, it strongly resembles a globular cluster (as I see them with the 8×56s) since it's just a diffuse, round spot with no central brightening. My 12×60 binos show it to be a 7′-wide galaxy of even brightness. I can also tell that it's slightly out-of-round and a touch longer north-south than east-west.



Classified as a dwarf starburst galaxy, NGC 4214 is so small (23,000 light-years across) that the only reason it's visible in binoculars is because it lies a mere 10 million light-years away. However, it's this proximity that makes it quite a fascinating study in large telescopes (*S&T:* May 2021, p. 22).

The final galaxy we're going to scare up with the help of the Hunting Dogs is **NGC 4449**. It lies almost 3°

north-northwest of Beta Canum Venaticorum, or about midway to M106. In fact, for years I unknowingly passed over NGC 4449 on my way to the brighter Messier! When I did finally pay it a visit, I was shocked to find it noticeably brighter than its listed magnitude of 9.6. With both my 8×56 and 12×60 binos, NGC 4449 offers a diffuse, 3′-wide glow that only with concentration reveals a bright center.

Like NGC 4214 before it, NGC 4449 is also a dwarf galaxy that also lies relatively nearby, at a distance of around 13 million light-years. Another similarity is that both have several bright star-forming regions to delight owners of double-digit telescopes.

One Last Thing

The final stop on our tour is not only the brightest at magnitude 6.8 but also the most southerly. Known as Centaurus A, the enigmatic galaxy **NGC 5128** only culminates at an elevation of 11° from my location in northern Arkansas. It isn't hard to find, though, when the grand globular cluster Omega Centauri (NGC 5139) is also visible, since the galaxy lies just 4.5° due north.

I can find the galaxy in my 7×35s without too much work, and it appears in my 8×56s as a soft, moderately sized glow. I can also see three roughly 10th-magnitude stars spaced 10′ apart below it. Turning my 12×60s towards it, I can discern the galaxy's round glow out to 6′ even though its cataloged dimensions are more than four times as large. Sadly, I can only detect the wide dust lane that so famously crosses NGC 5128 laterally with effort in my 5.1-inch reflector.

▲ **IRREGULAR DWARF GALAXY** Look for NGC 4449 in the western reaches of Canes Venatici. The reddish regions are evidence of ongoing star formation, while bluish white clusters of hot massive stars are scattered throughout. This image was taken with a 5.5-inch (140-mm) refractor.

Each galaxy on this tour is an amazing sight in binoculars — but if you have a telescope, don't hesitate to point it at these marvelous objects. Nevertheless, I hope I've encouraged you to use your binoculars just a little bit more next time you're out observing.

■ **SCOTT HARRINGTON** is an avid user of handheld binoculars and has seen more than two-thirds of the Astronomical League's Herschel 400 observing program in 8×56s.

Double-Barreled Delights

Object	Constellation	Surface Brightness	Mag(v)	Dist (M l-y)	Size/Sep	RA	Dec.
NGC 2841	Ursa Major	12.7	9.2	46	8.1′ × 3.5′	$09^h 22.0^m$	+50° 59′
NGC 2683	Lynx	12.9	9.8	29	9.3′ × 2.1′	$08^h 52.7^m$	+33° 25′
NGC 2903	Leo	13.5	9.0	30	12.6′ × 6.0′	$09^h 32.2^m$	+21° 30′
NGC 3115	Sextans	11.9	8.9	33	7.2′ × 2.4′	$10^h 05.2^m$	–07° 43′
NGC 3621	Hydra	14.3	9.7	22	12.3′ × 6.8′	$11^h 18.3^m$	–32° 49′
NGC 3521	Leo	13.2	9.0	40	11.2′ × 5.4′	$11^h 05.8^m$	–00° 02′
NGC 4365	Virgo	13.4	9.6	74	6.9′ × 5.0′	$12^h 24.5^m$	+07° 19′
NGC 4725	Coma Berenices	14.0	9.4	42	10.7′ × 7.6′	$12^h 50.4^m$	+25° 30′
NGC 4565	Coma Berenices	13.3	9.6	41	15.8′ × 2.1′	$12^h 36.3^m$	+25° 59′
NGC 4631	Canes Venatici	13.1	9.2	24	15.2′ × 2.8′	$12^h 42.1^m$	+32° 32′
NGC 4490	Canes Venatici	12.9	9.8	28	6.4′ × 3.2′	$12^h 30.6^m$	+41° 39′
NGC 4214	Canes Venatici	14.0	9.8	10	8.0′ × 6.6′	$12^h 15.6^m$	+36° 20′
NGC 4449	Canes Venatici	13.0	9.6	13	6.2′ × 4.4′	$12^h 28.2^m$	+44° 06′
NGC 5128	Centaurus	13.5	6.8	12	25.7′ × 20.0′	$13^h 25.5^m$	–43° 01′

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

MIKE KEITH

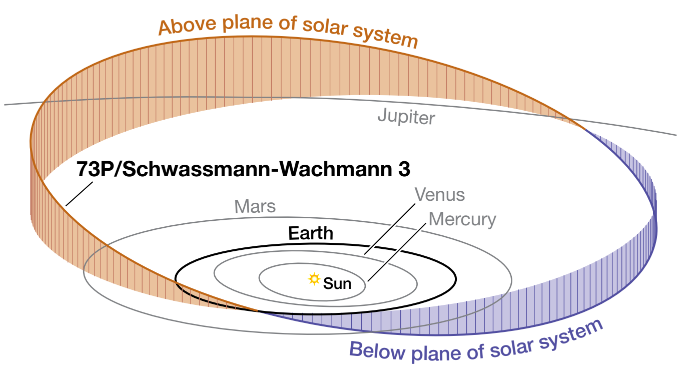
A New Meteor Shower?

A broken comet might produce a surprise display at the end of May.

On the night of May 2, 1930, German astronomers Friedrich Carl Arnold Schwassmann and Arno Arthur Wachmann were on the hunt for new asteroids at the Hamburg Observatory. On this night, however, one of their photographic plates instead recorded the image of a new comet — the third such find for the two astronomers (the others were in 1927 and 1929).

After its discovery, Comet 73P/Schwassmann-Wachmann 3 as it's now known (and abbreviated in this article to SW3) moved with increasing speed northeast across the constellation Hercules. Japanese astronomer Tosio Watanabe derived an orbit showing that it would pass only 0.0617 a.u. (9.23 million kilometers) from Earth on May 31st that year. Such a close approach suggested that the comet might briefly become a spectacular sight. But, alas, it didn't. Even at its closest, SW3 never got much brighter than 7th magnitude and sprouted a rather stubby, faint tail only about ½° long.

The comet was hardly a significant solar system object, measuring only around 1.3 kilometers (0.81 miles) across. Despite its diminutive size, Belgian-American astronomer George Van Biesbroeck, scrutinizing it with the 40-inch refractor at Yerkes Observatory, could see a minute, spindle-shaped body that "presented some resemblance to a spiral nebula seen edgewise" occupying the center of the coma. Notes the highly regarded comet expert John Bortle, "This may have been the first time a comet's solid nucleus had been glimpsed."



▲ **CIRCLING THE SUN** SW3 is a member of Jupiter's comet family — a group of about 400 short-period comets with aphelia near the giant planet's orbit. SW3's orbital period is 5.4 years, and it arrived at aphelion in late December 2019, some 5.213 a.u. from the Sun. The comet's next perihelion occurs on August 25th this year.

Although SW3 orbits the Sun every 5.4 years, no one saw it again for nearly five decades. Between 1935 and 1974, the comet came and went eight times without being observed, and it wasn't spotted again until March 1979. Its January 1985 return was missed, but it was recovered again early in 1990 during its best apparition since 1930. This time the comet peaked at magnitude 9 as it passed 0.3661 a.u. from Earth.

A "New" Comet Returns

In mid-October 1995, the Central Bureau for Astronomical Telegrams suddenly began receiving "numerous reports from observers worldwide of independent discoveries" of a comet verging on naked-eye visibility and sporting a dust tail 1° long, low in the western evening twilight.

But this wasn't a new comet at all — it was SW3.

Its appearance was astonishing, because during this return SW3 never came closer to Earth than 1.311 a.u. (on October 17th). By all rights, the comet should have peaked at magnitude 12. And yet there it was, shining 400 times brighter than expected. What caused this tremendous outburst?

Observations made in December that year at the European Southern Observatory in La Silla, Chile, showed that the comet's tiny nucleus had apparently fractured into four parts designated A, B, C, and D. The comet was again quite bright on its next visit, in the autumn of 2000. Two of the fragments (B and C) made the return trip together with a third one (a companion to C), which was first spotted late in 1996.

In the spring of 2006, the disintegrating comet made another appearance. On April 18th, the Hubble Space Telescope recorded 58 fragments, and between May 4th and 6th, astronomers using the Spitzer Space Telescope's Infrared Array Camera imaged 45 of the pieces. In all, SW3 ultimately broke into more than 68 bits, the largest of which passed closest to Earth on May 12th at a distance of 0.0782 a.u., with two smaller chunks coming even closer (see *S&T:* May 2006, p. 60).

MORE METEORS, PLEASE One of the year's richest, most reliable meteor showers is the Geminids in December, pictured in this composite photo of the 2021 display. Debris shed by SW3 may produce a similar spectacle at the end of May — or perhaps nothing at all.

October 2011 marked yet another unfavorable apparition for SW3, and on the comet's most recent return in March 2017, it showed signs that it was continuing to break apart and shed new pieces.

Comet Crumbs

A disintegrating comet with an orbit that comes very close to Earth suggests that a new meteor shower could be spawned. And this wouldn't be the first time our planet interacted with the dross of a broken comet. The most famous case is the breakup of Comet Biela (in 1842 or early 1843) and its association with spectacular Andromedid meteor storms occurring in 1872 and 1885 (*S&T:* Nov. 2020, p. 58). The question is, should we hope for a similar performance resulting from the recent breakup of SW3?

Shortly after the comet's discovery in 1930, scientists considered this possibility. Among them, Japanese astronomer Yoshitsugu Shibata forecasted that a meteor shower might occur as Earth passed close to the comet's descending node on June 9th that year. The assumed radiant was located in northern Hercules, near the 4th-magnitude star Tau (τ) Herculis, lending the potential display its moniker the Tau Herculids. Supposedly, around the time when the shower was predicted to take place, a brief bevy of faint (4th- and 5th-magnitude) meteors was reported by a lone Japanese observer who claimed to possess "very sensitive eyes." However, the credibility of the observations seems doubtful considering that he was viewing during a nearly full Moon and through a layer of high clouds. No other reports surfaced, so it's unlikely that an outburst in 1930 actually took place. Tau Herculid activity in the years that followed ranged from non-existent to sparse.

Now, because of the ongoing fragmentation of SW3, we could once again consider the prospects for a new meteor shower. Could this be the year?

Modelling Meteors

Three independent studies investigated the likelihood of a new SW3 meteor shower occurring this year at the end of May. A team from the University of Western Ontario led by astronomer Paul Wiegert studied the material shed by SW3 when it first split in 1995. Their research uses a computer

▼ **FLIGHTS OF FANCY** Artistic license may have been employed in this depiction of the Andromedid meteor storm of November 27, 1872. The display arose from the breakup of Comet Biela. Could the fracturing of Comet 73P/Schwassmann–Wachmann 3 (SW3) generate some kind of meteor activity this May? Computer modeling suggests it's possible.

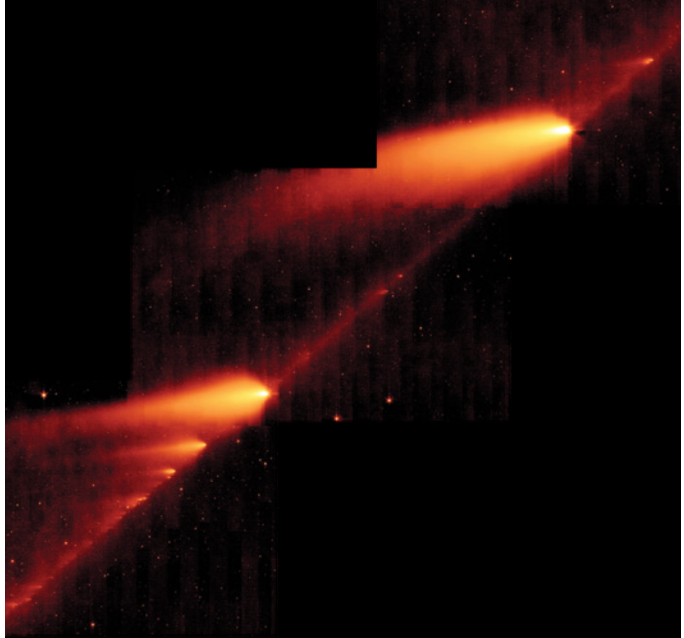
ANTIQUA PRINT GALLERY / ALAMY STOCK PHOTO simulation for the formation and evolution of comet dust trails developed in 2004 by Jérémie Vaubaillon at the Institute for Celestial Mechanics and Computation of Ephemerides in Paris, France. This model takes into account comets such as SW3 that orbit at heliocentric distances of less than 3 a.u. and that ultimately produce clouds of dusty debris.

The bits that crumble off a comet's nucleus spread out along its orbit (both ahead and behind) and in time form a thin, ribbonlike sheet mostly confined to the comet's orbital plane. Whenever Earth cuts through this plane fairly close to the comet's path, we have a chance for a meteor shower.

Vaubaillon's model simulates the evolution of a number of dust trails going back to the year 1801, each resulting from debris shed during a particular swing by the Sun. Wiegert's study predicts meteor activity originating from SW3 occurring around May 30–31, 2022 — but not from particles released during the 1995 apparition; rather, from those created during pre-discovery apparitions in 1892 and 1897. A maximum *zenithal hourly rate* (ZHR, the number of meteors a single observer would see under ideal conditions with the radiant directly overhead) of around 10 is possible from these 19th-century particles.

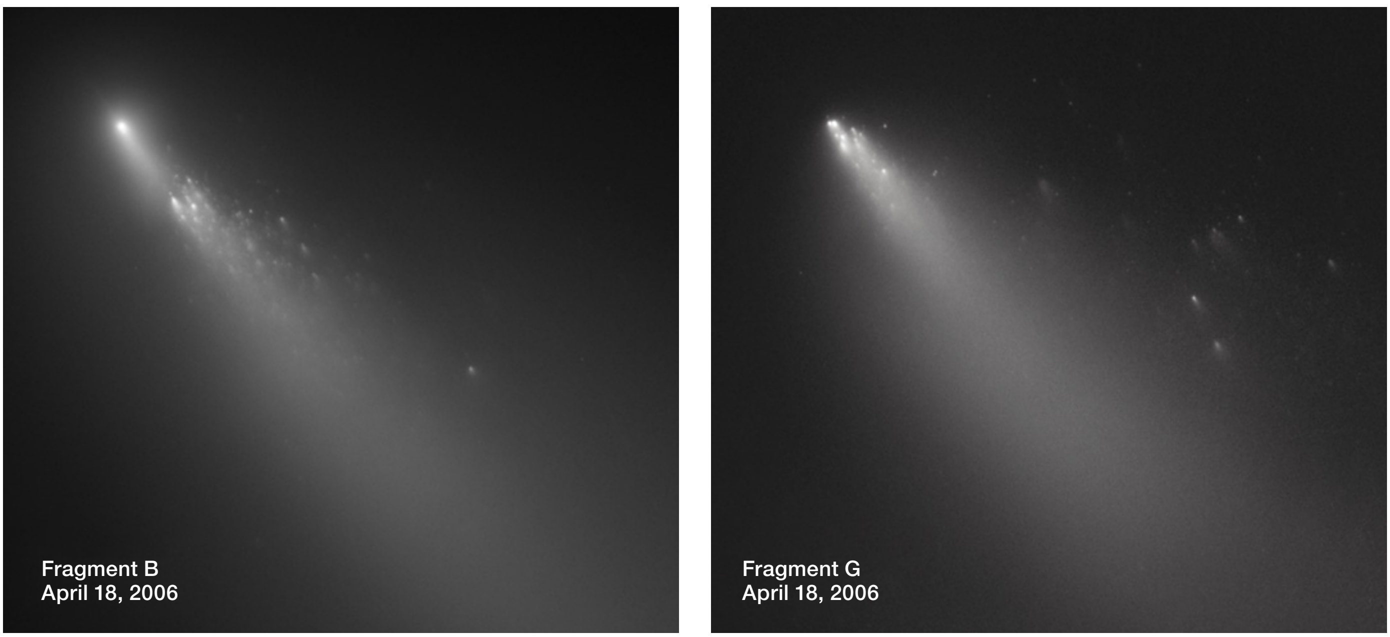
However, two other studies arrived at a different and more exciting outcome. In Germany, a group headed by meteor astronomer Hartwig Lüthen, and another team in Japan led by researcher Shun Horii, have both come to the same conclusion: This year Earth will, in fact, directly encounter material released when SW3 split in 1995.

The teams considered two important factors. First, the brightness spike that occurred in early October 1995 was likely due to a sudden and massive expulsion of dust. In such an unusual situation, particle ejection velocities are presumed



BIG BREAKUP The Infrared Array Camera on board the Spitzer Space Telescope recorded this image of SW3 on May 4–6, 2006. The brightest fragment at the upper right of the track is designated C, while fragment B is below and left of center. Spitzer's infrared view also captures the trail of dust left behind as the comet deteriorated during perihelion passages in 1995 and 2001.

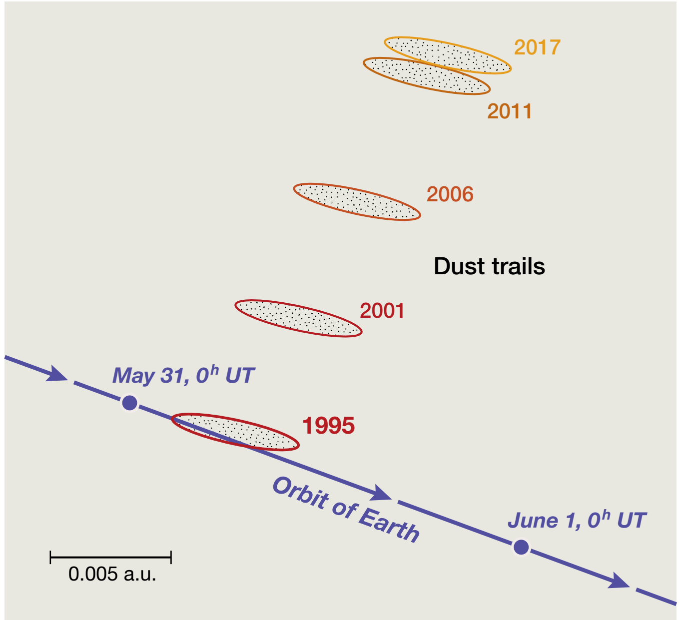
to be much higher than normal. Second, the particles making up most of the annual meteor showers are extremely small, ranging in size from sand grains to specks of dust with the consistency of cigar ash. But when a comet nucleus breaks up, some particles probably will be much larger, ranging upward in size from gravel to nugget-size pieces and quite possibly even bigger. Where such large particles end up along the comet's orbit depends in part on the spin of the comet's



▲ **HST VIEW** The Hubble Space Telescope imaged the continuing breakup of SW3 in 2006. As this pair of photos shows, each large fragment was in the process of generating numerous, smaller "mini-fragments."

nucleus and the location of the outgassing regions on it. Small particles trail the comet and are pushed away more rapidly by the pressure of sunlight regardless of the direction in which they leave the nucleus. Larger particles, however, are not affected by solar radiation. That's why the Lüthen and Horii teams didn't take the effects of radiation pressure into account in their calculations.

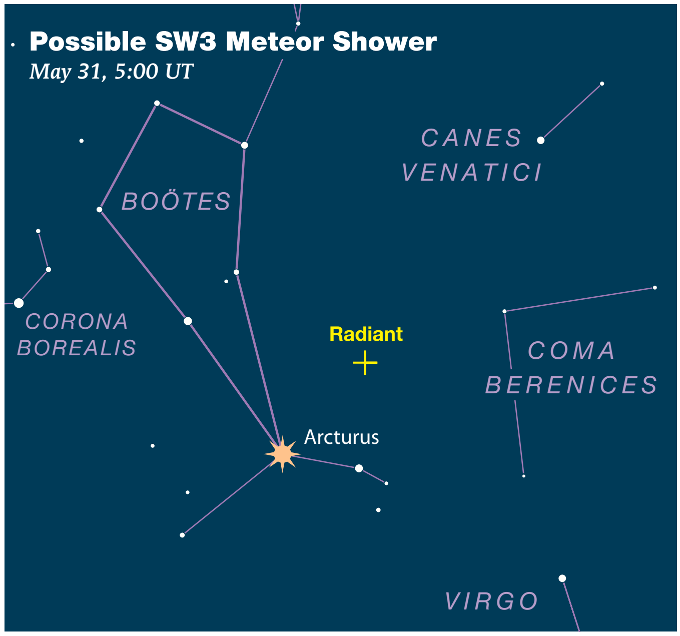
The large particle sizes combined with the high ejection velocities of the debris produced in 1995 could mean that material has migrated to a position forward of the comet. Both models calculate that the presence of particles leading the comet is necessary for a meteor outburst this month. (SW3 itself will not arrive at the descending node of its orbit until nearly three months later — long after Earth has moved on.)



▶ **DEBRIS STREAMS** This diagram shows the location of the cometary dust trails generated in 1995, 2001, 2006, 2011, and 2017. The shape of each trail is assumed to be like a tube whose diameter is 0.001 a.u. On May 31st UT, the dust trail ejected in 1995 is forecast to approach Earth as near as 0.00038 a.u.

COMETARY PAIR This stunning sequence of images shows SW3 fragments B and C during the comet's 2006 return.

DEBRIS STREAM DIAGRAM: ADAPTED FROM A DIAGRAM BY MIKIYA SATO; COMET FRAGMENT SERIES: MICHAEL JÄGER



▲ **LOOK HERE-ISH** The radiant "point" for a possible meteor outburst at around 5h UT (1 a.m, EDT) on May 31st could measure several degrees in diameter. The radiant's altitude during the display depends on your location (see map below).

"The display is especially promising," notes Lüthen. "The disintegration of SW3 in 1995 should have introduced a lot of dust particles into the trail." And Horii adds: "The dust trail ejected in 1995 will closely approach the Earth; meteors due to this dust trail are highly expected in 2022."

A Meteor Wild Card

Determining the potential intensity of a 2022 display of SW3 meteors is difficult, primarily because Earth hasn't interacted with the 1995 meteoroid stream previously. However, other SW3 debris trails may have produced meteors.

On June 2, 2011, NASA Cameras for All-sky Meteor Surveillance in California (CAMS) photographed three SW3 meteors, and on May 30–31, 2017, between 23:39 and 00:45 UTC, CAMS captured five more. Lüthen had forecasted possible activity for both these years. Dust trails shed by SW3 in 1952 and 1941 generated the 2011 and 2017 meteors, respectively. At the time, scientists considered both predictions somewhat doubtful since the respective distances between Earth and the debris trails were fairly large (0.0013 and 0.0011 a.u.).

Without taking into account the breakup of SW3's nucleus, we might expect a potential ZHR of around 14 this year. However, the 1995 trail Earth encounters this year could very well include a thick concentration of debris discharged in the wake of the comet's fracturing. Just how much thicker, and what this contribution ultimately means in terms of overall meteor numbers, is something of a wild card.

A tenfold increase would suggest rates of 140 meteors per hour — a strong outburst that would translate into a display similar to the annual Geminid or Quadrantid showers. But a 100-fold increase might mean a full-fledged meteor storm! As for how long any potential outburst might last, it's likely to be very brief — perhaps not more than a few hours. It'll pay to be on high alert the night of the display.

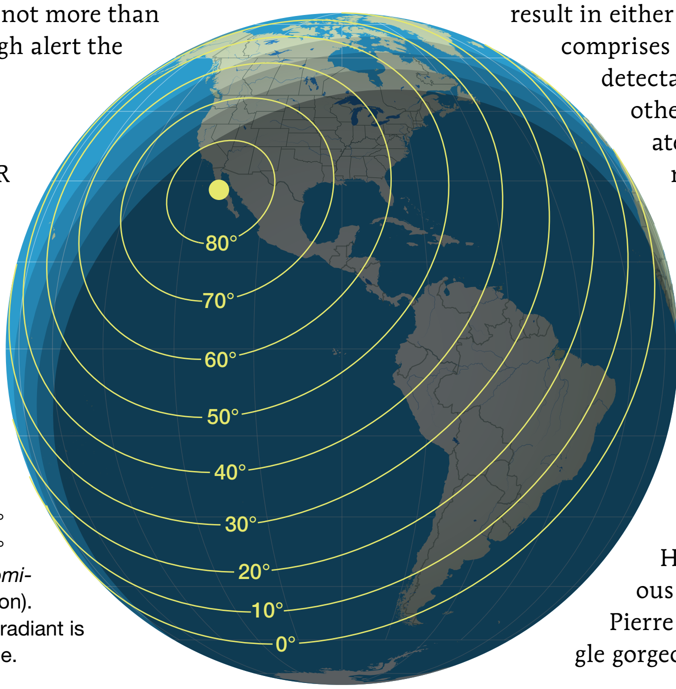
Sluggish Streaks

In addition to the predicted ZHR of this possible new display, the other factor to consider is the very slow velocity of the SW3 fragments as they enter Earth's atmosphere. The Leonids are swiftest of all with velocities of 72 km/s as they collide head-on with Earth. By comparison, material from SW3 will arrive at around 16 km/s — practically the slowest of all known shower meteoroids.

This is due to the fact that pieces in the debris stream are moving in the same general direction as Earth and must, therefore, catch up to our planet.

The low velocity of the SW3 meteoroids will likely result in either a display that predominantly comprises faint meteors or one that's only detectable with radio or radar. On the other hand, if some of the associated meteoroids end up being much larger than usual, that could offset their slow speeds and make for a rather bright meteor shower.

As a comparison, accounts of the Bielid meteors of 1872 describe them as primarily "slow, faint and evanescent," but some exceeded 1st magnitude, often appearing "red, with trains of orange sparks." And during the weak Tau Herculid shower of 2011, assiduous Canadian meteor observer Pierre Martin reported seeing a "single gorgeous Tau Herculid" of magnitude



▶ **RADIANT ALTITUDE** This map shows the visibility of a potential meteor outburst and is based on the assumption that peak activity will occur close to 5h UT on May 31st. The apparent altitude of the radiant is presented as concentric circles at 10° intervals. Also plotted are zones for *civil twilight* (Sun 0° to 6° below the horizon), *nautical twilight* (6° to 12° below the horizon), and *astronomical twilight* (12° to 18° below the horizon). From the Baja Peninsula, Mexico, the radiant is directly overhead at the appointed time.

RADIANT DIAGRAM: GREGG DINDERMAN / *S&T*, SOURCE: JOE RAO; RADIANT ALTITUDE GLOBE: GREGG DINDERMAN / *S&T*, SOURCE: JÉRÉMIE VAUBAILLON

FIRST FIND German astronomers Friedrich Carl Arnold Schwassmann and Arno Arthur Wachmann together discovered four periodic comets (the fourth was a shared discovery with famed American amateur astronomer Leslie Peltier). This composite photo shows their first find, Comet 29P/ Schwassmann–Wachmann 1 as it drifted westward through southern Auriga last autumn. The object reaches perihelion again in 2035.

MICHAEL JÄGER

–1 and golden-yellow in color that left behind "a thick wake."

Could that be a preview of what we might see this year?

Planning Your Observing Session

Up until now, debris trailing behind SW3 produced the meteors in the Tau Herculid displays. However, our forecast for 2022 includes meteoroids traveling ahead of the comet. The result is a radiant positioned not in Hercules but within the boundaries of the constellation Boötes, about 6° north-northwest of Arcturus, as shown in the chart on page 39.

The timing of the peak is for May 31st at around 5^h UT (1 a.m. EDT, or 10 p.m. PDT on May 30th), which means a large portion of the contiguous United States, south-central and eastern Canada (including the Maritime Provinces), Mexico, Central America, South America, and a small slice of West Africa are well-positioned to view the event. In the U.S. the radiant's altitude ranges from around 50° in eastern New England to 80° or higher in southern California and the Desert Southwest.

Across parts of the Pacific Northwest, the northern Rockies, and Great Plains, as well as a slice of the Canadian Prairies, northern Ontario, central Quebec, most of Newfoundland and Labrador, the peak is expected to rise during astronomical twilight, but the sky should still be sufficiently dark for sighting bright meteors.

Since the new Moon occurs on May 30th, there will be no interference from moonlight on the night of the possible SW3 meteor shower.

Final Thoughts

I'm excited to see what happens, though I have to admit I won't be holding my breath. Meteor showers are notoriously fickle, and it's possible that nothing at all will occur at the appointed time. There's also a possibility that these meteoroids could rapidly disintegrate as they enter our atmosphere, rendering them faint or invisible. But the youthful nature of the outburst material makes it seem like a good bet that there'll be *some* activity.

And if historical patterns are any guide, we're long overdue for an event such as this. Over the last couple of centuries, it seems that a new, strong shower emerges seemingly from nowhere with some frequency. Particularly noteworthy were the Lyrids in 1803, the Andromedids in 1872 and 1885, and the Draconids in 1933 and 1946. We haven't had a surprise meteor shower pop up in quite a while. Maybe 2022 is finally the year.

I'll be outside watching. Will you?

■ Contributing Editor **JOE RAO** has been writing about meteors for *Sky & Telescope* for nearly 30 years. He thanks David Asher, John Bortle, Peter Brown, Gary Kronk, Robert Lunsford, Junichi Watanabe, and Paul Wiegert for their expert assistance in the preparation of this article.

Digging Deeper

The more technically inclined reader looking for additional information about this May's potential meteor shower can peruse a research paper the author penned for the International Meteor Organization at: **https://is.gd/RaoIMO**.

1 **DAWN:** Kick the month off by sighting the tight pairing of Venus and Jupiter as they climb in the east-southeast before sunrise; only ½° separates the duo. Turn to page 46 for more on this and other events listed here.

2 **DUSK:** Aldebaran, the waxing crescent Moon, Mercury, and the Pleiades arc gracefully above the west-northwestern horizon.

6 **MORNING:** The Eta Aquariid meteor shower peaks. While it favors the Southern Hemisphere, viewers in the southern U.S. could catch some Eta Aquariids. The waxing crescent Moon sets before the radiant rises; see page 49 for details.

6 **DUSK:** Find the lunar crescent some 2½° left of Pollux in Gemini. Follow the pair as they sink toward the west-northwestern horizon with Castor on their right.

7 **DUSK:** The almost-first-quarter Moon is positioned around 3° north of the Beehive Cluster (M44) in Cancer; bring binoculars.

9 **DUSK:** The Moon, one day past first quarter, gleams in Leo. Roughly 4½° separates it from the Lion's brightest star, Regulus.

13 **EVENING:** Continuing its trek along the ecliptic, the waxing gibbous Moon visits Virgo and sits 4° upper left of Spica.

15 **EVENING:** Much of North America and all of South America will witness a total eclipse of the Moon, provided skies are clear (see page 48).

16 **EVENING:** Look toward the southeast to see the Moon, just past full, rise in tandem with Antares; about 2° separates the pair.

22 **MORNING:** Early risers will be greeted by the delightful sight in the southeast of the last-quarter Moon hanging 5° below Saturn.

24 **MORNING:** Jupiter and Mars rise together in the east, accompanied by the waning crescent Moon 7° right of the pair.

25 **DAWN:** Jupiter, Mars, and the Moon form a compact grouping in the east-southeast. As the trio climb higher, Venus rises in the east.

27 **DAWN:** Look east to find the thin lunar crescent 3½° below left of Venus. Catch this sight before sunrise washes it away.

29 **DAWN:** A mere ½° separates Jupiter from Mars as they adorn the east-southeastern horizon.
— DIANA HANNIKAINEN

The spiral galaxy NGC 3621 in Hydra is curious in that it has no central bulge, as shown in this image taken with the European Southern Observatory's MPG/ESO 2.2-meter telescope at La Silla Observatory, Chile. To learn more about other galaxies visible in May's skies, turn to page 26. ESO / JOE DEPASQUALE

MAY 2022 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				

FIRST QUARTER

May 9

00:21 UT

FULL MOON

May 16

04:14 UT

LAST QUARTER

May 22

18:43 UT

NEW MOON

May 30

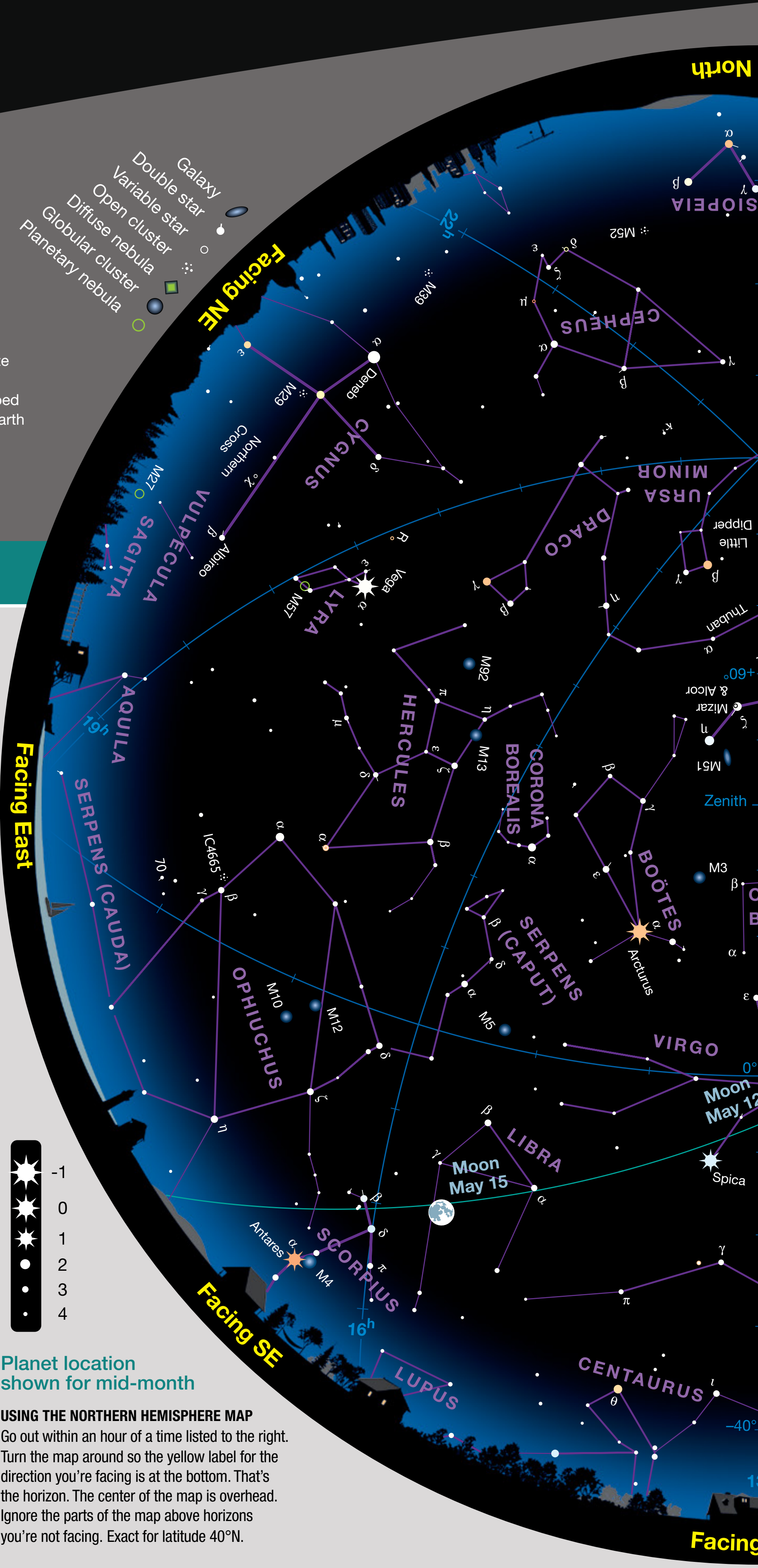
11:30 UT

DISTANCES

Apogee	May 5, 13^h UT
405,285 km	Diameter 29′ 29″
Perigee	May 17, 15^h UT
360,301 km	Diameter 33′ 10″

FAVORABLE LIBRATIONS

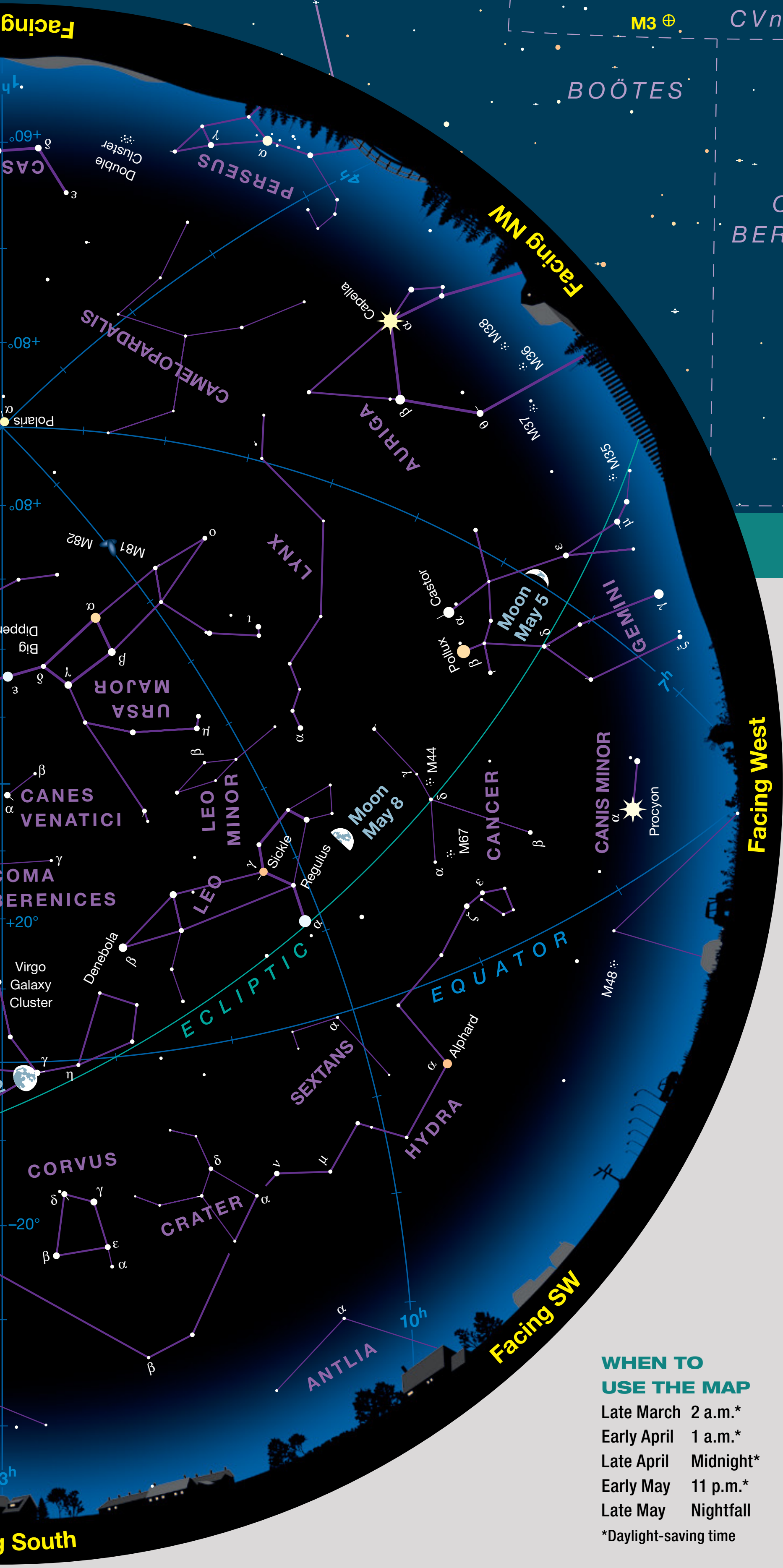
• Marinus Crater	May 3
• Neumayer Crater	May 4
• Schluter Crater	May 16
• Main Crater	May 18

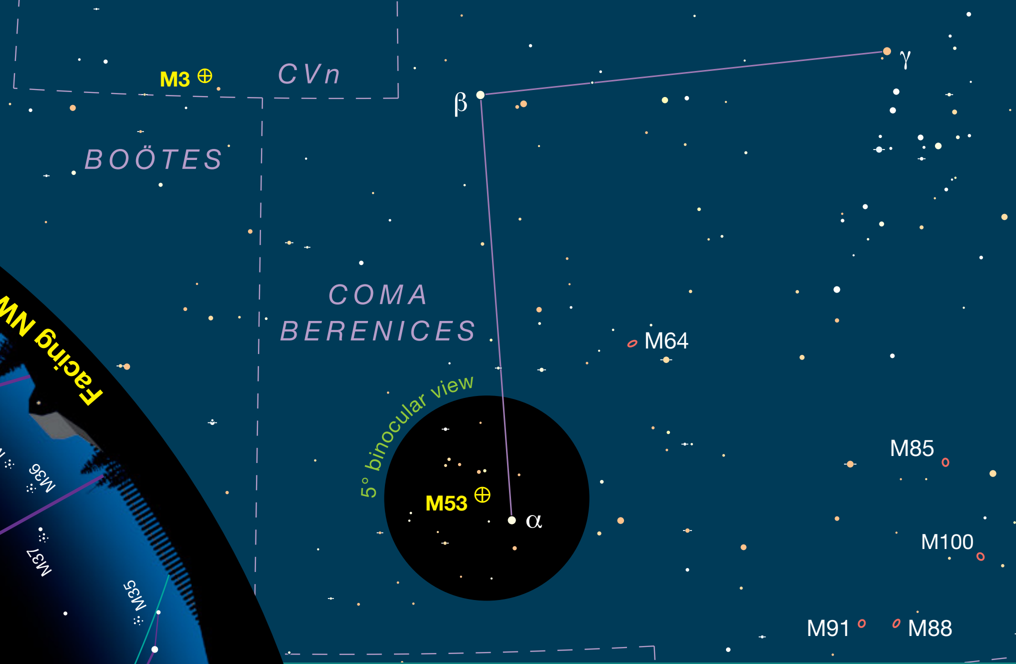


Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

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





Binocular Highlight by Mathew Wedel

Comparing Clusters Close to Coma

For a small constellation with no stars brighter than 4th magnitude, Coma Berenices, or Berenice's Hair, has a lot to offer: one of the finest nearby open clusters (see *S&T:* Apr. 2019, p. 43); galaxies galore in the Coma-Virgo Cluster; and an easy-to-find globular cluster, **Messier 53**. First locate 4.3-magnitude Alpha (α) Comae Berenices, the star also known by the beautiful name of Diadem. Almost exactly 1° to the northeast you should spot 8th-magnitude M53 as a round, fuzzy glow. Like all globular clusters, it's just a blob of fluff, even in my 15×70 binos. As usual with such objects, the romance is in the mind: taking in the combined light of hundreds of thousands of stars that shine back at us across a distance of 58,000 light-years from the diffuse galactic halo of the Milky Way.

One of my favorite observing pastimes is comparing objects in the sky. **Messier 3** is another glob in the same neighborhood that's often mentioned in the same breath as M53 (turn to page 54 for more on this cluster). M3 is over the border in Canes Venatici, the Hunting Dogs, but it's an easy star-hop from Coma Berenices. Draw a line from Gamma (γ) Comae Berenices, past Beta (β), and onward a little less than 7° to the east, where M3 gleams at 6th magnitude.

M3 and M53 are similar in intrinsic brightness, but M3 is only about half as far away from us, at 33,000 light-years. So the difference in brightness between the two clusters is mostly a function of their differing distances, and by comparing them we can start to get a feel for the grand scale of the galaxy. Now that's a view worth seeking out.

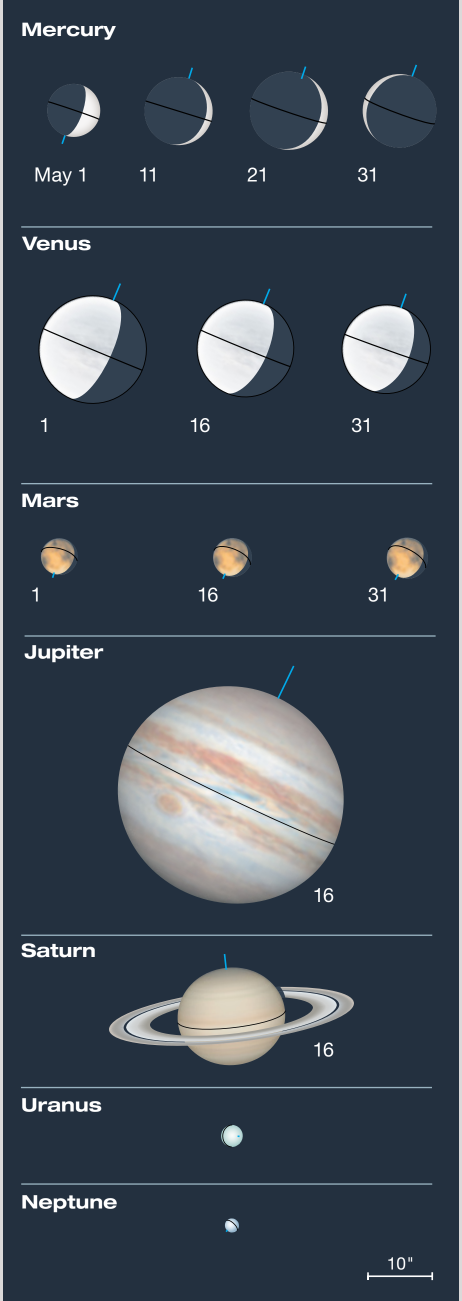
■ **MATT WEDEL** is obsessed with exploring the Milky Way Galaxy, starting with the mountains and deserts of southern California from which he observes.

WHEN TO USE THE MAP

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

*Daylight-saving time

Planetary Almanac



▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

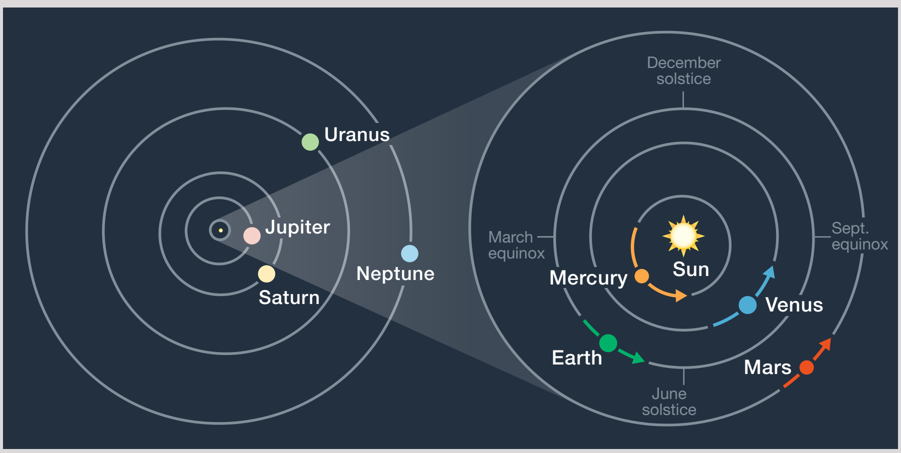
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during May. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dusk until the 9th • **Venus** low in the east at dawn all month • **Mars**, **Jupiter**, and **Saturn** visible at dawn all month.

May Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$2^h\ 31.6^m$	+14° 55′	—	–26.8	31′ 45″	—	1.007
	31	$4^h\ 30.2^m$	+21° 50′	—	–26.8	31′ 33″	—	1.014
Mercury	1	$3^h\ 51.5^m$	+22° 56′	20° Ev	+0.4	8.2″	33%	0.815
	11	$4^h\ 09.0^m$	+22° 39′	15° Ev	+2.6	10.6″	10%	0.633
	21	$3^h\ 55.8^m$	+19° 21′	2° Ev	—	12.2″	0%	0.552
	31	$3^h\ 38.8^m$	+15° 59′	13° Mo	+3.2	11.5″	7%	0.585
Venus	1	$23^h\ 54.0^m$	–2° 05′	43° Mo	–4.1	16.7″	68%	0.999
	11	$0^h\ 36.6^m$	+2° 05′	41° Mo	–4.1	15.6″	71%	1.073
	21	$1^h\ 19.8^m$	+6° 20′	39° Mo	–4.0	14.6″	74%	1.144
	31	$2^h\ 04.0^m$	+10° 27′	37° Mo	–4.0	13.8″	78%	1.213
Mars	1	$22^h\ 54.8^m$	–8° 36′	59° Mo	+0.9	5.7″	89%	1.629
	16	$23^h\ 36.9^m$	–4° 18′	62° Mo	+0.8	6.1″	88%	1.545
	31	$0^h\ 18.1^m$	+0° 03′	65° Mo	+0.7	6.4″	87%	1.463
Jupiter	1	$23^h\ 53.2^m$	–1° 54′	43° Mo	–2.1	34.8″	100%	5.665
	31	$0^h\ 13.9^m$	+0° 14′	66° Mo	–2.2	37.2″	99%	5.292
Saturn	1	$21^h\ 46.5^m$	–14° 30′	76° Mo	+0.9	16.5″	100%	10.083
	31	$21^h\ 50.4^m$	–14° 16′	104° Mo	+0.8	17.3″	100%	9.587
Uranus	16	$2^h\ 51.0^m$	+16° 01′	10° Mo	+5.9	3.4″	100%	20.699
Neptune	16	$23^h\ 42.1^m$	–3° 11′	60° Mo	+7.9	2.2″	100%	30.407

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**.



Close-Up on the Crow

Compact Corvus is a striking spring constellation.

▲ **COUNTING CROWS** Flying high in the spring sky is Corvus, the Crow. Of the 88 official constellations, little Corvus ranks #70 in area. However, because its four main stars are all moderately (and similarly) bright, Corvus is easy to identify even in moderately light-polluted conditions.

ALEXANDER JAMIESON / *CELESTIAL ATLAS* (1822) / UNITED STATES NAVAL OBSERVATORY LIBRARY / PUBLIC DOMAIN

Corvus, the Crow, is one of the classic signs of spring for evening skywatchers. What the constellation lacks in brightness, it makes up for with a compact and eye-catching geometric shape delineated by four 3rd-magnitude stars. The boxy formation is rendered even more noticeable by its proximity to Virgo's 1st-magnitude Spica, which is roughly 15° northeast of the Crow. As described last month, you can follow the Big Dipper's handle and "arc to Arcturus," then "drive a spike to Spica." But I recommend going even farther by "continuing the curve to Corvus."

The main pattern of Corvus is shown on our Northern Hemisphere map (pages 42 and 43), positioned in the south, just west of the *meridian* — the imaginary line that connects north to south and passes directly overhead. The constellation's main pattern is formed (working clockwise from upper left) by connecting the stars Algorab, Gienah, Minkar, and Kraz. These are also known as Delta (δ), Gamma (γ), Epsilon (ε), and Beta (β) Corvi, respectively. The stars shine at magnitudes 2.9, 2.6, 3.0, and 2.6 (again, clockwise from Algorab). Note that the brightness range spans less than half a magnitude. A very experienced observer can detect a difference of about one-tenth of a magnitude, but a half magnitude spread may go unnoticed by casual stargazers. The four main Corvus stars stand together as a team of near-equals.

There's a bit of oddness concerning the proper names of three of the stars. Algorab is basically alright, since it's Arabic for "the raven." After all, the raven is a crowlike bird, and the constellation was sometimes seen as a raven long ago. But Gienah means "wing" — a name it shares with Epsilon Cygni. Although Gamma Corvi is only 0.1 magnitude fainter than its Cygnus namesake, the latter is better known perhaps because it plays a key role as the outstretched wing of the celestial Swan. Then there's Minkar, which looks like a mere variant of Menkar, the proper name of the considerably brighter star Alpha Ceti. Both Menkar and Minkar appear to be derived from the Arabic word for "the nostril," which makes more sense for Cetus, the Whale (or Sea Monster), than for a crow.

What about Kraz? It's one of the 14 curious names introduced in *Skalnaté Pleso Atlas of the Heavens* — a popular set of charts drawn by Czech cartographer Antonín Bečvář in the late 1940s. It's possible that no one knows the original source or meaning of Kraz. Nonetheless, the International Astronomical Union officially approved the name in 2018, so it's with us for keeps now.

There's one more star in Corvus that has a proper name: Alpha (α) Corvi, which is also known as Alchiba. It's Arabic for "the tent," a term originally applied to the entire pattern of Corvus. Alpha, being the first letter of the Greek alphabet, is usually reserved for the brightest star in a constellation. But, at magnitude 4.0, Alpha Corvi is much fainter than the Crow's other main stars. Alchiba lies a little more than 2° roughly south of Minkar and is a full magnitude dimmer. The constellation's sixth star is Eta (η) Corvi, which is just a little more than ½° northeast of Algorab. Eta shines dimly at magnitude 4.3 — more than a magnitude fainter than its neighbor. (Algorab is also a fine double star in small telescopes.)

Corvus has always held a particular significance for me. In early May 1986, my region of the U.S. enjoyed a stretch of fantastically clear weather thanks to an "omega-block" weather system in New Jersey. That was when I glimpsed the extremely faint (yet prodigiously long) dust tail of Halley's Comet extending from the constellation Crater, across Corvus, and beyond. Even now, 36 years later, it remains one of the most thrilling sights of my life.

■ **FRED SCHAAF** continues to view the night sky from southern New Jersey's protected Pinelands.

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

Jupiter Greets Venus and Mars

A parade of planets puts on a dawn show.

SUNDAY, MAY 1

Except for a brief span during especially favorable Mars oppositions, the two brightest planets in the night sky are **Jupiter** and **Venus** — and this morning they sit side by side, separated by a scant 33′. That means you can see both worlds together in a small telescope running at moderate magnification. But more importantly, they'll be hard to miss by anyone awake at dawn who takes a moment to glance up at the sky. Expect friends and neighbors to ask, "What were those two bright stars I saw?"

The planetary pair were at their closest the previous morning (April 30th), but this is a new month and it's off to a great start. Although Venus vastly outshines Jupiter (magnitude –4.1 versus –2.1), it's not for nothing the latter is known as a gas *giant*. Big Jove's disk is double the size of its Cytherean neighbor. And for all you Mars fans, you'll have to wait until 2035 before the Red Planet once again displaces Jupiter as the second-brightest planet.

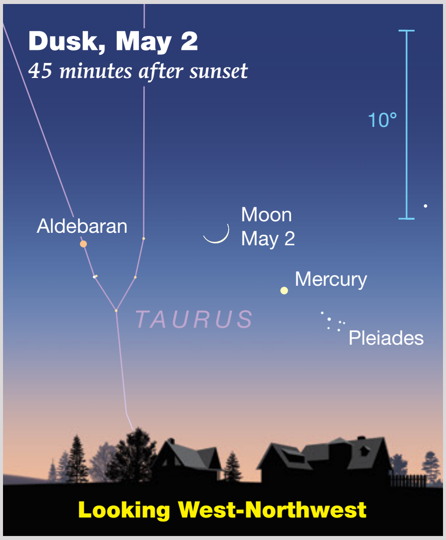
MONDAY, MAY 2

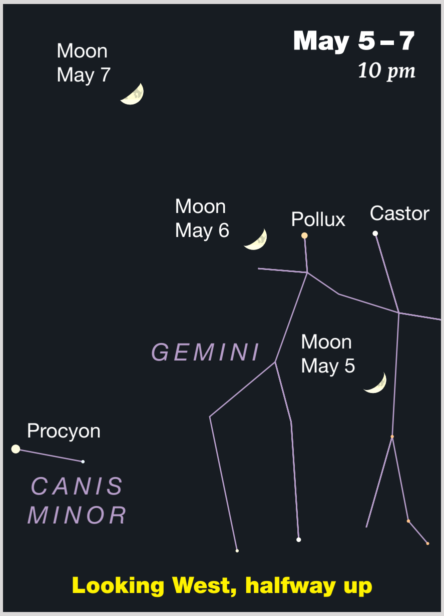
Here's one for those who prefer to do their observing at dusk rather than at dawn. As darkness falls, look to the west-northwest to catch the **Moon**, **Mercury**, and the **Pleiades** in a line. The area's other luminary is 1st-magnitude **Aldebaran**, sitting to the left of the very thin lunar crescent. Mercury is just past the midpoint of its most favorable apparition of the year. This evening it shines at magnitude +0.8 and sets nearly two hours after the Sun. The innermost planet moves quickly, however, and soon starts its plunge toward the horizon at a rate of roughly 1° per day, all the while rapidly fading away. For naked-eye observers, the current Mercury show is all but over by next Monday. But don't despair — the planet pops up again at dawn next month, albeit in far less favorable circumstances. For now, though, enjoy the sight of Mercury positioned less than 3° from the center of the Pleiades and a bit more than 4° from the Moon. Depending on how bright the sky is when you take in this scene, you may find binoculars handy for drawing out the cluster's stars from twilight's glow.

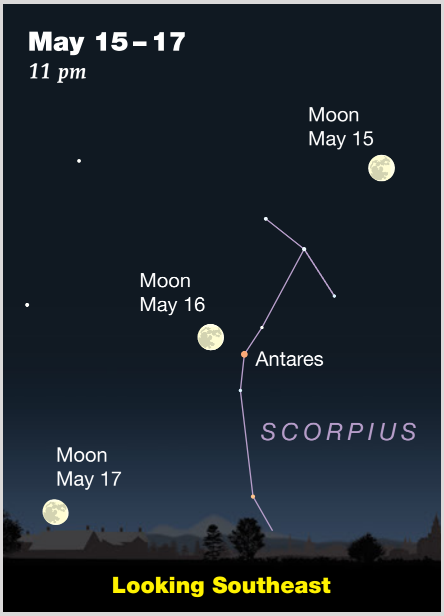
FRIDAY, MAY 6

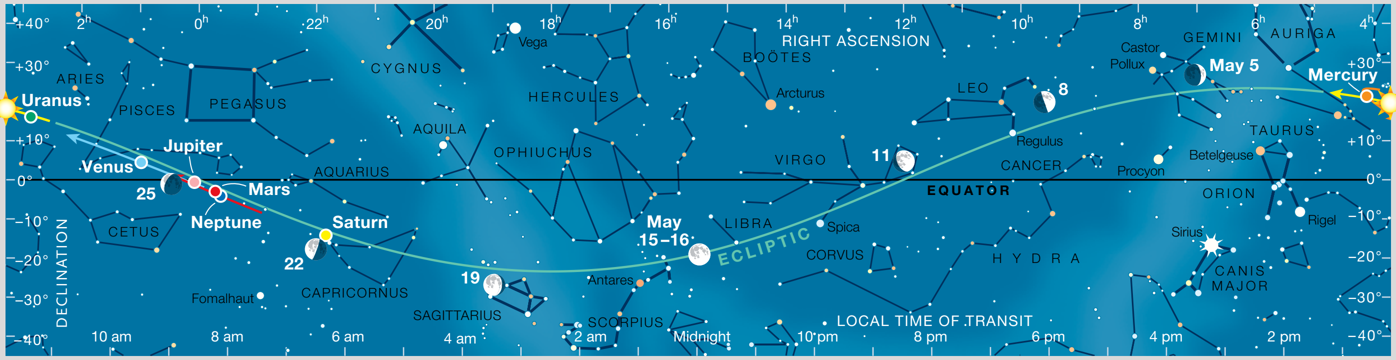
In May, the **Moon** approaches to within 5° of four 1st-magnitude stars. The first of these encounters is with 1.2-magnitude **Pollux** on the 6th. That evening the waxing lunar crescent lies a touch less than 3° to the left of the star. But what makes this sight a little extra spe-

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







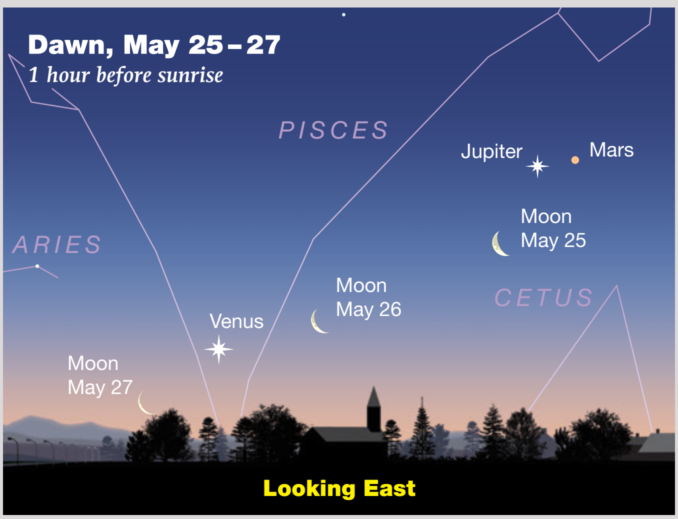


▲ The Sun and planets are positioned for mid-May; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

cial is the nice, three-in-a-row line that includes nearby **Castor**, which is about 4½° right of Pollux. At magnitude 1.6, Castor is noticeably fainter than its fellow Gemini twin. And if we expand our view to include +0.1-magnitude Capella and +0.4-magnitude Procyon, the naked-eye scene has even more luster. The closest Moon/bright-star encounter this month will be on the 16th, when the nearly full Moon and **Antares** rise together with just 2° between them.

FRIDAY, MAY 27

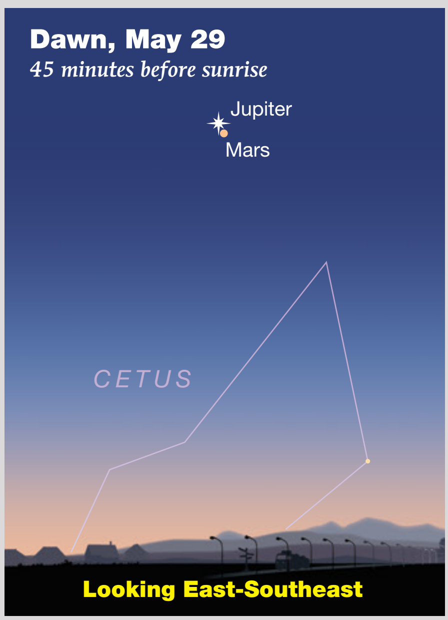
When it comes to naked-eye sky sights, they don't come much better than pairings of the **Moon** and **Venus**. At dawn today, the two are separated by around 3½° — one of their best conjunctions in 2022. They're close enough that you can appreciate them together in binoculars, which help show earthshine adorning the slender lunar crescent. Binoculars are also helpful if you sleep in past sunrise and still want to catch Venus. People are often surprised by how easy it is to see this planet even in broad daylight — and having the Moon nearby is a big help. The first step is to locate the lunar crescent and focus your binoculars (precise focus is crucial), then look about one binocular field to the right of the Moon to catch the silvery glint of Venus. The later you look, the farther the two objects will be from each other.



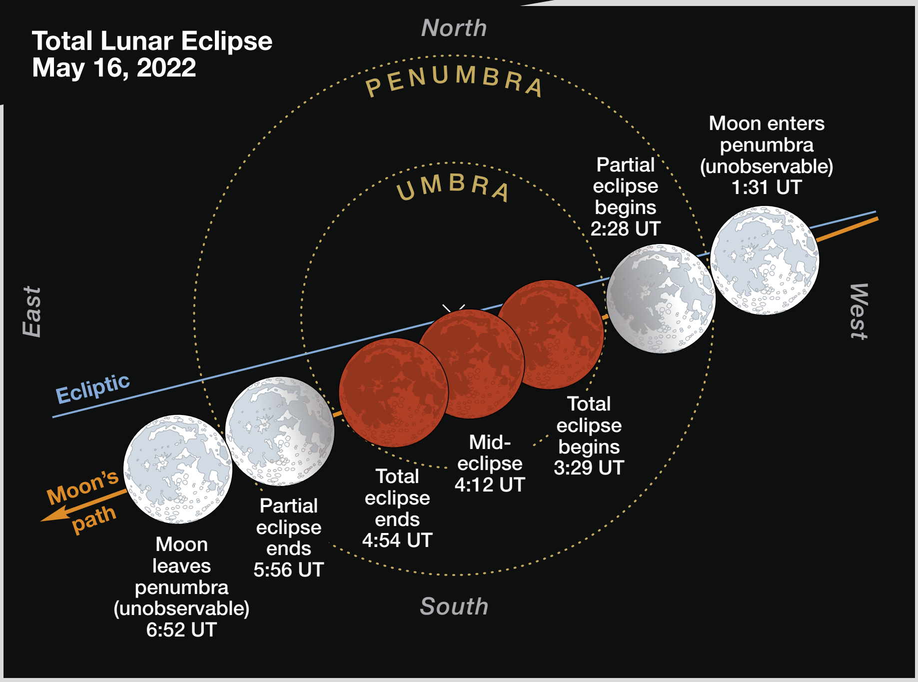
SUNDAY, MAY 29

The best conjunction this month is arguably the one between **Mars** and **Jupiter** occurring this morning. The pair rise together in tight formation a little before 3 a.m. local daylight time. The apparent gap between the two planets has been narrowing for some time, and today they're at their closest. Just 35′ separates them — a close match for Jupiter's meetup with Venus at the start of the month. But this time, Jupiter is the brighter planet. At magnitude –2.2, it's nearly 15 times brighter than Mars, which glows at magnitude +0.7. Both objects are drifting eastward at the moment, but Mars is doing so at a rate of 5° per week compared with Jupiter's leisurely pace of just 1° per week. As a result, by the end of June they'll be separated by nearly 20°.

It's still early days in the apparitions of both planets, though Mars's rapid eastward movement means it'll take much longer to climb above the thick layer of blurring atmosphere that lies near the horizon. Mind you, the Red Planet's diminutive size means it won't be a compelling telescopic target for quite some time regardless.



■ Consulting Editor **GARY SERONIK** has been keeping an eye on the planets for five decades.



A Flower Moon Eclipse

This month offers the first total lunar eclipse in a year.

For many Northern Hemisphere skywatchers, May occupies a sweet spot between two of amateur astronomy's biggest banes: winter cold and mosquitos. May's full Moon is traditionally known as the Flower Moon, echoing the agreeable nature of this time of year. And when a total lunar eclipse falls in this merry month, you'll certainly want to stay up to watch the whole thing.

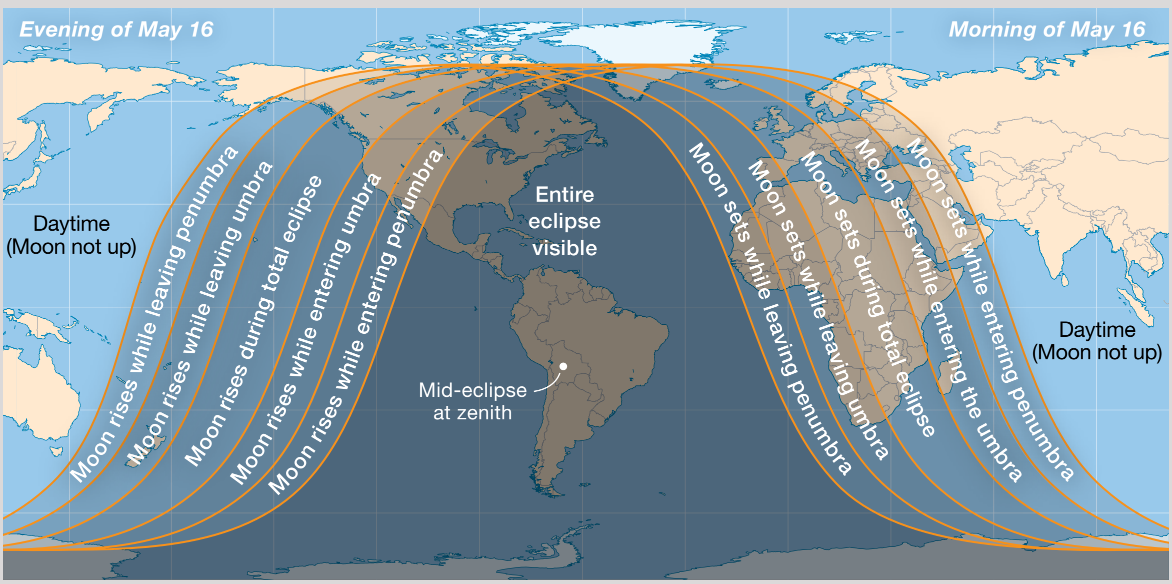
Unlike last November's near-total event, on the night of May 15–16 the entire Moon will be covered by Earth's inner shadow. The Moon traverses the southern half of the umbral shadow, where it spends a generous 85 minutes. The color and brightness contrast between the Moon's northern hemisphere (which grazes the center of the umbra) and southern hemisphere should make the lunar globe appear distinctly three dimensional.

Observers across the Americas will witness most or all of the eclipse. The partial phase begins at 10:28 p.m. EDT on May 15th (2:28 UT on May 16th), but keen eyes might detect the grayish shading of Earth's penumbral shadow draped across the left side of the lunar disk half an hour earlier. Totality runs from 11:29 p.m. EDT on May 15th to 12:54 a.m. EDT on May 16th (3:29 to 4:54 UT on the 16th), with greatest eclipse occurring at 12:12 a.m. EDT (4:12 UT). As the Moon slowly exits the umbra, the partial phase plays out in reverse until 1:56 a.m. EDT (5:56 UT). Finally, the penumbral portion of the eclipse concludes at 2:52 a.m. EDT (6:52 UT).

In North America, viewers in the eastern half of the continent will see all phases of the eclipse. Along the West Coast, the Moon rises around sunset with totality about to begin. Although twilight compromises the view, a low Moon in deepening dusk should offer some beautiful photographic possibilities as the sky darkens with totality underway.

From San Francisco, skywatchers will see a squished, lunar sliver rise in the southeastern sky as the Sun sets in the west. The total eclipse begins about 15 minutes later, with the Moon becoming increasingly apparent in a darkening sky.

As astronomical twilight ends, the Moon starts to exit the umbra. Since totality occurs close to sunset, you



GREGG DINDERMAN / S&T, SOURCE: USNO (2)

can point one arm at the Moon and the other at the Sun and imagine yourself aligned with Earth's shadow.

For observers in Europe and Africa, the eclipse is a morning event with totality happening at dawn. From London, England, where the total phase begins shortly before moonset, the Moon will resemble a faded watercolor low in the southwestern sky a half-hour before sunrise.

As a bonus, observers across much of the U.S., Canada, and parts of Mexico and Central America can watch the totally eclipsed Moon occult the 6th-magnitude double star S672, in central Libra. The 6.3- and 8.9-magnitude components are 11.2″ apart, with a nearly perfect east-west alignment (position angle of 280°). First one star, then the other, will disappear in stepwise fashion. From Chicago, immersion occurs about 10:45 p.m. CDT on May 15th, and the stellar eclipse ends at around 11:57 p.m., just three minutes after the end of totality. For observers in the southwestern U.S. and in Central America, the Moon will miss the double and instead occult the 5.5-magnitude star HD 138413. From Tucson, Arizona, the totally eclipsed Moon covers the star from 8:30 p.m. to 9:09 p.m. MST.

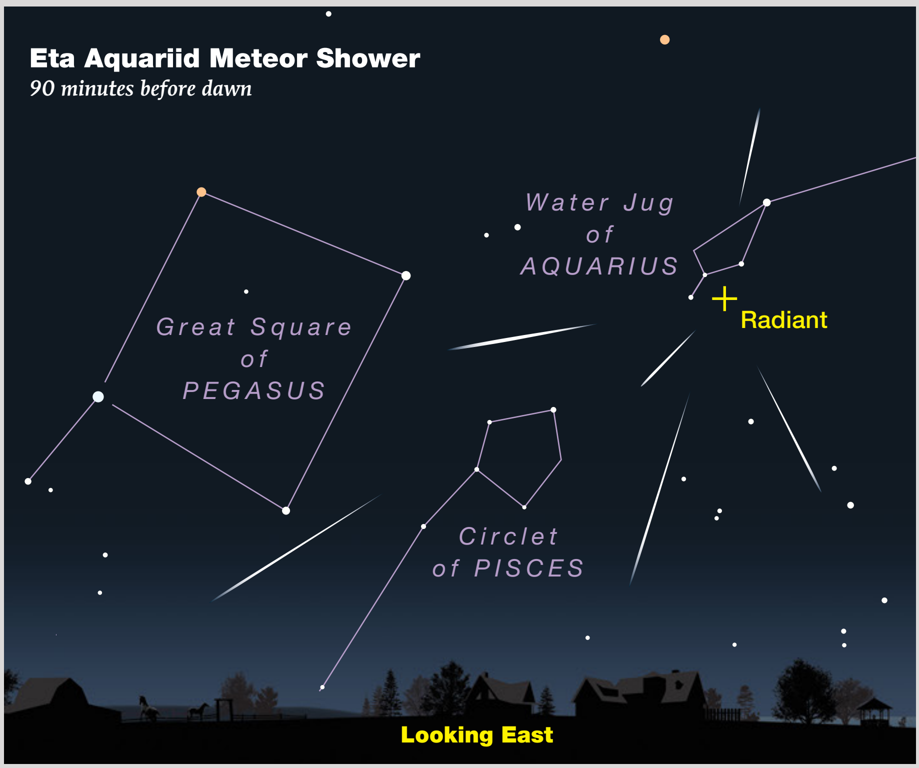
▲ May's lunar eclipse can be enjoyed all across the Americas, but for some observers in the western U.S. and Canada, totality occurs during evening twilight, creating a striking color contrast between the ruddy Moon and darkening blue sky. This photo was captured from Victoria, British Columbia, during the September 2015 twilight eclipse.

The sight of the reddened Moon poised at the fringe of our galaxy's starry carpet will be wondrous and offer a lovely photo op, too. Try to take in the eclipse as far from light pollution as possible to better appreciate the sight. The eastern half of the country will have the best Milky Way views simply because the eclipse happens later in the evening there, allowing time for Scorpius and Sagittarius to rise.

The color, size, and shape of the umbral shadow vary from eclipse to eclipse in part due to the changing aerosol content of Earth's atmosphere. To help contribute to a better understanding of these variations, I encourage you to participate in our crater timing project. Details can be found at **https://is.gd/eclipsetimings**.

Meteors from Halley

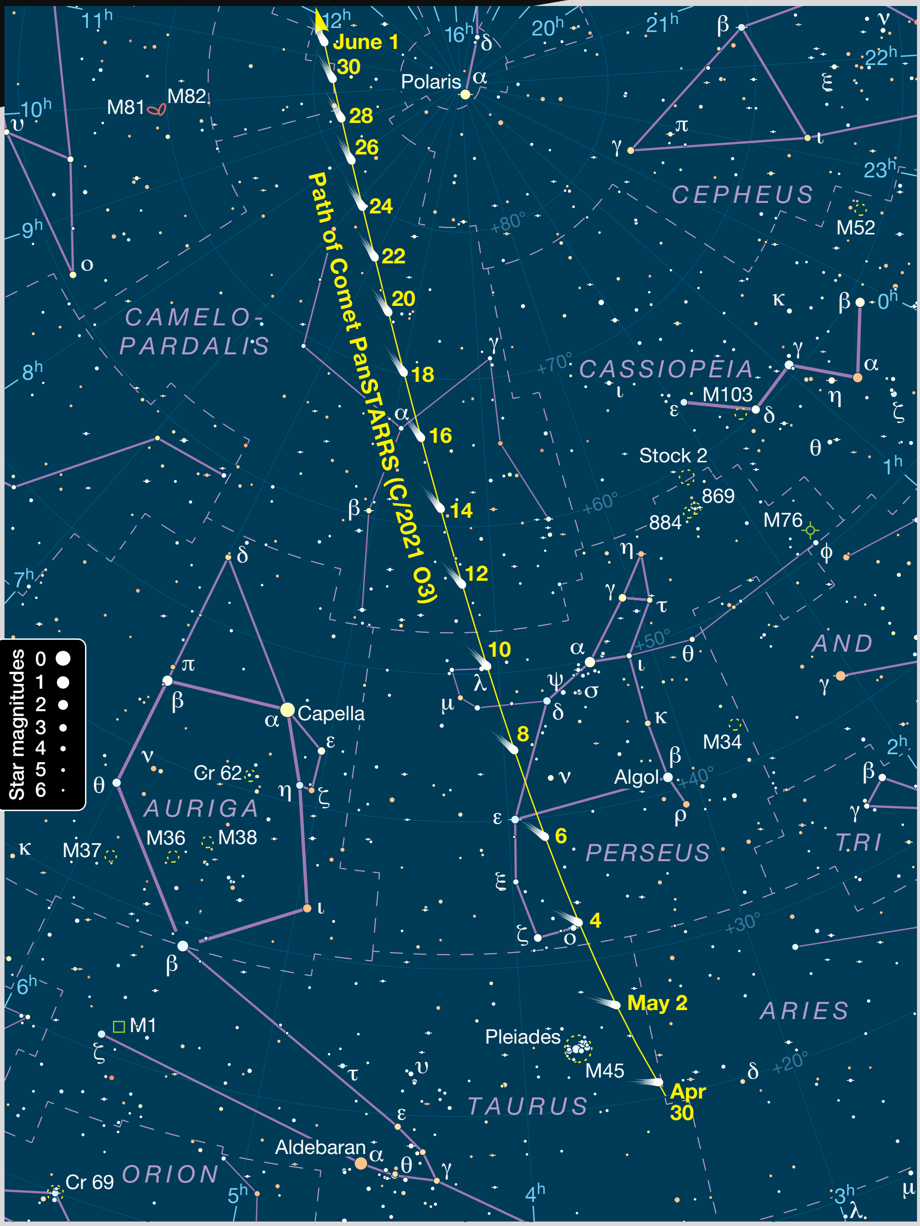
COMET 1P/HALLEY may be a distant 35 a.u. (5.2 billion kilometers) from Earth this month, but fragments spalled from its nucleus during previous flybys will flare just 100 kilometers (62 miles) overhead during the annual Eta Aquariid meteor shower. Peak activity occurs around 8^h UT on May 6th (4 a.m. EDT). The timing is ideal because the radiant, located in the Water Jar asterism in Aquarius, doesn't rise until around 3 a.m. local daylight-saving time. However, that also means there's only a one-hour observing window before the start of morning twilight. At least the Moon (a waxing crescent in the evening sky) won't interfere.



For meteor watchers in the Southern Hemisphere, the radiant climbs high in the sky and produces 50 to 60 meteors per hour. From mid-northern latitudes, however, a lower radiant means the rate is likely to be closer to 10 to 30 per hour. Aquariids are swift, with speeds of 66 kilometers per second, and produce persistent trains. The shower has a long maximum, with steady activity from about May 3rd to the 9th.

The Eta Aquariids are no match for the Perseids or Geminids, but the display may be your best shot at sighting some aspect of Halley's famous comet.

GARY SERONIK



▲ The comet's position is plotted for 0^h UT.

A Visitor from the Oort Cloud

IT'S POSSIBLE THAT by the time you read this, Comet PanSTARRS (C/2021 O3) will have disintegrated. But if it survives its close brush with the Sun on April 21st, during the first week of May it will quickly move northward and perhaps brighten to 6th magnitude and sprout a short tail.

PanSTARRS could make its first appearance during evening twilight in late April. On April 30th, it stands about 5° high one hour after sunset. That same evening, it passes some 3° west of the Pleiades (and a little more than 4° west of Mercury) while speeding north-northeast into Perseus at a rate of about 3° per day. On May 8th, the same day it passes closest to Earth at 90 million kilometers, PanSTARRS becomes circumpolar for observers at mid-northern latitudes. On the 27th it passes closest to Polaris (8.5°), but by then it's expected to have faded considerably from its peak brightness.

Action at Jupiter

THROUGHOUT MAY, Jupiter slowly gains altitude and telescopic appeal. At mid-month it rises around 3:30 a.m. local daylight time and climbs to nearly 20° above the east-southeastern horizon at the start of civil twilight. On the 15th, the planet displays a disk 36″ across and shines at magnitude –2.2. It'll be at its biggest and brightest at opposition, on September 26th.

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 tabulated on the facing page. Find events timed for when Jupiter is at its highest.

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

April 1: 7:36, 17:31; **2**: 3:27, 13:23, 23:19; **3**: 9:15, 19:10; **4**: 5:06, 15:02; **5**: 0:58, 10:54, 20:49; **6**: 6:45, 16:41; **7**: 2:37, 12:33, 22:28; **8**: 8:24, 18:20; **9**: 4:16, 14:12; **10**: 0:08, 10:03, 19:59; **11**: 5:55, 15:51; **12**: 1:47, 11:42, 21:38; **13**: 7:34, 17:30; **14**: 3:26, 13:21, 23:17; **15**: 9:13, 19:09; **16**: 5:05, 15:00; **17**: 0:56, 10:52, 20:48; **18**: 6:44, 16:39; **19**: 2:35, 12:31, 22:27; **20**: 8:23, 18:18; **21**: 4:14, 14:10; **22**: 0:06, 10:02, 19:57; **23**: 5:53, 15:49; **24**: 1:45, 11:40, 21:36; **25**: 7:32, 17:28; **26**: 3:24, 13:19, 23:15; **27**: 9:11, 19:07; **28**: 5:03, 14:58; **29**: 0:54, 10:50, 20:46; **30**: 6:42, 16:37

May 1: 2:33, 12:29, 22:24; **2**: 8:20, 18:16; **3**: 4:12, 14:08; **4**: 0:04, 9:59, 19:55; **5**: 5:51, 15:47; **6**: 1:42, 11:38, 21:34; **7**: 7:30, 17:25; **8**: 3:21, 13:17, 23:13; **9**: 9:08, 19:04; **10**: 5:00, 14:56; **11**: 0:52, 10:47, 20:43; **12**: 6:39, 16:35; **13**: 2:30, 12:26, 22:22; **14**: 8:18, 18:13; **15**: 4:09, 14:05; **16**: 0:01, 9:56, 19:52; **17**: 5:48, 15:44; **18**: 1:40, 11:35, 21:31; **19**: 7:27, 17:22; **20**: 3:18, 13:14, 23:10; **21**: 9:05, 19:01; **22**: 4:57, 14:53; 23: 0:49, 10:44, 20:40; **24**: 6:36, 16:31; **25**: 2:27, 12:23, 22:19; **26**: 8:14, 18:10; **27**: 4:06, 14:02, 23:57; **28**: 9:53, 19:49; **29**: 5:45, 15:40; **30**: 1:36, 11:32, 21:27; **31**: 7:23, 17:19

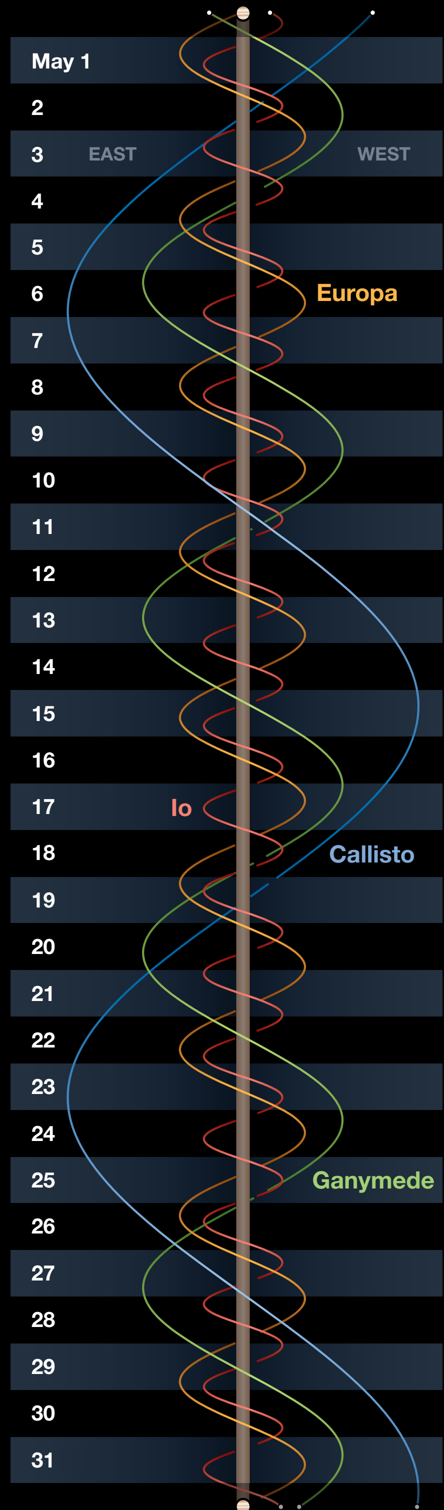
These times assume that the spot will be centered at System II longitude 16° on May 1st. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 16° and 1²/₃ minutes later for each degree more than 16°.

Phenomena of Jupiter's Moons, May 2022

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

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Jupiter's Moons



The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites' positions east or west of Jupiter.

The Surprising Tale of Mercury's Tail

The innermost planet sports a comet-like appendage.

A planet's ability to retain an atmosphere depends on its mass, temperature, and the types of gases present. Massive planets have high *escape velocities* — the speed required for atoms and molecules of gas to break free of a planet's gravitational influence. If temperatures are sufficiently high and escape velocities low, even heavy gases will gradually diffuse into space.

Mercury is both the smallest planet in the solar system and the closest to the Sun. The planet is only 5.5% as massive as Earth, with surface temperatures reaching a blistering 430°C (800°F) near the equator. Prior to NASA's Mariner 10 spacecraft flyby in 1974, astronomers suspected that Mercury might have a thin but appreciable atmosphere composed of heavy gases like carbon dioxide and argon produced by radioactive potassium decaying in the planet's crust.

The sensitive ultraviolet spectrometer aboard Mariner 10 failed to detect these gases but did find an exceedingly tenuous envelope of hydrogen, helium, and atomic oxygen. More rarefied than the best vacuum that any laboratory can produce, the isolated atoms detected rarely collide with one another. The absence of mutual collisions is also characteristic of Earth's *exosphere* — the outermost layer of our planet's atmosphere that begins at an altitude of about 700 kilometers (435 miles) and extends over 9,000 km to the boundary of interplanetary space.

▲ Italian amateur Andrea Alessandrini captured Mercury's tenuous sodium tail using a 66-mm f/4.8 refractor and a Pentax K3-II DSLR camera equipped with a narrowband sodium filter. His striking image taken on May 13th, 2021, required a 7-minute exposure guiding on the planet.

Hydrogen and helium are the lightest of all gases and quickly escape Mercury's feeble gravity. They are continuously replenished by the *solar wind*, the stream of charged particles that emanates from the upper atmosphere of the Sun. This hot plasma buffets Mercury up to ten times more intensely than it does Earth.

In 1985, American astronomers Andrew Potter and Thomas Morgan detected sodium in the atmosphere of Mercury using a high-resolution spectrograph and the 107-inch reflector at the McDonald Observatory in Texas. The abundance of this highly reactive metal proved to be greater than either hydrogen or helium.

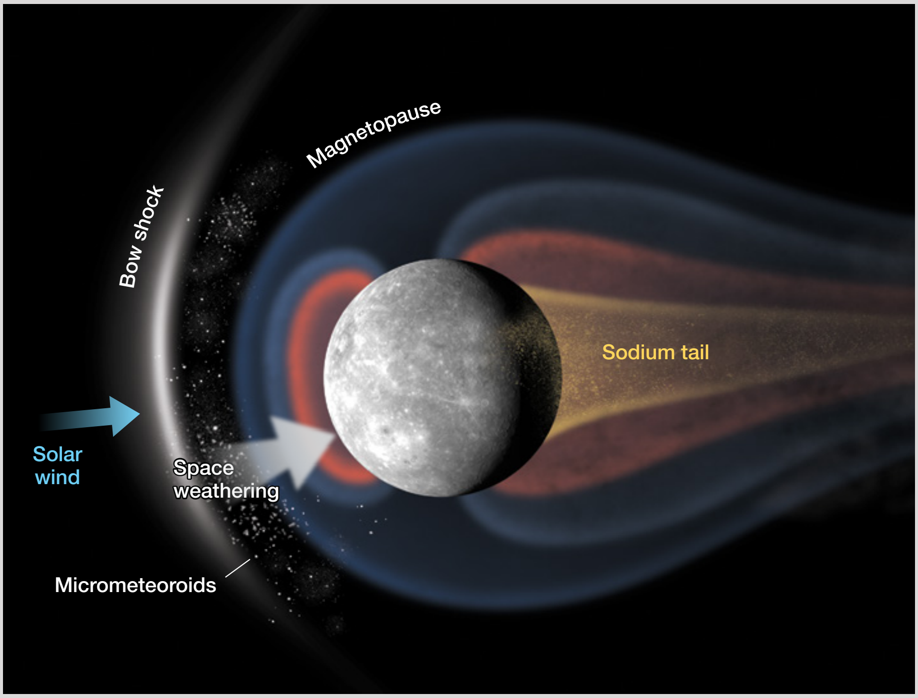
The presence of sodium had eluded Mariner 10's UV spectrometer because the element lacks an appreciable signature in the ultraviolet region of the spectrum but does emit a very strong signal in visible light. When a crystal of table salt (sodium chloride) is held in a gas flame, it imparts an intense yellow color because sodium's spectrum is dominated by a pair of very closely separated lines at wavelengths of 589.1 and 589.6 nanometers in the yellow region of the spectrum.

The ions in the solar wind are electrically charged, so their trajectories are influenced by magnetic fields. Earth's magnetic field deflects the solar wind and prevents our atmosphere from being stripped away, but Mercury's magnetic field has only 1% the strength of our planet's and provides scant protection. The ions from the solar wind strike Mercury at velocities of hundreds of kilometers per second, transferring their energy and dislodging atoms from surface minerals in a process known as *sputtering*.

Micrometeorite bombardment appears to be a second source of Mercury's sodium. The flux of meteoric material increases near the Sun and is about eight times more intense at the orbital distance of Mercury than at Earth's. Instruments aboard NASA's Messenger spacecraft, which orbited Mercury between 2011 and 2015, detected a transient plume of sodium during a meteor shower on Mercury associated with material shed by Comet 2P/Encke. No coronal mass ejection or other energetic solar event occurred at the time, so an impact origin for the plume seems highly likely.

In addition to sodium, Messenger's instruments also detected potassium, calcium, and magnesium in Mercury's exosphere, but these elements lack sodium's strong spectral signature. The same solar radiation that sputters atoms of sodium and other metals off Mercury's surface sweeps them away from the Sun to form a comet-like tail, fulfilling a 1986 prediction by the Chinese planetary scientist Wing-Huen Ip. A tail extending 41,000 km from Mercury was detected in 2001 by Andrew Potter of the National Solar Observatory using the huge, 1.6-meter-aperture McMath-Pierce Solar Telescope atop Kitt Peak in Arizona.

Seven years later, Jeffrey Baumgardner and his colleagues at Boston University's Center for Space Physics tried wide-angle imaging using a narrowband filter that selectively transmitted sodium's yellow emission lines. They were amazed to record a tail extending more than 2.6 million km from the planet. From an Earthbound vantage point, this tail extended 1½°, three times the apparent diameter of the full Moon. Baumgardner's team determined that an atom of sodium blasted from Mercury's surface takes only 15 hours to be driven to the end of its tail.



▲ Mercury's sodium tail is produced when ions from the solar wind and a constant rain of micrometeoroids vaporize Mercury's surface rocks. At high altitudes the released sodium atoms overcome the planet's gravitational influence and are accelerated in the anti-sunward direction by radiation pressure to form a tail.

The Messenger spacecraft found dramatic changes in the abundance of sodium in Mercury's exosphere and the intensity of sodium emission from its tail. In 2020 Japanese investigators presented evidence that increases in the amount of sodium released by micrometeoroid impacts during encounters with cometary dust streams are responsible for this variability.

Amateurs can record images of Mercury's tail using surprisingly modest equipment. A Wratten 12 or 15 yellow filter will darken the background sky by selectively transmitting light emitted by ionized sodium while blocking other wavelengths. Even higher contrast can be achieved with a narrowband dielectric interference filter centered at 589.2 nanometers like the one available at **https://is.gd/Sodiumna**. Still, the tail is exceedingly faint and requires an exposure of several minutes. Stacking several short exposures is also a viable option.

Mercury is notoriously difficult to observe due to its close proximity to the Sun. This spring, the planet has its most favorable elongation for northern observers, reaching greatest eastern elongation on April 29th. At sunset on that date the planet will be nearly 19° above the western horizon for observers at a latitude of 40°N. During the last week of April and the first week of May it should be possible to image Mercury against the backdrop of a reasonably dark sky. The planet sets as twilight deepens, so the window of opportunity will be brief. A transparent sky free of light-scattering haze is essential. Careful preparation and no small amount of luck are required to record one of the solar system's largest but most insubstantial features.

■ Although Contributing Editor **TOM DOBBINS** regards Mercury as an unrewarding telescopic target, he's keen to try to capture an image of its tail.

GREGG DINDERMAN / S&T, MERCURY: NASA / JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY / CARNEGIE INSTITUTION OF WASHINGTON

Beauty Beyond Boötes

The hunting hounds of the Herdsman chase a ball of stars named M3.

When it comes to constellations, does size matter? Not really.

Constellations vary greatly in the amount of sky they cover. Crux, with an area of only 68 square degrees, is the smallest constellation, while Hydra, sporting 1,303 square degrees, is the largest. However, soaking up a lot of celestial real estate doesn't necessarily translate to a rich trove of telescopic treasures. Consider Boötes, the Herdsman. Measuring 907 square degrees, Boötes ranks a respectable 13th out of the official 88 constellations but contains exactly zero deep-sky objects (aside from a handful of double stars) for suburban scopers.

For the opposite situation, look to the herder's hunting dogs. Canes Venatici shapes up at 465 square degrees, earning it the middling rank of 38th. Yet the hounds have lots to chew on, including five Messier objects. Among them is the lovely globular cluster **M3**, located in Canes Venatici, ½° north of the border with Boötes. If I were the keeper of the constellations, I'd nudge that boundary just a little and award M3 to the Herdsman, giving the big guy something to brag about.

▲ **CELESTIAL CHANDELIER** Adrift in the galactic boondocks some 35,000 light-years from Earth, globular cluster M3 in southernmost Canes Venatici is jam-packed with several hundred thousand very faint suns.

RON BRECHER

Finding M3

We backyard astronomers like globular clusters. The best ones visible from mid-northern latitudes put up a good fight against light pollution. Moreover, most globulars are well placed during the warmer months. M3 is the first to arrive each spring — and Mr. Boötes can help us find it. Let's follow his directions.

As May opens, zero-magnitude Alpha (α) Boötis — Arcturus — shines high in the east at nightfall. Imagine a line stretching from Arcturus to 3rd-magnitude Alpha Canes Venaticorum, better known as Cor Caroli, 26° northwest of the Boötean beacon. Almost halfway to Cor Caroli the line grazes M3 on its southwest side. If your telescope has a red-dot (or similar) finder, you'll need to estimate that location carefully before aiming your scope. Use a low-power, wide-field eyepiece, as your initial try likely won't be bang-on-target.

If you're working with an optical finderscope, I invite you to follow my somewhat roundabout but moderately scenic star-hop route (with a few bonuses I'll describe shortly). Starting at amber Arcturus, six steppingstones form a 13°-long arc trending northwestward toward M3. Our first hop is to 6.3-magnitude HD 125040, not quite 1° north of Arcturus. After that, a 1.75° hop lands on 6.4-magnitude HD 124713. Longer jumps of about 3° and 4° take us past 4.8-magnitude 12 Boötis and 5.0-magnitude 9 Boötis, which stands out because it glows orange. Then it's onward to 6.2-magnitude HD 119081. That final, golden-hued steppingstone lies in Canes Venatici, where it guards the 6.2-magnitude globular less than ½° northeastward.

M3 materializes in finderscopes as a condensed fuzzy spot in contrast to the equivalently bright, pinpoint-sharp guardian star. Various catalogues list the cluster as being 16′ to 18′ in diameter. I'm deploying telescopes of four different sizes to check it out.

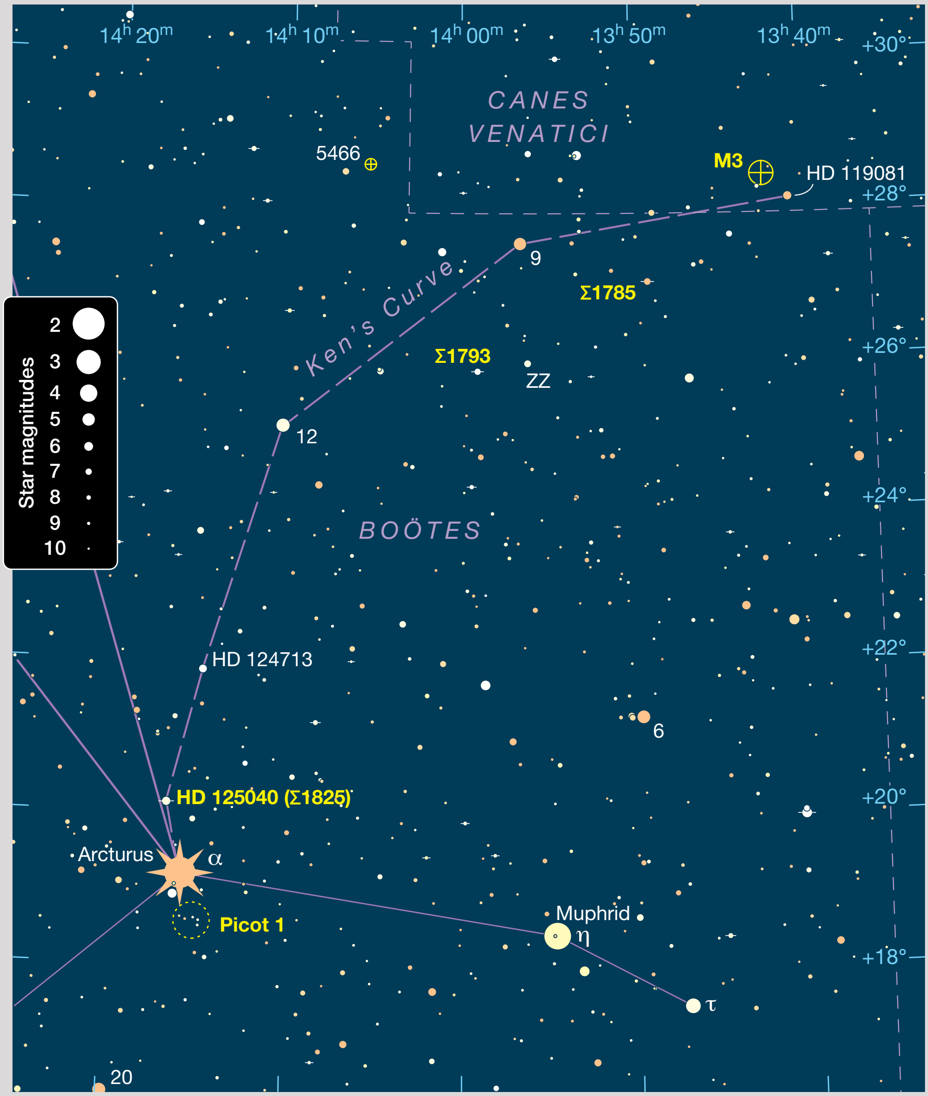
Scoping the Target

In my 4¼-inch (108-mm) f/6 Newtonian reflector working at 27×, M3 is a minuscule fuzzball captured inside a 20′-long isosceles triangle of 8.4, 9.8, and 10.6-magnitude stars. Long-exposure images show the cluster essentially filling the triangle. Alas, M3 is much smaller than that in the eyepiece of a city-based 4¼-inch.

At 72×, the globular is pale and diffuse around the periphery but way brighter near the center. Overall, it's maybe 3′ in diameter, and that includes a misty halo I can detect when staring a little to the side of the target, an observing technique called *averted vision*. It works because the edge of the eye is extra-sensitive to low light. Strangely — yet delightfully — the best way to grow a globular is to look slightly away from it.

Although M3 contains hundreds of thousands of suns, the brightest of them glimmer at about magnitude 12.7. Resolving the fuzzball into individual stars is a tough task for my mini-Newtonian. At 93× the tenuous halo is granular at best, its broad central area featureless. My 4.7-inch f/7.5 apochromatic refractor does better. Operating at 129×, the apo produces faint stars scattered throughout the halo and a mottled texture in the central region; 200× delivers a dim but distinctly grainy mass that partially resolves into "dust" around the edge.

My 7.1-inch f/15 Maksutov-Cassegrain reflector cruising at 90× delivers a pleasing degree of resolution in M3's outskirts. The entire peripheral region becomes obvious at 113×. Upping to 159×, I perceive numerous dots salting the interior; better yet, the cluster grows to roughly 5′ across. As in my smaller scopes, though, the delicate scene in the Mak-Cass fades with increasing magni-



▲ **THE ROUTE TO M3** The globular cluster M3 is located roughly halfway between Arcturus and Cor Caroli. A gently curving arc of "finderscope-friendly" stars will guide you to the spot.

▲ **ARCTURUS ASTERISM** Just south of brilliant Alpha (α) Boötis is the caterpillar-like asterism Picot 1, shown near the bottom edge in this photo. The grouping is also known as Napoleon's Hat.

ALAN DYER

fication. Using both hands to block out stray light, I stare patiently for several moments to let my retina absorb the faint photons.

Time for my favorite light bucket, a 10-inch f/6 Dobsonian. Working at 64×, the 10-inch resolves M3's outskirts into pinpricks of light. Both luminosity and density intensify toward the cluster's broad, bright middle. At 169×, that massive middle resolves into more stars than I can count. Applying 218× results in a fainter but noticeably bigger sphere. With averted vision, the globular swells to 7′ or 8′ in diameter. Staying dark-adapted is the key to getting M3 to barely half its rightful size and teasing out shy cluster members.

Binaries Along the Way

My rambling route to M3 has a few treats for double-star enthusiasts. The first is easily spotted at the Arcturus end. Just north of Arcturus is HD 125040, also known as **Struve (Σ)1825**, a compact binary possessing 6.5- and 8.4-magnitude components 4.2″ apart. Farther along the way is orangey 9 Boötis. At No. 9, we hop 1¾° southwestward to **Σ1785**, whose 7.4- and 8.2-magnitude stars are separated by a very slim 2.6″. From there, we head southeast nearly 2° to the 6.8-magnitude variable ZZ Boötis (creamy in color) and use that landmark to veer eastward another 40′ to **Σ1793**. This specimen comprises 7.5- and 8.4-magnitude stars 4.8″ apart.

The three binaries aren't showstoppers but, hey, they're easy pickings. I can see them in an 8×50 finderscope. For Σ1785 and Σ1793, my advice is to ensure you have 9 Boötis in the finder field, then shift slowly to the targets. Actually, I can snare each binary without the finder, provided I use my lowest magnification for a wide field-of-view and, beginning at 9 Boötis, sweep carefully star to star. Give it a try, bearing in mind that each double requires medium to high magnification for a reasonably clean split. The 120-mm apo nails all three sets at 100×.

I'll finish with a short side trip — all you need for guidance is Arcturus. Place blazing Alpha toward the northwestern edge of your telescope field at low-power, then look 40′ southward (past a 6th-magnitude star) and a tad westward. You should see a curvy asterism, 20′ in length, formed by seven stellar points ranging in magnitude from 9.4 to 10.6. Called **Picot 1**, the sinuous pattern resembles a caterpillar humped up in mid-crawl. Despite Arcturus blazing nearby, I can recognize the Picot-piller in my little Newtonian at 27×. If your scope is smaller than mine, you might need extra magnification to detect the faintest star, atop the hump. If you still can't recognize the figure, shove that Arcturian streetlight slightly outside your eyepiece field and — presto! — the cosmic caterpillar will appear.

What's that, you say? You don't like creepy-crawly caterpillars? No problem — think of it as Napoleon's Hat, or as I do, a celestial Slinky.

■ Contributing Editor **KEN HEWITT-WHITE** is the founder and chief promoter of the Boötes Booster club.

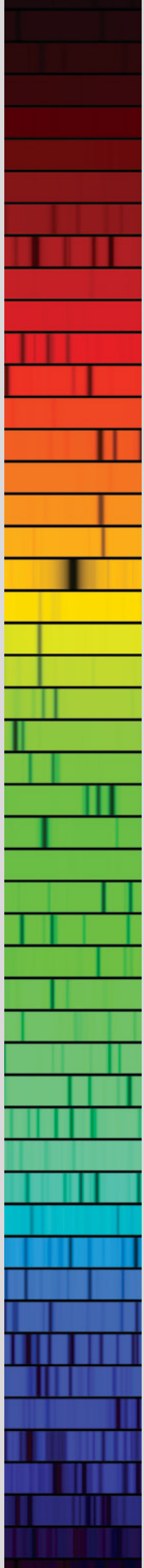
Boötes Plus

Object	Type	Mag(v)	Size/Sep	RA	Dec.
M3	Globular cluster	6.3	18.0′	$13^h\ 42.2^m$	+28° 23′
Σ1825	Double star	6.5, 8.4	4.2″	$14^h\ 16.5^m$	+20° 07′
Σ1785	Double star	7.4, 8.2	2.6″	$13^h\ 49.1^m$	+26° 59′
Σ1793	Double star	7.5, 8.4	4.8″	$13^h\ 59.1^m$	+25° 49′
Picot 1	Asterism	—	~20′	$14^h\ 14.9^m$	+18° 33′

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

Decoding Light

Ready to start splitting starlight? Take a dive into spectroscopy.



◀ **CHEMICALS IN OUR SUN** In this strip from a larger spectrum, wavelength increases from bottom to top (and from left to right). Superposed on the familiar colors of the visible spectrum are dark absorption lines, fingerprints from the elements that constitute our nearest star.

N. A. SHARP / NOAO / KITT PEAK / FTS / AURA / NSF

You're no doubt familiar with a prism's ability to split light into a spectrum, but have you ever considered doing it at a telescope? While *photometry* tells us how an object's brightness varies with time, *spectroscopy* gives us insight into the guts of the object. Spectroscopy informs us that stars have different chemical elements churning within; that accretion disks swirl around black holes; that galaxies recede from us. And more, much more. With the advent of affordable astronomical cameras and — more recently — spectrographs, the art of deciphering the elemental makeup of astronomical objects is within your reach.

Backyard spectroscopy. Big mountaintop telescopes are equipped with spectrographs that yield exquisite resolution, far beyond what you can achieve. So you might ask yourself, "Why bother?" Remember, obtaining observing time on the big telescopes is extremely competitive. Professional astronomers thus often have big gaps in their data sets — gaps they're eager for someone to help them fill. The big advantage of the amateur community is essentially continual access to observing opportunities, especially when it comes to transient events: At the drop of a dew shield, observers can head to their backyards or dark-sky sites and get cracking. In addition, having the community flung far and wide across the globe potentially means full coverage of an event — it can't be cloudy *everywhere* at the same time, can it?

Now that spectrographs as well as standard reduction software and pipelines are more readily available, you can conduct spectroscopy with your own equipment in your own backyard. In addition, obtaining a viable spectrum used to take hours upon hours in the days of yore; today, this operation is reduced to a matter of minutes with an 8-inch scope for targets of magnitude 10 to 12, for example.

Initiatives such as the Astronomical Ring for Access to Spectroscopy (**https://is.gd/aras_spec**) are a testament to the fact that the amateur spectroscopic community is thriving. Efforts such as these are extremely valuable, since long-term spectroscopic monitoring of variable stars and their ilk by professionals is lacking. The American Association of Variable Star Observers wanted in on the action, too, and so in 2019 it launched the AAVSO Spectroscopic Database. The database is free of charge and open to all observers, and the AAVSO encourages all spectroscopists — from beginners to experts — to get involved.

Start splitting. If you're eager to investigate the wonderful world of spectroscopy, head over to the AAVSO's dedicated webpage (**https://is.gd/aavso_spec**). There you'll find a general introduction to astronomical spectroscopy as well as select targets and observing priorities. Useful specs accompany each class of object: recommended scope size, frequency of observation, required resolution, and desired signal-to-noise ratio, among other details. Crucial to the enjoyment of an exercise is understanding its goal, and the webpage does a sterling job of equipping observers by noting why the data for each class are sought and what they're expected to reveal. An excellent place to start is the video linked at the top of the webpage, which features spectroscopy enthusiast Tom Field and fellow observers sharing their knowledge and love of the craft.

Before you whip out that spectrograph, do study the Guide to Getting Started in Spectroscopy (**https://is.gd/aavso_spec_guide**). As Steven Shore, current lead of the AAVSO Spectroscopy Observing Section, says, "How observations are obtained and reduced and what sort of data are presented are more delicate an issue than for photometry." He also urges observers to pay careful attention to calibration and to meticulously record observing conditions, spectral interval, and data-reduction procedures.

Don't be discouraged by the seeming complexity of the field. The returns on the satisfaction of knowing that you're probing fundamental physics are huge. You'll also be adding valuable data to the scientific literature. There's something for everyone: If you're interested in dwarf novae, or microquasars, or Cepheids — or even Cepheids with X-ray flashes — there's a target for you. As Shore encourages, "Whatever is interesting, do it." And there's so much that's interesting out there.

■ Observing Editor **DIANA HANNIKAINEN** used to spend a lot of time trying to unravel microquasars' X-ray spectra.

 by Sean Walker

Leonard's Surprising Show

Comet C/2021 A1 closed out 2021 with a photographic bang.

MEANDERING TAIL Comet Leonard displays knots and kinks in its bluish ion tail as seen from the slopes of Roque de los Muchachos on La Palma, Spain. The comet's extensive tail spans more than 36° in this tracked, two-frame mosaic recorded on the evening of December 26, 2021, with a Canon EOS 6D operating at ISO 3200 and a 50-mm lens.

JAN HATTENBACH

It isn't often that observers are treated to two good comets in less than two years. The last time I can recall something similar was in 2007 when Comet McNaught and Comet 17P/Holmes bookended the skies. Comets tend to be unpredictable. While we can plot their paths across the sky after discovery, how bright they get and what tail activity arises are influenced by several factors. Some comets perform well below expectations, and some even disintegrate altogether as they near the Sun. But once in a while, one of these icy bodies performs far better than expected and puts on a memorable display.

The story of Comet Leonard (C/2021 A1) began at the start of 2021 when Senior Research Specialist Gregory J. Leonard of the University of Arizona's Lunar and Planetary Laboratory noticed it on images recorded January 3rd. He was searching for near-Earth asteroids for the Catalina Sky Survey using the 1.5-meter (60-inch) telescope on Mount Lemmon in Arizona. A faint, 19th-magnitude object at about 5 a.u., it soon became apparent that the object's orbit would bring it close to the Sun and Earth precisely one year later.

Comet Leonard was predicted to achieve a maximum brightness of about 4th magnitude, making it a good binocular and telescopic target for dedicated observers, though not something to drag your friends and family out to see. Over the course of the year, the comet followed this script — a faint object slowly brightening as it approached the inner solar system. But by early October, it brightened to almost 7th magnitude while sporting a short dust tail. Hopes began to rise among optimistic comet aficionados that a pretty good show was about to begin.

Serendipitous Encounters

By November, the comet continued its steady brightening trend as it crept through Ursa Major and Canes Venatici in the morning sky. Along the way, it passed by several distant *(continued on page 62)*

▲ **RARE CONVERGENCE** As Comet Leonard passed globular cluster M3 in the morning hours of December 3rd, imagers Tom Masterson and Terry Handcock recorded a bright fireball during one of the 120-second exposures used in this colorful composite.

WAGGING TAIL After transitioning to an evening object, Comet Leonard sported numerous streamers, kinks, and knots that changed shape as the solar wind pushed material down the comet's ion tail. Following perihelion on January 3rd, gas production began to subside and Leonard started to display both a thin ion tail and a pronounced dust tail.

GERALD RHEMANN (6)


December 28, 2021
January 1, 2022
January 3, 2022

(continued from page 59)
galaxies, offering imagers some excellent photographic opportunities. On the morning of November 24th, the comet passed directly between irregular galaxies NGC 4631 and NGC 4656. Nine days later, it slipped by globular cluster M3, with the comet's tail sweeping across the distant star cluster.

By the start of December, Leonard reached naked-eye visibility, though it was quickly racing toward morning twilight. About this time, comet watchers began reporting Leonard exhibiting outbursts of activity that notably increased its brightness while also sparking fears that the icy object was breaking up.

Observers waited with bated breath as Comet Leonard transitioned from a morning to an evening target. By December 15th, it was spotted just a few degrees above the horizon in evening twilight, undergoing an outburst that raised its brightness to about magnitude +3.5 — a harbinger for the main act to come.

The Southern Show

When Comet Leonard transitioned into the evening sky, it entered the southerly constellations of Ophiuchus and Sagittarius, visible for northern observers in deepening twilight. However, the best part of the show occurred for those situated near the equator and in the Southern Hemisphere. Due

▲ **VISUAL IMPRESSIONS** Ian Thompson of Albany, New Zealand, sketched fine striations and arcs within the comet's pseudo-nucleus while viewing Leonard at 40× with his 8-inch Cassegrain on December 24th.

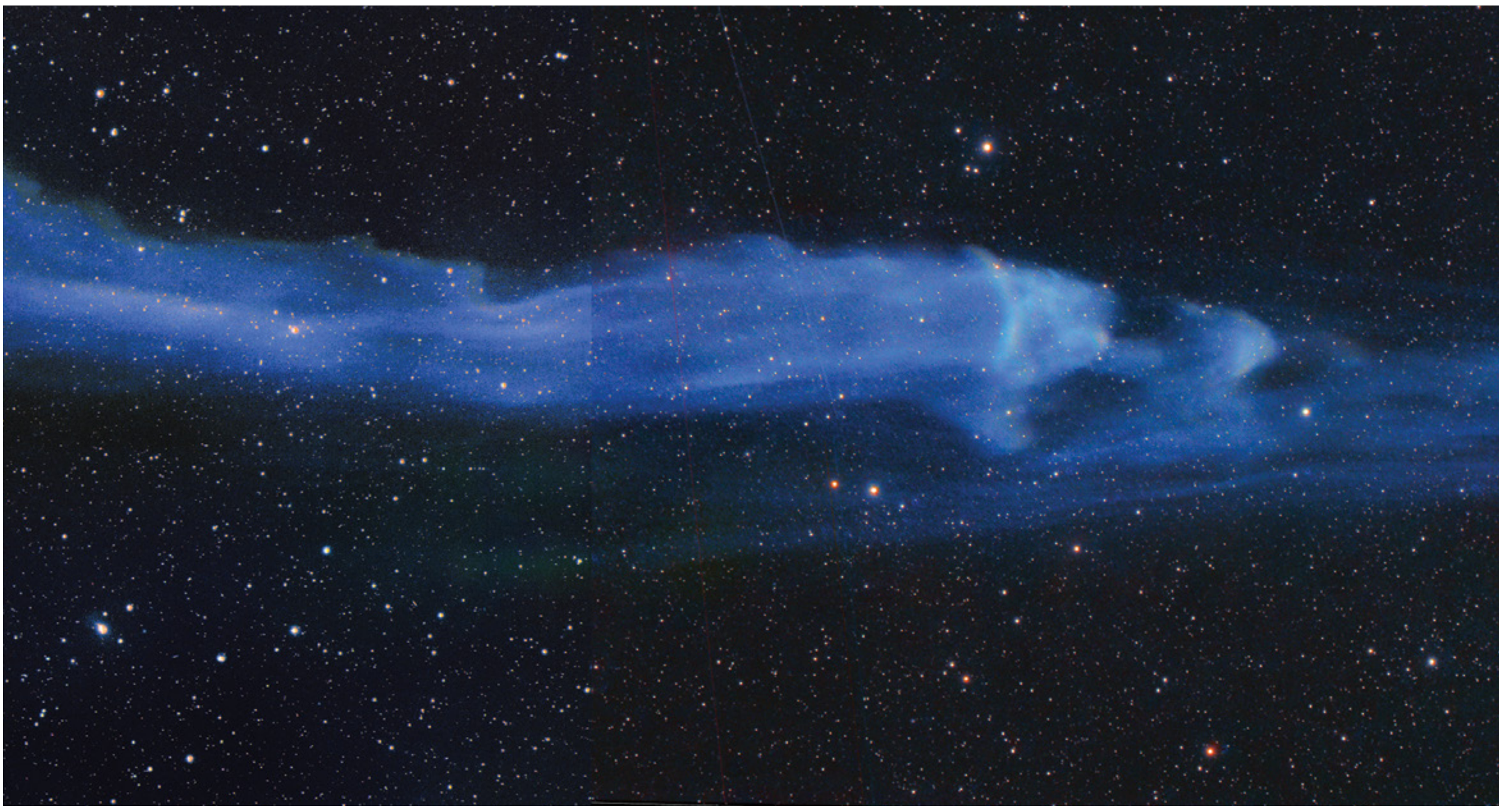
INTERPLANETARY PERSPECTIVE ESA and NASA's Solar Orbiter recorded Comet Leonard on December 18th with Mercury and Venus visible at top right.

ESA / NASA / NRL / SOLOHI

GIJS DE REIJKE

ZODIACAL LINEUP Comet Leonard appears to compete with the brightness of the zodiacal light as seen above Tenerife, Spain. The planets Jupiter, Saturn, and Venus also line up from top to lower right in this composite image recorded on December 28, 2021.

GREGG RUPPEL



to the comet's geometry as seen from Earth, its rapidly growing tail ran parallel to the horizon as seen from mid-northern latitudes. Farther to the south, however, it was possible to easily spot its bright coma and, under dark skies, a faint tail several degrees long.

As C/2021 A1 rose higher each night, its complex tail began to come into view. On December 20th (one night after its historically close encounter with Venus), the comet experienced a second outburst that brightened its pseudo-nucleus by a full magnitude or more.

Images of the comet taken after December 18th show complex streamers of gas and dust extending at least 10°. These features moved rapidly down the tail, requiring short exposures to properly "freeze" the details in photographs.

Several additional outbursts occurred through the end of 2021. Comet photographer Michael Jäger explained that each outburst began with a nearly full magnitude brightening of the coma, followed a day later by a large kink or knot flowing down the comet's bluish ion tail. Outbursts occurred on December 23, 26, 30, and January 1, with other, minor outbursts seen later.

Ian Thompson of Albany, New Zealand, noted while sketching his impressions through the eyepiece on the evening of December 24th that ". . . as twilight began to fade, I saw the green glow of the coma, followed by the orange-yellow dust tail extending over about 5°."

While a few degrees of the tail's length was visible to the naked eye, wide-angle photos from extremely dark sites revealed its greatest extent to be a surprising 60° or more on the closing nights of 2021. While Comet Leonard experienced a few more outbursts as it passed through perihelion on January 3rd, gas production fell off rapidly afterward, leaving the comet with a thin ion tail and slightly curved dust tail to compete with the waxing Moon.

Comet Leonard put on a good performance for observers and photographers in both hemispheres, even if it didn't quite make the list of truly great comets. At press time for this issue, Leonard's show wasn't completely over. Its below-naked-eye visibility and its tail can be measured in arcminutes rather than degrees, but the comet is still undergoing outbursts that brighten the coma.

Comet Leonard's orbit has it heading into interstellar space, never to return. So, let this gallery of its brief but memorable visit sustain your appetite until the next time a bright, hairy "star" graces our skies.

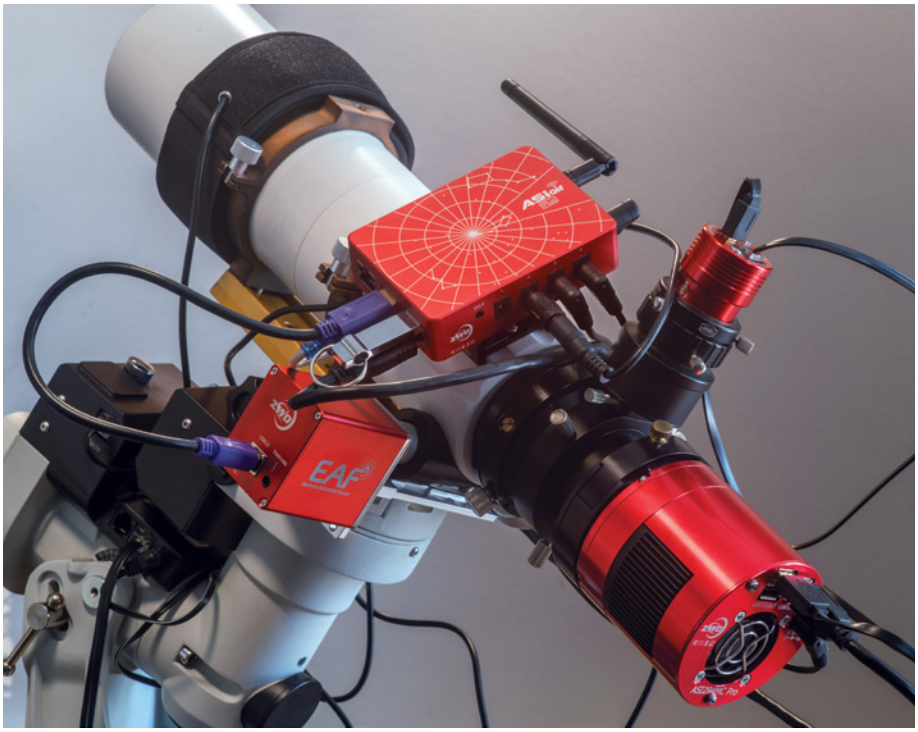
■ Associate Editor **SEAN WALKER** had one good view of Comet Leonard before it moved on to more southerly declinations.

◀ **A MATTER OF PERSPECTIVE** Distant galaxies NGC 4656 and NGC 4631 briefly hosted cometary visitor C/2021 A1 on November 24th as the comet raced towards its January 2022 perihelion.

▼ **FLOWING DOWNSTREAM** A day after each outburst, observers noted a thick knot of gas travelling down the comet's blue ion tail. Michael Jäger captured this particular clump the evening of December 26 using a remote imaging telescope in Namibia.

ZWOptical's ASIair Plus

This little device does a lot more than control your imaging gear.



▲ The ASIair Plus is shown ready for a night of imaging atop the author's William Optics 71-mm f/4.9 refractor. Attached to the ASIair is an ASI294MC Pro camera at lower right, a ASI120MM Mini autoguiding camera inserted into the off-axis guider, and the ZWO EAF focus motor at lower left. Three of the four 12-volt outlets are used for powering a dew heater, the main camera's TEC colling, and an iOptron CEM 25P mount. A USB drive is inserted into the last available USB 3.0 port to store the night's images.

ALL PHOTOS BY THE AUTHOR

ASIair Plus

U.S. Price: $299

astronomy-imaging-camera.com

What We Like

Provides reliable, wireless operation of a wide range of Go To mounts and ZWOptical imaging devices

No additional software required

What We Don't Like

Power supply not included

Compatibility limited to ZWO devices and some DSLRs

IT'S CLEAR THAT in modern astrophotography one recent trend is here to stay. Imagers want to be comfortable while recording the night sky, not sitting by a dew-soaked laptop next to their telescope while their cameras make dozens of guided exposures. After all, who really wants to feed the mosquitoes or shiver through subfreezing nights? Most of the work in deep-sky imaging is now automated thanks to Go To mounts, autoguiders, and critical-focus devices.

One new piece of equipment that enables comfortable, remote astrophotography is ZWOptical's ASIair Plus. It's the company's third model of ride-along computer and accessory hub controlled via a smartphone or tablet. This compact device mounts atop your telescope, controlling and powering your various imaging components.

I reviewed the original ASIair almost three years ago (*S&T:* Sept. 2019, p. 66). The ASIair Plus is smaller than the original unit, though that doesn't make it any less capable. It's housed in an attractive, red-anodized aluminum case measuring about 10 × 6⅔ × 2¼ centimeters (approximately 3⅞ × 2⅝ × ⅞ inches). The device comes with six cables: three having 5.5-mm × 2.1-mm barrel connectors on each end, as well as one male-to-female extension cable. There's also a 2-meter Ethernet cable and a ¾-meter USB 3.0 cable.

The ASIair Plus has four USB connections located on one end: a pair of black USB 2.0 ports and two blue USB 3.0 sockets. On the opposite end are four 5.5-mm × 2.1-mm 12-volt power jacks with a combined output of 6 amps. There's a tiny LED by each power port that lights up when each is activated by the control app. The four LEDs and three others located on another side of the case aren't bright enough to interfere with your night vision. The Wi-Fi antenna is on one end along with the 12V power input and switch. The side opposite the power jacks has a USB-C port as well as a TF card slot (also known as Micro-SD) and threaded holes that accept the finder-bracket mounting shoe.

Although the company states the ASIair Plus operating manual is downloadable from its website, at the time of this review it wasn't available. However, the manual for the ASIair Pro is available, and its operation and features are virtually identical to the Plus version.

Setting Up

Before mounting the ASIair Pro on your scope, I recommend you initially install and configure all your imaging devices indoors to make sure everything works together before heading out to the scope. The first step is to download the *ASIair* app from either the Apple marketplace or Google Play Store, depending on the smart device you'll be controlling the computer with. Be sure to check for updates regularly, as ZWOptical is constantly making improvements to the app. I installed it on my iPhone 8 and on my Generation 6 iPad.

The ASIair Plus attaches to most scopes with an aluminum dovetail shoe designed to fit in the quick-release finderscope brackets found on most commercial telescopes. The shoe can be positioned on the bottom or on the side of the device. Additionally, there's a ¼-20 threaded socket by each of the bracket ports that can be used as an alternate mounting point.

After installing the app, plug in the unit, turn it on, and link it to your tablet or smartphone. Curiously, ZWOptical doesn't include the 12-volt, 5-amp power supply for the device itself, though it's available on the company's website for $29. Fortunately, I had a compatible one handy. About 30 seconds after powering up, the Wi-Fi activates (signaled by an audible beep), and you can connect your tablet or smartphone and launch the app.

Next, configure your mount, imaging and autoguiding cameras, as well as any electronic focusers or filter wheels you intend to use. As programmed, the ASIair Plus is limited to controlling ZWO cameras and peripheral devices, with the exception of Canon and Nikon cameras. It can, however, drive a wide range of Go To mounts. I used it to control my iOptron CEM25P mount as well as my observatory telescope with its Losmandy Gemini 2 Go To drive system. Both connected with no problems.

App Control

Once the device is configured to work with your gear, you're ready to set up an imaging plan. The *ASIair* app displays a series of intuitive icons along the top of the screen for each device. Starting from left, there are settings for the device itself (Wi-Fi, power-port control, etc.). Next is the camera settings followed by autoguiding, telescope, filter wheel, focuser, and finally storage (such as the TF card or internal storage). Devices not connected are grayed out.

Users can program entire imaging plans that include everything from the exposures of the sky to calibration frames. Multiple targets can be programmed for a given night. These plans are configured by tapping Autorun on the right side of the screen and then creating an imaging schedule. You can save these schedules for future use or modify them later. I set up imaging schedules that included everything except dark and flat-field images.

The four power-out ports on the

▲ The ASIair Plus comes with four cables for its power connections, one USB 3.0 cable, and an Ethernet cable. Users will have to purchase the 12-volt, 5-amp power supply for the device separately or provide their own.

▲ As a control station, the ASIair Plus is loaded with ports and switches. 1 This end includes the 12-volt, 5-amp power input, the on/off switch, and the Wi-Fi antenna at right along with the reset button and a red LED indicator. 2 Four USB ports are located on the opposite end — two black USB 2.0 and a pair of blue USB 3.0 ports. An Ethernet port at left permits hardwiring of the device to a network. 3 A single jack at left connects to the shutter release cable of certain Canon or Nikon DSLRs. Four power ports line this side of the device, each having an LED indicator that lights up when each is activated in the *ASIair* app. 4 The side opposite of the power ports has a USB-C connection used to transfer files from the device's internal memory. The TF card slot (commonly known as a Micro-SD card) accepts up to 1-terabyte cards. At center is a ¼-20 threaded hole for mounting the device. The smaller threaded holes are an alternative connecting location for the mounting shoe (seen at the bottom of the unit).

ASIair Plus combined are limited to 6 amps total output, so during most of my tests they powered my guiding and imaging cameras, an electronic focuser, and a dew-prevention band. The app shows the total current being used by each power port.

Strong Wi-Fi

The most obvious and welcome improvement with the ASIair Plus over the original model is its increased Wi-Fi range. The Plus model supports 2.5G and 5G transfer speeds, both offering considerable range, with the 5G transferring images faster, though at the cost of shorter range.

When I tested the ASIair Plus inside my observatory, I never lost connection despite the unit being separated from my iPad by about 10 feet — including about 10 inches of flooring and insulation. Outdoors, with the device controlling my iOptron mount, I could walk about 100 feet away and still retain a solid connection as long as there were no objects between it and my tablet.

I began to experience intermittent connections as I attempted control from about 150 feet away using the 2.5G option. My tablet couldn't detect the ASIair Plus outside at all once I stepped inside my house at the same distance with a wall in between. Users who travel to remote imaging sites can expect a solid, continuous connection from ASIair Plus while comfortably seated inside a warm car several feet away from the imaging rig.

In addition to the Wi-Fi improvements, the app is much more responsive in general than the version I used three years ago. A full-resolution, 12-megapixel image from my ZWO ASI294MC Pro camera transfers to my iPad in about 6 seconds over the 5G connection, and there was virtually no lag when changing some imaging parameters despite the autoguider working away in the background.

Camera Compatibility

As noted earlier, the ASIair Plus will only control ZWOptical's deep-sky, planetary, and autoguiding cameras, as well as some DSLR cameras. A list of compatible models of both Nikon and Canon appears in the manual, but be forewarned: Not all DSLRs are treated equally. Some Nikon models require the use of a shutter-release cable in addition to the standard USB connection when controlled with the ASIair Plus. There are no such caveats for Canon cameras. At this time, the ASIair Plus doesn't support mirrorless cameras.

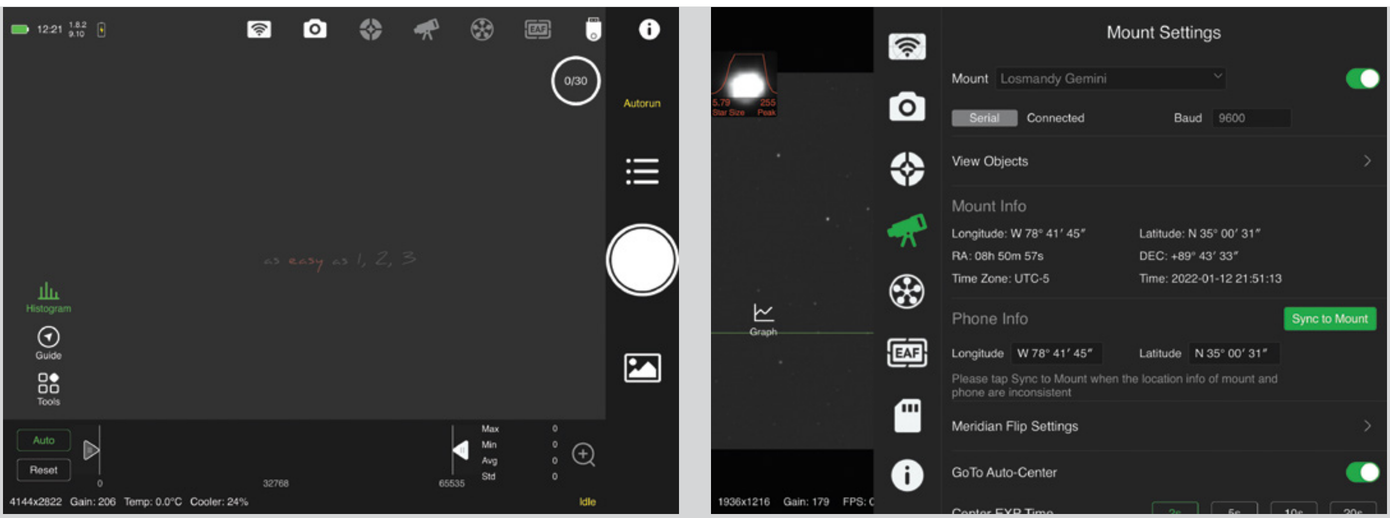
Testing this compatibility, the ASIair Plus picked up my Nikon D300, D750, and D850 cameras instantly. I also tested its connectivity with a friend's Canon 77D, and it was also instantly recognized in the app. Both Canon and Nikon DSLRs must be set to save in RAW format for ASIair Plus to operate them.

Storage Space

Unlike the earlier ASIair, the firmware resides on an internal drive with an additional 20 gigabytes of free space. Users can save images to this space or to a TF card. The computer can accept TF cards of up to 1 terabyte in size, though only a 32GB card is included. Images saved to either location are easily transferred to a desktop computer via the high-speed USB-C port.

I preferred using a USB flash drive to store my image files before moving them to my main computer for post-processing. This method requires using one of the USB ports, but three ports remain for my ZWO ASI294MC Pro color camera and ZWO EAF focus motor, as well as for connecting to my mount. (I plugged my autoguider into the built-in hub on my ZWO ASI294MC Pro camera.)

Moving the images from the internal memory requires the destination



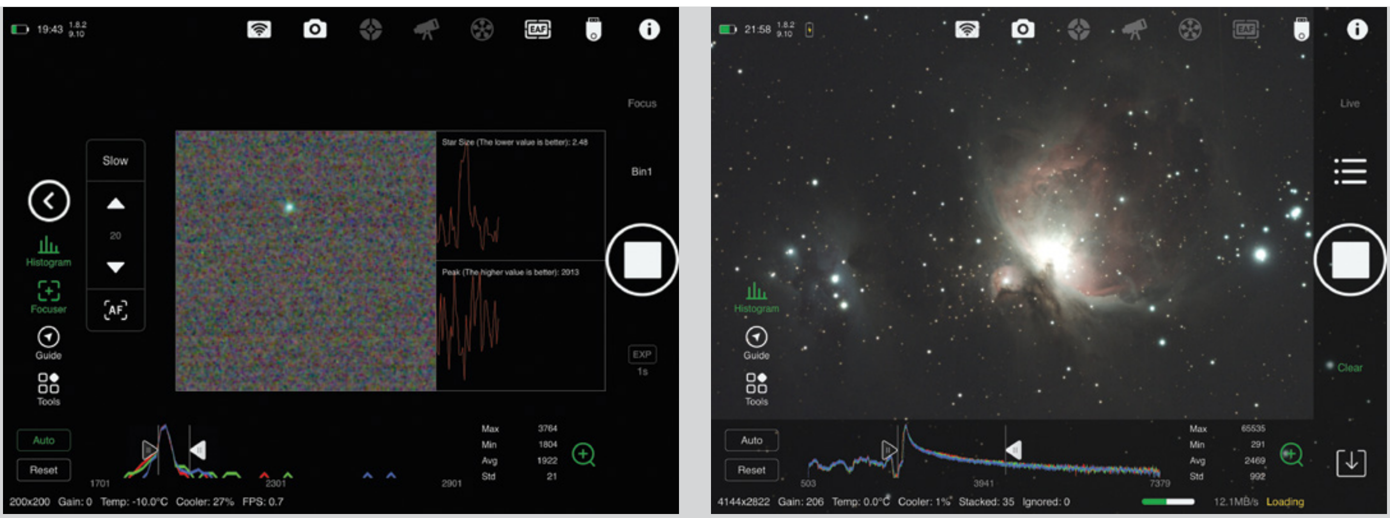
▲ *Left:* After launching the *ASIair* control app, the user is first prompted to connect to the device through a Wi-Fi connection. After that, simply select each camera, the mount, a filter wheel, and focuser by clicking each icon along the top of the screen. The icon for additional memory changes depending on the location the recorded images are to be saved (the author used a USB flash drive for his tests). *Right:* The Mount Settings screen features a pull-down menu of dozens of compatible tracking mounts. Near the bottom of the screen, users can set the parameters for an automatic meridian flip to avoid having gear collide with the tripod.

computer to be located close to ASIair Plus, which itself needs to be powered to access its internal storage. The *ASIAir* app includes a feature for moving the saved files from one storage location to the other.

Overall, the ASIair Plus functions like any modern computer, and it automatically detected peripherals when they were connected. Unplug one USB device and plug in another and the device knows it. A small box appears on the screen stating that a new camera is connected and what type it is. It then appears instantly in the camera selection menu.

On top of its deep-sky imaging capabilities, the *ASIair* app also includes planetary-imaging control and processing tools. I did some lunar imaging using the ASIair Plus and utilized the app to sharply focus the scope on-screen using the ZWO EAF focus motor and recorded several AVI files. The stacking feature in *ASIair* takes a little longer than the same task does on my desktop computer running planetary-stacking

▶ The ASIair Plus controlled all the gear seen on page 66 to produce this image of M42 and M43 in Orion. The device orchestrated 25 perfectly tracked 120-second exposures before successfully slewing to and imaging a second programmed target.



▲ *Left:* The focus screen of the app displays two graphs showing star measurements. The top graph displays star size, while the bottom one indicates the brightness value. Arrows at left move the ZWO EAF focus motor. *Right:* The *ASIair* app allows users to “live stack” images as they accumulate, a capability that is particularly helpful at public outreach events.

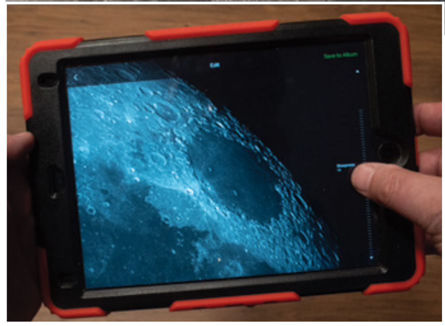
software, but the resulting image was just as sharp as any I've produced using *Registax* or *Autostakkert!3*.

Other Helpful Features

Besides being a robust control station, the ASIair Plus can live-stack deep-sky images, facilitating "electronically assisted astronomy" or public outreach by allowing you to share the view as the image builds up over the course of several minutes. Live stacking can also apply calibration frames to the image, which eliminates any hot pixels and corrects vignetting.

Deep-sky imagers will appreciate the AISair's onboard plate-solving capability. The app can quickly analyze the stars in an image and determine exactly where in the sky the telescope is pointing — usually within seconds. This is a particularly helpful feature if you're imaging one object for a night or more, since the *ASIair* app will quickly adjust the pointing of your telescope to match the field from the night before or when the mount performs a meridian flip.

This plate-solve function also assists a powerful polar-alignment routine in the *ASIair* app. An onscreen display indicates where the pole is and where the mount's polar axis is pointed, allowing very precise adjustments. There's no need for the pole to even be visible, as the app uses nearby field stars during repeated short exposures to figure out the mount's precise orientation.



▶ The ASIair Plus also includes tools to record, stack, and sharpen images of the Sun, Moon, and planets. The author captured this closeup of the Moon a day after full phase. He stacked and sharpened the result entirely with his iPad running the *ASIair* app.

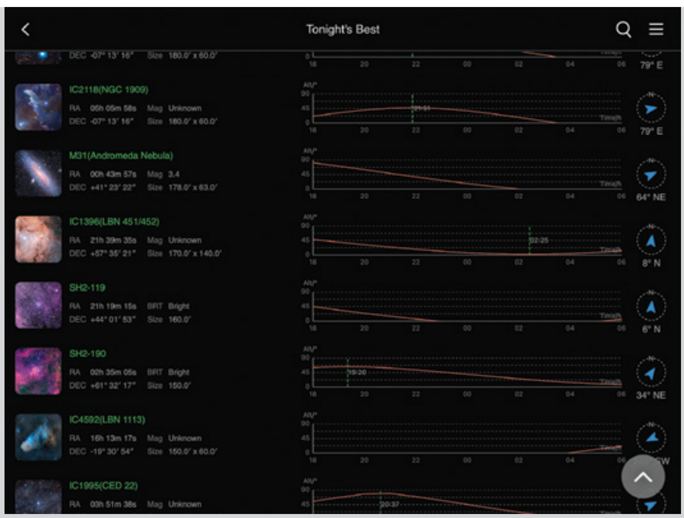
The ASIair Plus can also work with planetarium programs installed on your phone or tablet to control the Go To functions of your mount. I tested this capability by using *Sky Safari Pro* on my iPad with my iOptron CEM25P equatorial mount. Once the app had plate-solved an image, another tap brings up an annotated view of the field with all the deep-sky objects in it identified.

The Bottom Line

In my 2019 review of the original ASIair, I encouraged readers to stay tuned for updates that would take care of connection issues and sporadic Wi-Fi. Those changes were definitely incorporated into the ASIair Plus.

Opening up the ASIair Plus for use with other brands of cameras or filter wheels would certainly be welcomed. But for imagers already invested in ZWOptical gear, it already may be time to retire that old imaging laptop and order ASIair Plus in time for the next clear, dark-of-the-Moon stretch. The device is easy to learn and packed with a welcome array of features that can make all types of astrophotography easier.

■ Contributing Editor **JOHNNY HORNE** welcomes the recent downsizing trend in imaging control systems. He predicts that soon he'll be scripting imaging commands with his smart watch.



▲ *Left:* ASIair Plus has the ability to quickly plate-solve an image after it downloads, which helps ensure the device will exactly match a field from night to night. *Right:* The *ASIair* app also includes extensive information on what's up in the sky. After a plate-solve, users can select Tonight's Best from the tools menu screen to show a list of objects available for imaging on a given night. Each item in the ledger displays an image of the object and a graph plotting the object's altitude above the horizon throughout the night.

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New iCam Cameras
CEM40N
GEM45N
CEM70N
iOptron
www.iOptron.com
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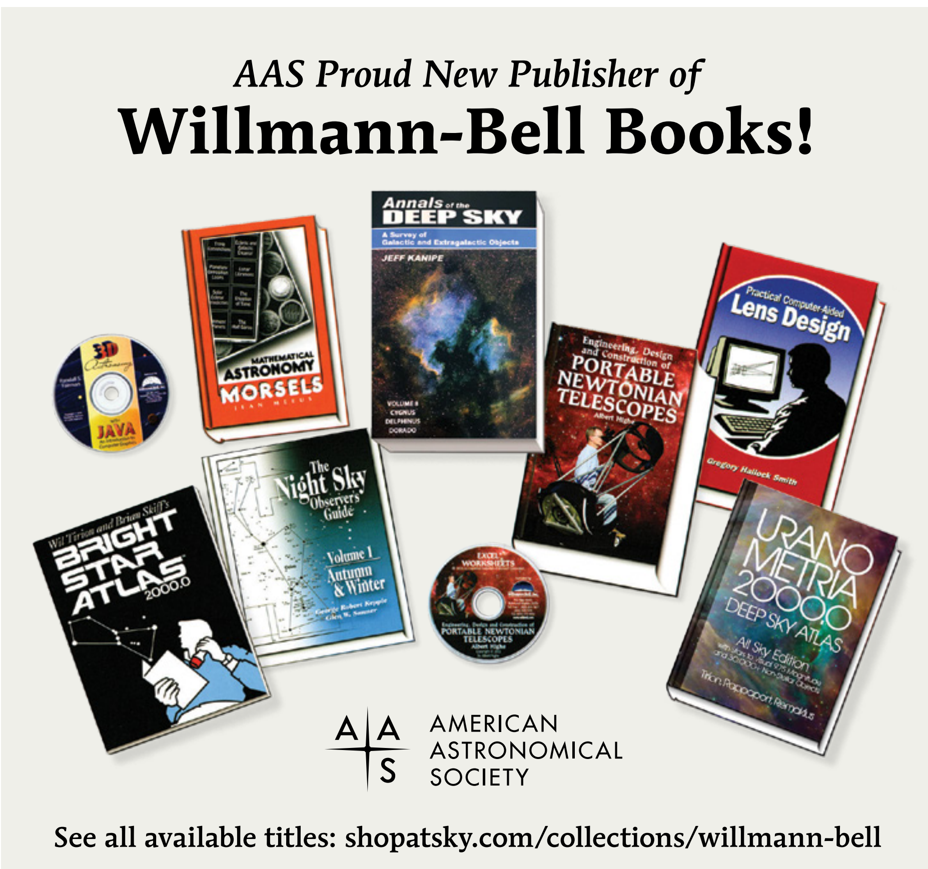
*NUC computer not included



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▲ PLANETARY CAMERAS

iOptron now offers a family of high-speed cameras for planetary imaging and autoguiding. The iOptron iCam series are small cameras housed in aluminum bodies designed to fit directly into any 1¼-inch focuser. Each version utilizes both dead-pixel-suppression technology and high-conversion gain to produce low-noise images with high-dynamic range. The iCam 462C ($259) features a Sony IMX462 color CMOS sensor with a 1,944 × 1,096 array of 2.9-micron-square pixels and can achieve frame rates of 136 frames per second (FPS). The iCam 464C ($309) is a 4.2-megapixel Sony IMX464 color CMOS detector with 2.9-micron-square pixels in a 2,712 × 1,538 array with downloads as fast as 93 FPS. The iCam 178M ($309) uses a 6.4-megapixel Sony IMX178 monochrome CMOS sensor with 2.4-micron-square pixels in a 3,060 × 2,078 array that can record up to 60 FPS. Each iCam includes an ST-4-style port to connect to and guide most telescope mounts.

iOptron
6F Gill St., Woburn, MA 01801
781-569-0200; ioptron.com

▲ 4-INCH ED REFRACTOR

Astro-Tech adds a new model to its extensive line of ED refractors. Astro-Tech AT102EDL ($1,199) is a 102-mm (4-inch) f/7 doublet with an objective that pairs one FCD-100 ED element with a rare-earth lanthanum element to produce sharp, color-free views. The tube weighs roughly 4.2 kilograms (9.3 pounds) and measures 60 centimeters (23.6 inches) long with its dew shield retracted. The AT102EDL comes with a 2½-inch-format, dual-speed focuser with built-in camera-angle adjustments and includes both 2- and 1¼-inch eyepiece adapters with non-marring brass compression rings. Each scope purchase comes with an aluminum lens cap, a pair of CNC-machined mounting rings, carrying handle, and a Vixen-style dovetail mounting plate.

Astro-Tech
Available from Astronomics
680 24th Ave. SW, Norman, OK 73069
800-422-7876; astronomics.com

◀ SMART DEW CONTROLLER

Celestron unveils its line of dew-prevention accessories with the release of its Smart DewHeater Controller 2x ($259.95). This device powers two dew-prevention strips as well as an additional 12-volt accessory (such as your telescope mount). At the heart of the Smart DewHeater is a powerful microprocessor that monitors the ambient temperature and humidity, ensuring only enough power is sent to the heating strips to ward off dew from your telescope optics. The unit works with both Celestron's dew-heater rings and third-party dew-heater bands with the addition of Celestron's Thermistor for Smart DewHeater Controllers ($14.95). The Smart DewHeater Controller includes built-in clamps to connect to Losmandy-style dovetail bars and can be controlled directly with Celestron Go To telescope hand controls or through its *CPWI* telescope-control software.

Celestron
2835 Columbia St., Torrance, CA 90503
310-328-9560; celestron.com

New Product Showcase is a reader service featuring innovative equipment and software of interest to amateur astronomers. The descriptions are based largely on information supplied by the manufacturers or distributors. Sky & Telescope *assumes no responsibility for the accuracy of vendors' statements. For further information contact the manufacturer or distributor. Announcements should be sent to nps@skyandtelescope.org. Not all announcements can be listed.*

A Solid-Glass Schmidt-Cassegrain Aims High

These two projects are monolithic monuments to ingenuity.

▲ Rik's telescope is made from a solid cylinder of glass. The Schmidt corrector and secondary are ground into one end, and the primary mirror is ground into the other.

IN NOVEMBER 2021 an online video went viral. My inbox filled with emails all containing the same link, all with the same subject line: "You must write about this!" Indeed, I must. If this isn't the coolest telescope I've ever seen, then I haven't seen a telescope.

What Dutch optical engineer Rik ter Horst has made is quite possibly the world's most compact Schmidt-Cassegrain telescope. And he's made it out of a single piece of glass.

The diagram and photos on these pages tell you everything in an instant: The Schmidt corrector is ground into the front face, as is the secondary mirror, and the primary mirror is ground into the back face. In between, where a typical SCT is full of air, Rik's telescope is solid glass. It does have one cavity: A light baffle is drilled into the body and blackened on the sides. And there's one additional feature that a normal SCT doesn't have: The back surface provides one final opportunity to fine-tune the light path on its way out of the scope.

Rik ter Horst does all the grinding and polishing at this one-meter-square workstation.

The telescope is tiny, with a clear aperture of only 25 millimeters (one inch). That might lead you to think this is a scale model or a mere curiosity, useless for anything but its novelty. Au contraire. This telescope has found a place that's quite literally out of this world: In December 2022, Rik's monolithic telescope will rocket into space aboard Portland State University's OreSat, where it will return live video of the Earth to anyone, particularly high school students, who want to build a receiver and connect.

The scope wasn't developed with spaceflight in mind. Rik got the idea over 25 years ago, when he noticed that the optical molds he was making for the fabrication of ophthalmic cataract replacement lenses looked a lot like the front end of a Schmidt-Cassegrain telescope. For fun he ground the back of a mold convex, and the results were promising enough that he used an optical design program to model the ideal curves for a real scope. In 1995 he made a model that worked, and he posted his results on the Cloudy Nights astronomy forum.

Fast forward to 2020 when the Portland State Aerospace Society was accepted into the launch queue for a CubeSat — a small, free-flying, citizen-science satellite carried into orbit as extra payload when space permits.

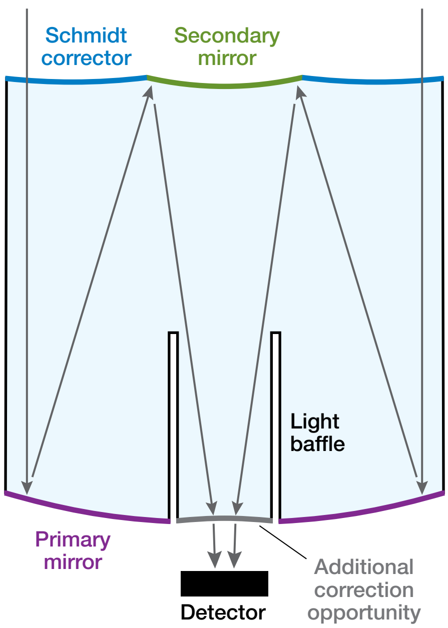
RIK AT HIS WORKBENCH: RIK TER HORST; MONOLITHIC TELESCOPE: JERRY OLTION

▲ A lens mold (bottom) inspired a rough prototype (left), which eventually led to the final concept (top right).

Despite their diminutive size (10 cm, or 4 in, per side), CubeSats do all sorts of cool science. PSU's CubeSat will monitor the global distribution of cirrus clouds and provide live video of its ground track.

To do the latter, the satellite needs a telescope. Surprisingly, there aren't any standard telescopes available for CubeSats, at least none that are available on a university science budget. But one of the Aerospace Society students discovered Rik's Cloudy Nights topic, project director Andrew Greenberg contacted Rik, and the collaboration was born.

I got the opportunity to visit the PSU campus and look at the engineering unit, the prototype CubeSat that the students are building to finalize the design for the real thing. They're building the entire satellite — the framework, the circuit boards, everything — from scratch, mostly so they can open-source the design to make it freely available to anyone who wants to build a CubeSat themselves. Rik's telescope sits proudly on top, where it will peer down at Earth and send its images to anyone who tunes in via Wi-Fi. Users can request photos of specific spots, and the satellite will provide them on its next pass.



▲ The solid Schmidt-Cassegrain telescope has all the parts of a normal SCT, minus the air. In addition, there's one extra surface at the rear used to fine-tune the light path.

Resolution from 418 kilometers up is about six meters per pixel, so you're not going to catch your neighbors sunbathing, but you'll be able to recognize your neighborhood. The images provided will be invaluable for monitoring wildfires, light pollution, cloud cover, and anything else on a medium-to-large scale.

The telescope I saw at PSU was also a technology demonstrator. Rik is making another one for the actual flight. He's making it out of fused silica for its low coefficient of thermal expansion. There's only 27.5 mm of space to work with, including the detector, so that imposes some severe restraints on the design. It'll be f/5, which is very fast for an SCT, requiring strong aspheric surfaces that make grinding and polishing all the harder.

Amazingly, Rik does the entire process by hand at a workstation only a meter square. His first scope took nearly half a year in between other projects, but even working continuously the new scope will take about three months. Rik says, "This is one of the most difficult and challenging optics I've made in my life."

As I write this, a test satellite called OreSat0 is set to launch in February. Andrew says its primary purpose is "to not catch fire." OreSat itself will follow this December. It would be neat to think that it, and Rik's amazing monolithic telescope, will be up there in orbit for centuries, a monument to ingenuity for our descendants to marvel at a millennium from now. But alas, what goes up must come down. OreSat will de-orbit in about two years due to atmospheric drag. And as Andrew says,

▲ This freeway sign photographed through Rik's tiny telescope is over half a mile away

"Not only will we be Oregon's first satellite, but we'll be Oregon's first meteor shower, too."

I for one would love to be on the ground track when that happens. Having seen both Rik's telescope and the satellite in person, I'd love to watch it go out in that final blaze of glory.

For more information about the telescope, visit Rik's Cloudy Nights topic at **https://is.gd/SolidSCT**.

For more about OreSat, visit the Portland State Aerospace Society's website at **oresat.org**.

■ Contributing Editor **JERRY OLTION** is pretty sure he's seen a telescope.

▲ The telescope peers out the end of OreSat, a two-unit CubeSat 10 × 10 × 20 centimeters on a side (about 4 × 4 × 8 inches). A 3D-printed protective shroud holds it in place.

LENS MOLD, PROTOTYPE, AND FINAL SCT: RIK TER HORST; LIGHT PATH DIAGRAM: GREGG DINDERMAN / S&T; FREEWAY SIGN: ANDREW GREENBERG; TELESCOPE ON CUBESAT: JERRY OLTION

CELESTIAL TULIP

Douglas Struble

Several energetic young stars, including bluish HD 227018, power Sharpless 2-101 (top), an emission nebula in Cygnus. The H II region below it is LBN 171. North is to the left.

DETAILS: *Stellarvue SVX 102T-R Raptor APO refractor with ZWO ASI1600MM Pro camera. Total exposure: 21¾ hours through Astrodon Hα and OIII filters.*

△ TRIANGULUM TREAT

Mathieu Guinot

The Triangulum Galaxy, M33, bristles with bright, pinkish star-forming regions. It is the third-largest spiral in the Local Group and lies about 3 million light-years away.

DETAILS: *Lacerta 250-mm Photo-Newton reflector with ZWO ASI2600MM Pro camera. Total exposure: 21½ hours through Antlia Hα and LRGB filters.*

◁ PUT A RING ON IT

Bruce Waddington

The foreground star HD 83535 happens to align perfectly with the edge of the planetary nebula Abell 33 in Hydra, inspiring its nickname, the Diamond Ring Nebula.

DETAILS: *PlaneWave CDK12.5 Dall-Kirkham telescope with QSI 640 camera. Total exposure: 12.3 hours through LRGB and OIII filters.*

▷ NGC 4731

Warren Keller and Mike Selby

Barred spiral NGC 4731 is a member of the Virgo Cluster of galaxies. Gravitational interactions with a neighboring galaxy distorted its broad arms.

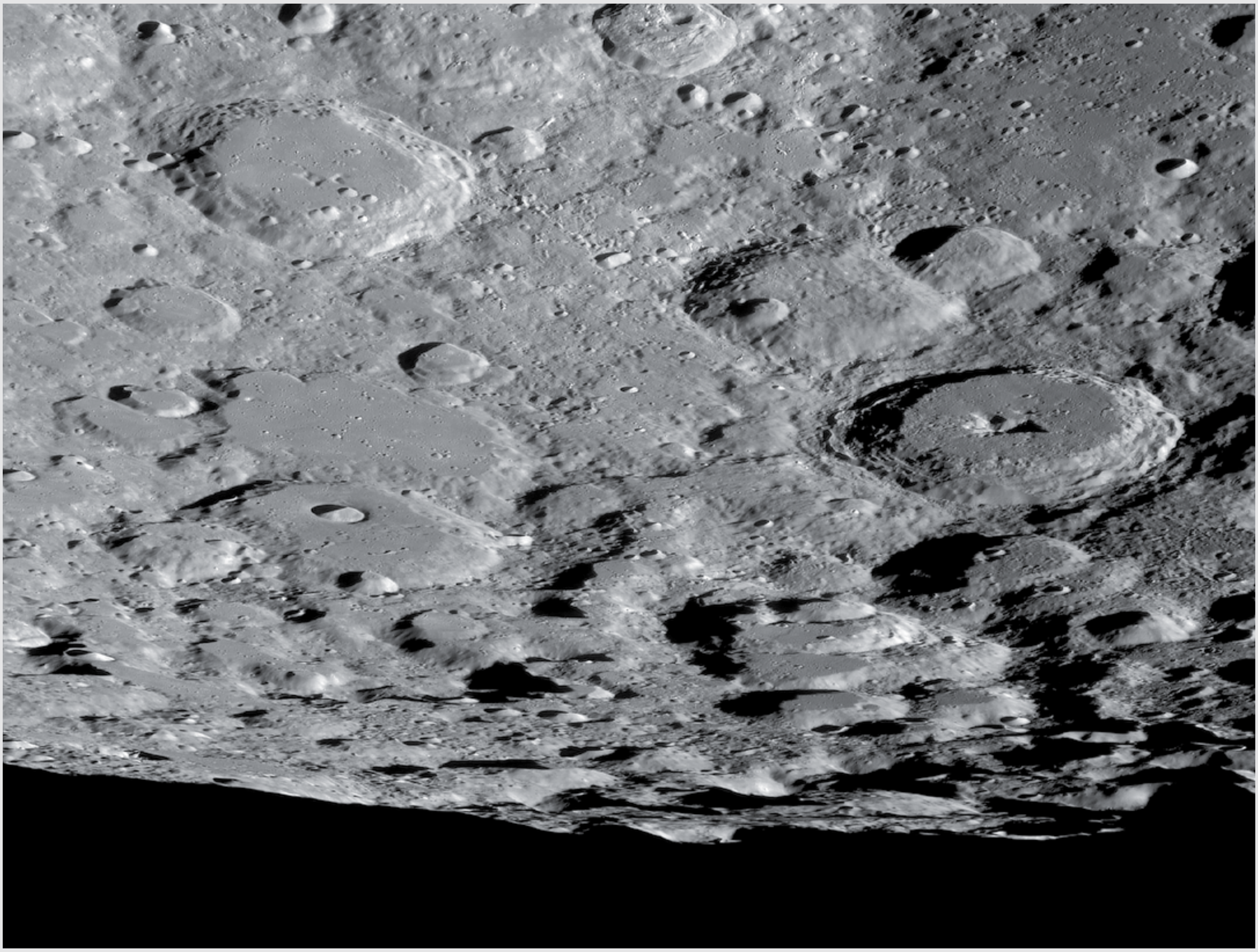
DETAILS: *PlaneWave PW1000 Dall-Kirkham telescope with FLI ProLine PL16803 camera. Total exposure: 20½ hours through LRGB filters.*

▽ ROUGH TERRAIN

Christian Viladrich

This high-resolution view of the lunar South Pole resolves countless craterlets within prominent Blancanus (top left), Casatus (lower left), and Moretus (right).

DETAILS: *Astrosib RC500 Ritchey-Chrétien telescope with ZWO ASI1600MM Pro camera. Stack of 300 exposures each 15 milliseconds through a red filter.*



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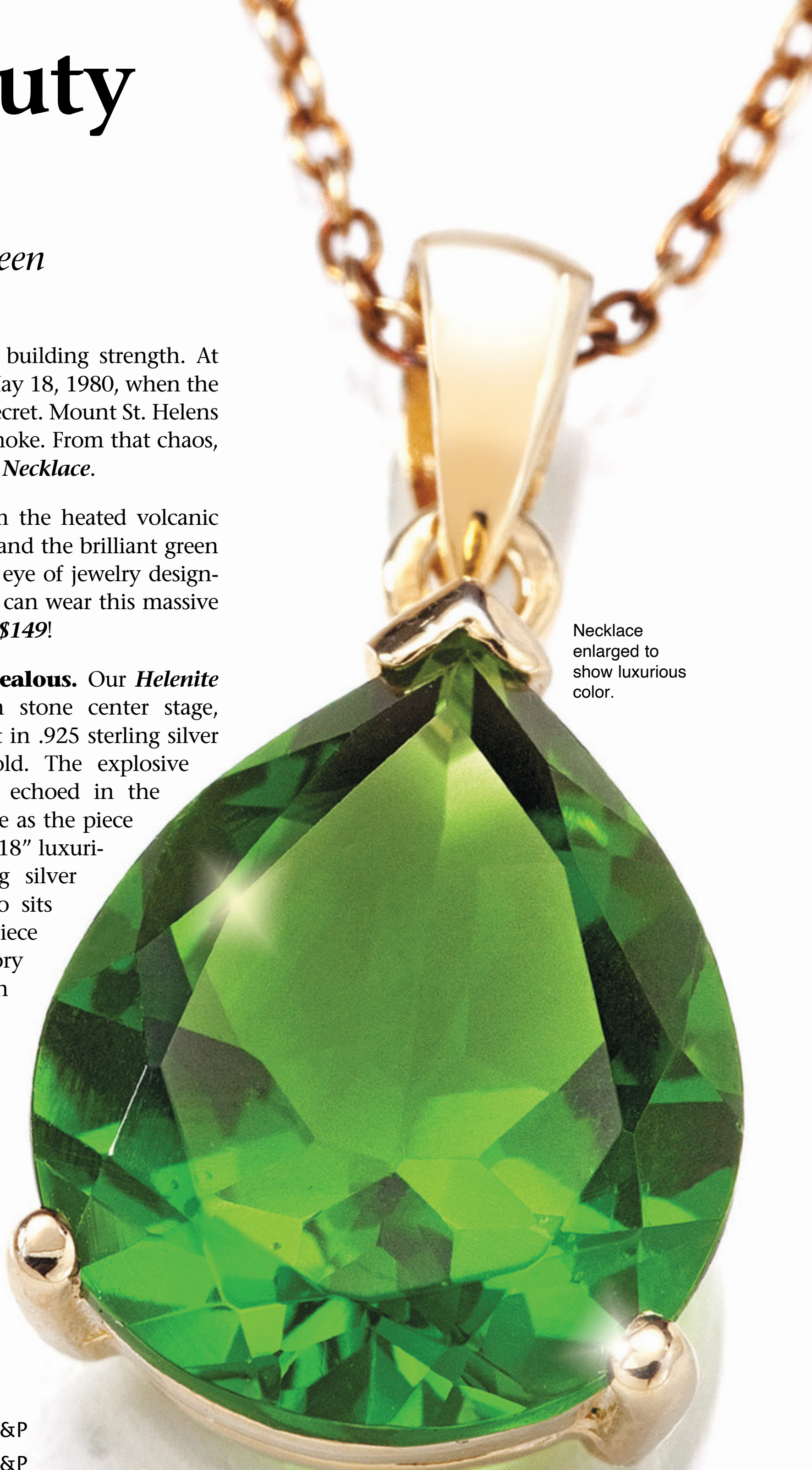

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Event Calendar

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

April
GLOBAL ASTRONOMY MONTH
Everywhere!
https://is.gd/astrowithnoborders

April 9–10
NORTHEAST ASTRONOMY FORUM
Suffern, NY
neafexpo.com

April 22–30
INTERNATIONAL DARK SKY WEEK
Everywhere!
idsw.darksky.org

April 24–May 1
TEXAS STAR PARTY
Fort Davis, TX
texasstarparty.org

April 27–30
MIDSOUTH STARGAZE
French Camp, MS
rainwaterobservatory.org/events

May 7
ASTRONOMY DAY
Everywhere!
https://is.gd/AstronomyDay

June 2–5
CHERRY SPRINGS STAR PARTY
Cherry Springs State Park, PA
cherrysprings.org

June 3–5
MICHIANA STAR PARTY
Vandalia, MI
michiana-astro.org

June 18–25
GRAND CANYON STAR PARTY
Grand Canyon, AZ
https://is.gd/GCSP2022

June 22–25
BRYCE CANYON ASTRO FESTIVAL
Bryce Canyon National Park, UT
https://is.gd/brca_astrofest

June 22–26
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

June 22–26
YORK COUNTY STAR PARTY
Susquehannock State Park, PA
http://yorkcountystarparty.org

June 23–26
EASTERN SIERRA DARK SKY FEST
Mammoth Lakes, CA
https://is.gd/EasternSierraDSF

June 23–26
WISCONSIN OBSERVERS WEEKEND
Hartman Creek State Park, WI
https://is.gd/WIObserversWeekend

July 22–31
SUMMER STAR PARTY
Plainfield, MA
rocklandastronomy.com/ssp.html

July 24–29
NEBRASKA STAR PARTY
Valentine, NE
nebraskastarparty.org

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

JACOB W. FRANK / NPS

The Final Frontier

It might be closer than* Star Trek *would have you think.

▲ You don't need to travel to the edge of space to have a mind-altering celestial trip. Just witness totality during a total solar eclipse (above, as seen from Chile in 2019).

SEAN WALKER / S&T

ON OCTOBER 13, 2021, I watched with fascination as William Shatner, better known to the world as the fictional Captain James T. Kirk of the starship *Enterprise*, took a 10-minute ride on a rocket to the edge of space.

Although a consummate actor, Shatner seemed deeply and genuinely affected by the experience. Upon stepping out of the Blue Origin capsule after returning to Earth, he was initially at a loss for words. But he soon began a stunning and seemingly spontaneous soliloquy on his voyage above the Kármán line — the unofficial upper boundary of our atmosphere 100 kilometers (62 miles) up. Shatner described the sight of what his alter ego Captain Kirk had called "the final frontier" as ". . . looking into blackness, into black ugliness . . ." In contrast, looking down at our living blue planet, with the delicate boundary of air just above it, he saw ". . . mother and Earth and comfort . . ."

I've never traveled to the edge of space and doubt I ever will. I'm in my 60s, and even if I live to be 90 — Shatner's age during his flight — I suspect that the cost will still be too great, or my health too frail, for me to make such a journey. But I envy him and everyone else who's had the privilege of rocketing above the atmosphere, if ever so briefly.

Something about the brevity of Shatner's brush with space resonated with me, and I soon realized why. I have had a similarly brief but momentous cosmic experience — in fact, multiple times.

I witnessed the first of five total solar eclipses I've enjoyed in 1998, from the shores of Aruba. To prep for the trip, I'd packed a small telescope, camera, binoculars, solar filters for each optic, and several rolls of film. I'd studied the different phenomena that accompany a solar eclipse, from shadow bands to Baily's Beads. And yet when totality commenced, I was in awe, totally dumbstruck.

I knew the sight of the Moon slowly covering the Sun, revealing the glorious solar corona, would be amazing, and it was: graceful, beautiful, and otherworldly, a white light so pure that nothing on Earth can compare to it.

What I wasn't prepared for was how the entire world around me changed. The shore and the sea were lit only by that wondrous light. It altered my perception of the landscape, the sea, and color itself. The birds and small animals grew quiet. Altogether, the reality of our situation on Earth suddenly became clear: We live inside a tiny bubble of life in a vast and inhospitable universe. When totality ended a couple of precious minutes later, I was practically in tears.

It's a curious coincidence that the average total solar eclipse lasts about as long as Shatner spent in zero-g. The brevity of these experiences no doubt amplifies their intensity. For many of us, the next best chance to see an eclipse will be two years from now, on April 8, 2024, when the path of totality will pass through Mexico, the U.S., and Canada.

Shatner said he hoped he'd never recover from his trip to space. I'd be happy to let him know that I've never recovered from the experience of witnessing a total solar eclipse.

■ **ANDRÉ BORMANIS** is a writer and co-executive producer for the Hulu television series *The Orville*. He has also written for *Star Trek: Voyager* and *Star Trek: Enterprise*.


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