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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

MAY 2021

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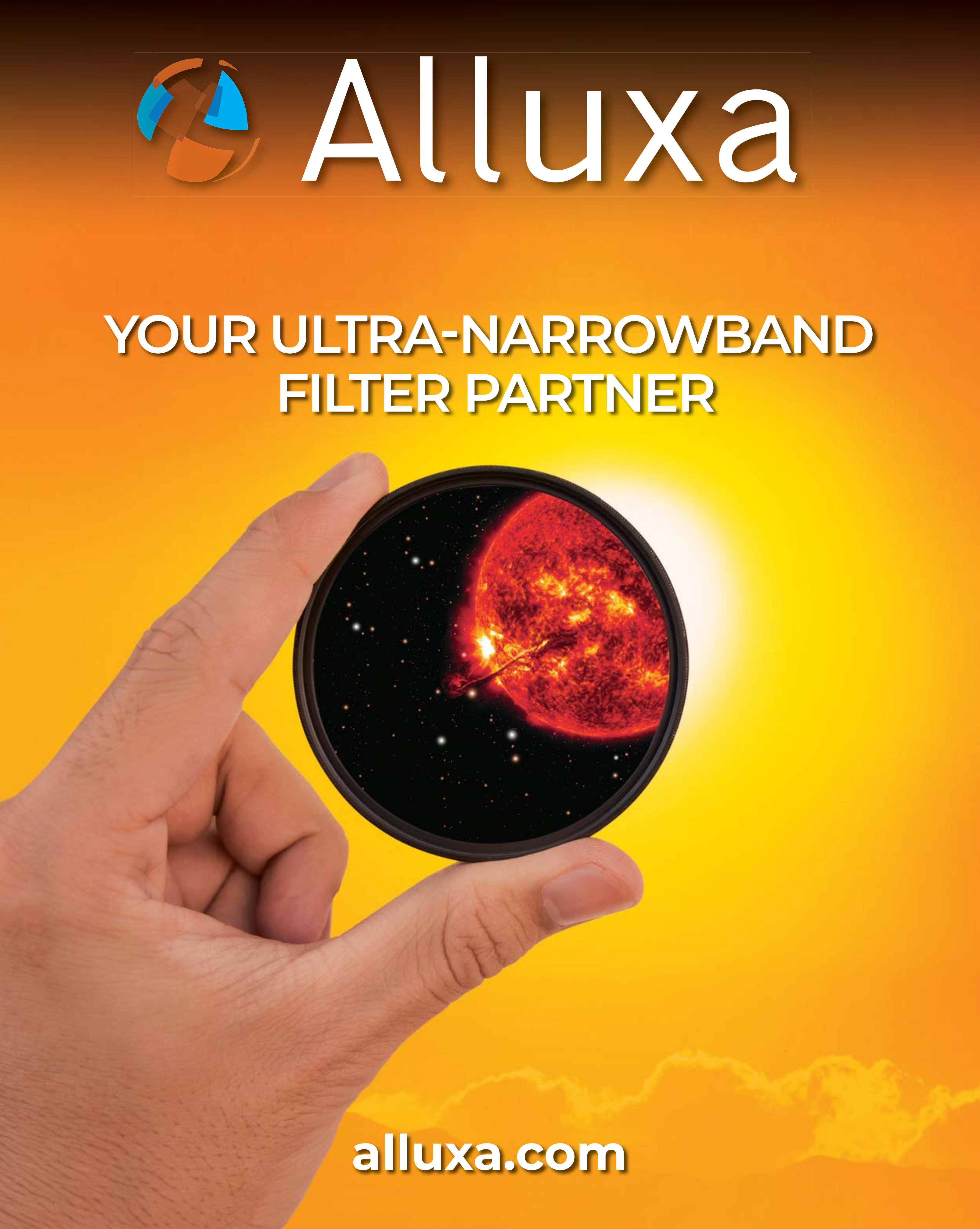
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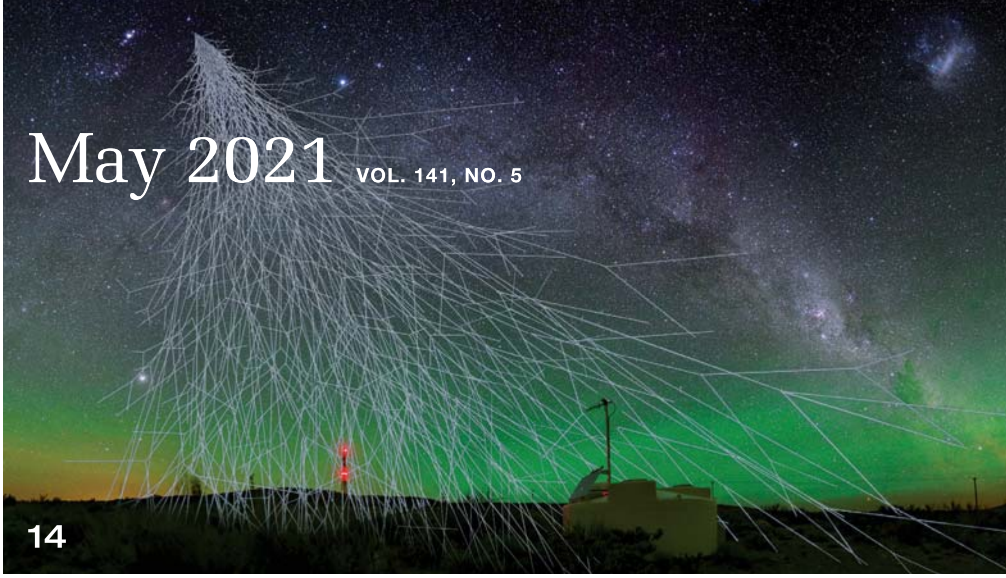

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The strange-looking galaxy NGC 4861 in Canes Venatici

PHOTO: ESA / HUBBLE / NASA

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Overtones of Awe

IN *SKY & TELESCOPE* we often delve into the nitty-gritty of astronomical observation and science. That's the locus where astronomers, both pro and amateur, inch forward into new terrain, advancing our appreciation and understanding of the universe.

But astronomy offers abundant opportunity for stepping back from that leading edge at any time to consider the big picture. Arwen Rimmer's article on biosignatures (page 34) epitomizes the kind of *S&T* story that leaves you agog at both the scientific challenge and the philosophical implications.

Rimmer's feature focuses on the efforts of researchers who are laying the groundwork for detecting potential signs of life in exoplanet atmospheres. The work is akin to Linnaeus' formulation of the system of binomial nomenclature for organisms. Just as we can't talk about myriad individual species without a clear descriptive architecture to help distinguish them, we can't identify possible biomarkers if we haven't first outlined the innumerable ways that chemicals can behave in gaseous environments.

▲ Does life exist out there? Detail of the Hubble Ultra Deep Field, a view of nearly 10,000 galaxies

NASA / ESA / S. BECKWITH (STSCI) AND THE HUDF TEAM

Even as you marvel at the daunting task these actors on the scientific stage have set themselves, you're vaguely yet inescapably aware of the tantalizing backdrop. It's that age-old, far-reaching question that underlies all their work: Is there life beyond Earth?

Finding life elsewhere would be one of the greatest scientific discoveries of all time. If we determined that life had emerged at least twice independently — here and out there — we'd know that life is likely ubiquitous in the cosmos. Imagine the shakeup to our anthropocentrism. Copernicus displaced Earth from the center of the physical universe. Darwin unseated *Homo sapiens* from the center of the biological universe. Unearthing extraterrestrial life, especially intelligent life, might expel us humans from the center of the metaphysical universe as well.

Notwithstanding the threat to our collective ego, the possibility of life extrinsic to our world might well lie at the heart of our love for the stars. If we knew without a doubt that Earth held the only living things in the universe, would we still "look up" with the same passion? How much of our fascination with the physics and chemistry beyond Earth is due to that still hypothetical component, the biology? Without an answer about the existence of extraterrestrial beings, can we really be said to know ourselves?

How you answer these metaphysical questions is up to you. But we hope you go through a two-stage process while reading *S&T*: become engrossed in the specifics, then push back in your chair, stare off into the distance, and wonder.

Editor in Chief

SKY & TELESCOPE
The Essential Guide to Astronomy

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

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◀ The staff of Yerkes Observatory, including E. E. Barnard (center of back row), stand in front of the 40-inch refractor with Albert Einstein on May 6, 1921.

In "Wildfires Threaten Observatories" (*S&T:* Jan. 2021, p. 12), David Dickinson and Sabrina Garvin mention that Edward Emerson Barnard's historic California home near Lick Observatory burned down. He discovered Jupiter's fifth moon, Amalthea, while living there. Considering that Galileo found the first four nearly 300 years before, Barnard's 1892 discovery was special.

In 1895, Barnard moved to the University of Chicago, which was preparing to open the new Yerkes Observatory on beautiful Geneva Lake in Williams Bay, Wisconsin. While there, he used the 40-inch (1-meter) refracting telescope for more than 20 years. His grand astronomical obsession occupied virtually every starry night. Unfortunately, clear skies in Wisconsin are not guaranteed. Barnard made sure not to miss them when available. He was reportedly in the observatory while the temperature inside was –26°F.

Oddly, while Barnard was there, a golf course started play in the shadow of the venerable dome. Being a daytime sport, it probably did not bother him.

While the University of Chicago no longer operates the telescopes at Yerkes, they and their domes will live on under the guidance of the Yerkes Future Foundation (*S&T:* Mar. 2020, p. 10).

Dennis Horvath
Greendale, Wisconsin

Johannes Hevelius was a significant and, in many ways, tragic figure during the transition from naked-eye to telescopic observing in the 17th century. Michael Mendillo's article, "The Schiller Enterprise" (*S&T:* Jan. 2021, p. 64) doesn't reflect his true character well.

Hevelius was one of many people who devised revisions of the constellations and their subjects or, in his case, entirely new ones in those years. Mendillo says Hevelius's comment that astronomers have not used Julius Schiller's names for the constellations since their release reflects "a fear of obscurity." In actuality, he may have simply been anticipating a lack of public interest. And the article reduces Hevelius's actual statement that the previous atlas is not "universally convenient and marketable, and . . . is owned by very few among the learned" to "Hevelius was concerned with the practical matter of selling his new atlas."

Johannes Hevelius was an amiable man who tried, in a contentious era, to get along with others as best he could — as found by the young Edmond Halley, who visited him in 1679 to iron out a technological disagreement with Robert Hooke and John Flamsteed. Hooke, Flamsteed, and Hevelius were all members of the Royal Society, and Halley sent Hevelius a testimonial letter commending his kindness and candor.

Eric Rachut
Moody, Texas

Star Hopping with Sky Safari

I have a comment about the *S&T* Test Report "*SkySafari 6 Pro*" by Rod Mollise (*S&T:* Jan. 2021, p. 30). The adjustable limiting magnitude of the display is a notable feature for those of us with manual mounts who have to star hop. If I set the Magnitude Limit under the Stars option in the settings to the faintest star I can see straight on, I can match the screen with the night sky pretty well. But if I also enter my instruments into *SkySafari*, select them under Scope Display in Observe, and zoom in to match the selected optics, the magnitude limit increases so I can see the fainter stars. The resulting image matches up with what I see in the eyepiece.

To star hop, I select my finder and optics on Scope Display and center my Telrad finder on the first star. Then, I match the image on *SkySafari* to what's in my 8×50 finder and hop to my destination with the finder or until I have to switch to the eyepiece. I then zoom in again on *SkySafari* to match my eyepiece and continue. It makes star hopping much easier.

Mike Fratto
Syracuse, New York

SS *Mars*

Several years ago, I sailed from Norfolk, Virginia, to Tortola in the British Virgin Islands. I was hand steering at night with all the navigation lights off while two crew members slept below. I tethered myself for safety, had the

YERKES OBSERVATORY

compass lights off, and was steering southeast by the stars. Then, I saw a large ship heading toward my port side; I could see its red bow light. I was now on alert for a converging course.

I could tell that it was getting closer because the red bow light was rising higher. Then, I began to see stars under the light. I finally figured out that it wasn't a ship but Mars! It was so red! I never had to change course to avoid that collision.

We continued sailing using celestial navigation and eventually found the island Jost Van Dyke and then Tortola.

Ray Locke
Venice, Florida

Geminids in the City

I was glad to see the Geminids receive the recognition they deserve in "Get Ready for the Geminids" by Joe Rao (*S&T:* Dec. 2020, p. 14). For the past couple of decades, I've considered them the year's best meteor shower. I've never had very good luck with the Perseids, and even the Leonids of the early 2000s were in my opinion somewhat lacking, since I apparently missed the peak due to poor planning.

However, the Geminid meteor shower of 1994 was truly memorable. At the time, I was collecting data for my PhD dissertation, imaging Seyfert galaxies and quasars with a 24-inch (0.61-meter) telescope on a rooftop on the University of California, Los Angeles campus in the middle of some of the worst light pollution modern cities have to offer. The equipment, an optical CCD camera and a liquid-nitrogen-cooled infrared CCD camera (that was made on campus), easily pulled signals out of the murk. Visually, I struggled to make out 2nd-magnitude stars!

During exposures, I'd leave the dome and stroll around the roof. I wasn't expecting much that night. However, I was astounded to see these bright tears that just kept coming! Every minute or two, another pleasingly bright one would slowly streak through the mostly featureless sky. Of course, I couldn't help but think about how many I *wasn't* seeing — it must have been spectacular away from the city. Yet it far surpassed any meteor shower I'd seen before or since.

Brant Nelson
Ayer, Massachusetts

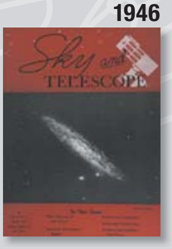
FOR THE RECORD

- PuWe 1 is not the largest known planetary nebula, as stated in "Springtime Blossoms" (*S&T:* Mar. 2021, p. 63), but it is one of the largest planetaries known.
- The table in "Catching Celestial Butterflies" (*S&T:* Feb. 2021, p. 18) should have stated that M76 lies at +51° 34'.

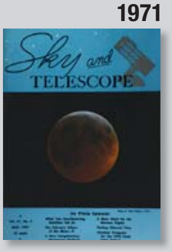
SUBMISSIONS: Write to *Sky & Telescope*, One Alewife Center, Suite 300B, Cambridge, MA 02140, USA or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1946



1971



1996

◖ May 1946

Chirp, Chirp "Professor E. B. Frost [was] director of the Yerkes Observatory from 1905 until 1932. In his later years he was blind, yet carried on some of his own correspondence, printing in capital letters on a narrow ribbon of paper. At the end, he signed himself, 'E. B. Frost, IPSE.' I knew him for only a little while but I shall never forget his telling me about Dolbear's formula.

"In the middle of the night, when a cricket in the dome is your only companion, count the number of chirps in 15 seconds, add 40 to it, and the result will be the temperature, Fahrenheit. . . . This is Dolbear's formula. . . . I don't know who Dolbear was or what he did. [But] I've used his formula and it usually works."

Roy K. Marshall wrote this for the column Astronomical Anecdotes. (For those whose Latin is rusty, "ipse" means "himself.")

◖ May 1971

Dimmer Skies "The *extinction coefficient* is the loss in magnitudes of a star's light at the zenith, in clear-sky conditions. . . .

"A group of University of Washington astronomers, in a study called Project Astra, is compiling present and past measurements of extinction, made at observatories in all parts of the world, to study the long-range changes in the earth's atmosphere caused by man-made pollution. One of the first results is a comparison of the extinction at Mount Wilson Observatory at two epochs half a century apart . . .

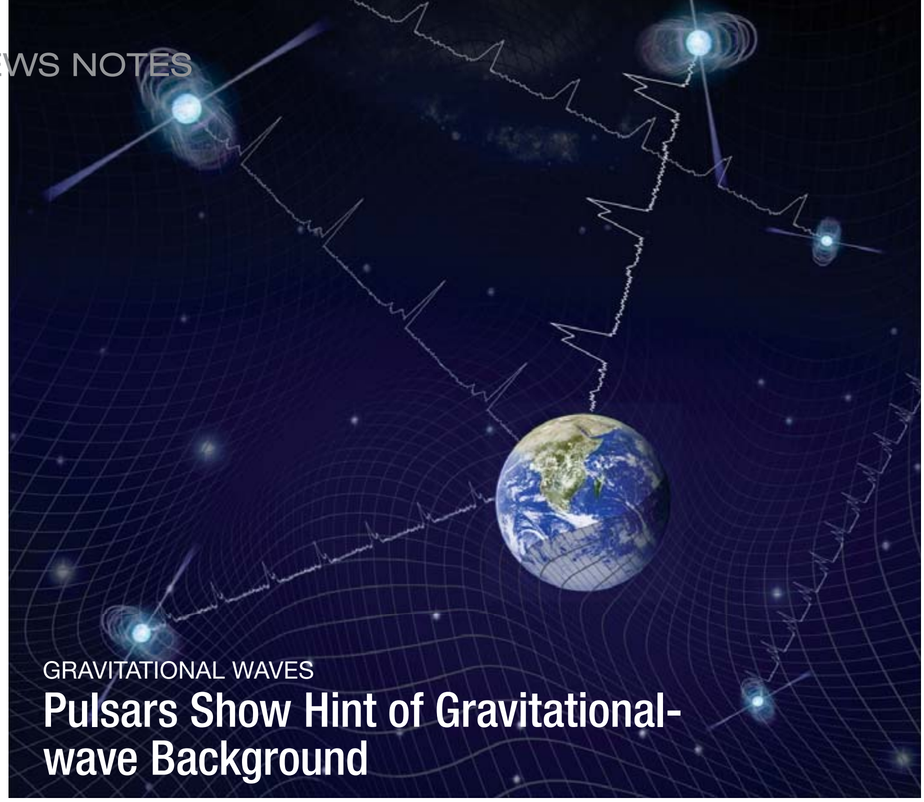
"Over the 50-year interval, the extinction coefficient increased by 0.27 magnitude at a wavelength of 3500 angstroms (ultraviolet), by 0.09 magnitude at 4400 (blue), and 0.10 magnitude at 5500 (yellow). 'These are large differences,' notes [project chair Paul W.] Hodge . . . 'We came to realize [that astronomical extinction methods] far surpass in accuracy the existing equipment used in air pollution studies.'"

◖ May 1996

Hubble Deep Field "[For] 10 consecutive days beginning last December 18th, [the Hubble Space Telescope] directed its gaze to a nondescript field near the Big Dipper's handle. . . .

"The resulting montage was unveiled to an eager gathering of astronomers and journalists on January 15th. [Space Telescope Science Institute director Robert] Williams announced that the results were 'all that we could have hoped for.' [The Hubble Deep Field] contains over 1,500 galaxies, some as faint as 30th magnitude . . . And they all lie in a patch of sky no larger than that covered by a grain of sand held at arm's length. This implies that over 50 billion galaxies now lie within humanity's grasp."

Since then, other tiny fields have been imaged even more deeply by the Hubble Space Telescope. The goal is to see what galaxies looked like as soon after the Big Bang as possible.



GRAVITATIONAL WAVES

Pulsars Show Hint of Gravitational-wave Background

THE COLLISION of two stellar-mass black holes creates a "pop!" of gravitational waves that eventually surges over Earth — and detectors — in a matter of seconds. But when two supermassive black holes merge, their pop draws out like the sound in a slow-motion video. The many-years-long signal blends in with those coming from other supermassive binaries in the universe. Now, astronomers may have picked up a hint of this constant low-frequency hum of gravitational waves.

▲ The NANOGrav observes pulsars scattered throughout the galaxy, as illustrated here, in an effort to detect gravitational waves.

Pulsar-monitoring projects, also known as *pulsar timing arrays* (*S&T:* Jan. 2019, p. 22), have been on the lookout for this background buzz for more than a decade. One such project, the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) announced significant progress at the 237th meeting of the American Astronomical Society in January.

Pulsars, the compressed remainders of massive supernova explosions, power jets of plasma that sweep across Earth like a lighthouse beam. Millisecond pulsars, which whirl around as fast as the blades in a kitchen blender, keep especially regular time, rivaling atomic clocks on Earth.

As early as 1979, astronomers were already dreaming of using these timekeepers to search for gravitational waves — and now they're doing just that, looking for tiny changes in millisecond pulsars scattered across the galaxy.

"We created a galaxy-size detector within our own Milky Way," says Joe Simon (now at University of Colorado, Boulder), who led the team that published in the December 20, 2020, *Astrophysical Journal Letters*. After analyzing 12½ years of observations, NANOGrav has detected a low-frequency signal that looks exactly like what scientists would expect colliding supermassive black holes to emit — but the team can't yet be certain.

To establish that the low-frequency buzz comes from gravitational waves, NANOGrav scientists first need to

GAMMA-RAY BURSTS

Magnetars Make Some Short Gamma-ray Bursts

HIGHLY MAGNETIZED neutron stars can produce powerful flares that masquerade as short gamma-ray bursts (GRBs), astronomers argue, after finding another GRB associated with a *magnetar*. This time, the gamma rays came from the magnetar itself rather than the circumstances of its birth (*S&T:* Apr. 2021, p. 9).

After spotting GRB 200415A, astronomers pinpointed it to the Sculptor Galaxy (NGC 253), 11.4 million light-years away. Observations showed this GRB behaving much like so-called giant flares coming from Milky Way magnetars. The team presented the observations at January's virtual meeting of the American Astronomical Society and in three papers, two in the January 14th *Nature* and one published January 13th in *Nature Astronomy*.

Rarely, magnetars can generate powerful X-ray and gamma-ray flares. Astronomers think twisted magnetic field lines crack the neutron star's dense crust, releasing relativistic plasma through the fracture.

Sculptor's gamma-ray flare released about a million times less power than expected from the collision of two neutron stars, which are thought to make most short GRBs (those less than 2 seconds long). But a nearby magnetar flare may look like a short GRB, just like a nearby firecracker can sound as dramatic as a remote blast of TNT.

Astronomers have triangulated other short GRBs to neighboring galaxies, but GRB 200415A is one of the most convincing cases of magnetars as the source. To make it a shoo-in, astronomers would have liked to see the event's tail end, which might have revealed a

▲ Tangled magnetic fields of a magnetar release a speedy blob of plasma accompanied by a short gamma-ray flare.

PULSARS: NANOGRAV / T. KLEIN; GIANT FLARE: NASA GSFC / CHRIS SMITH / USRA / GESTAR establish that the signal they see is correlated across space.

"Here on Earth, we're bobbing in an ocean of low-frequency gravitational waves," Simon explains. The passing waves slightly jostle our planet, and as Earth moves toward one pulsar, its signals arrive a little sooner than expected. Signals from a pulsar in the opposite direction would come slightly later.

Gravitational waves are by their nature *quadrupolar*, which means that when they travel, say, along the *x*-axis, spacetime squeezes along the *y*-axis and stretches along the *z*-axis (and vice versa). That same squeeze-stretch action happens along multiple axes, so the actual correlation pattern is complex and difficult to suss out of the signal detected so far.

But scientists are confident they will, and soon, with estimates ranging from within the year to a few years. "Trying to detect gravitational waves with a pulsar timing array requires patience," says NANOGrav chair Scott Ransom (National Radio Astronomy Observatory). "It's great that these new results are exactly what we would expect to see as we creep closer to a detection."

■ MONICA YOUNG

---

slowly fading pulsation. Unfortunately, that telltale signal is too faint to be visible outside our galaxy.

"The possibility that a subset of short gamma-ray bursts is associated with magnetar giant flares was suggested long ago," says Roberto Turolla (University of Padua, Italy), who was not part of this study. "This detection is key in proving it right."

Scientists hope to find and study additional magnetar flares with StarBurst, a small gamma-ray-detecting satellite in development as part of NASA's Astrophysics Pioneers program. Eric Burns (Louisiana State University) says, "The study of GRB 200415A is really laying the groundwork for future research."

■ GOVERT SCHILLING

LAUER ET AL. / *ASTROPHYSICAL JOURNAL* 2021

COSMOLOGY

New Horizons Measures "Extra" Visible Light

NASA'S NEW HORIZONS MISSION to the outer solar system has turned its cameras to far-off vistas — and found more light than expected. This has potential consequences for galaxy evolution and perhaps even cosmology.

Team member Tod Lauer (NSF's NOIRLab) and colleagues used the Long Range Reconnaissance Imager (LORRI) camera to image regions above and below the star-filled galactic plane and measure the *cosmic optical background*. The team subtracted all known sources of visible light, including stars and galaxies in the image, as well as light from those outside the field of view that scattered into the camera. Computer simulations aided the removal of stars and galaxies too faint for the camera to resolve. The team also subtracted Milky Way starlight scattered off interstellar dust, basing the latter on observations of galactic cirrus.

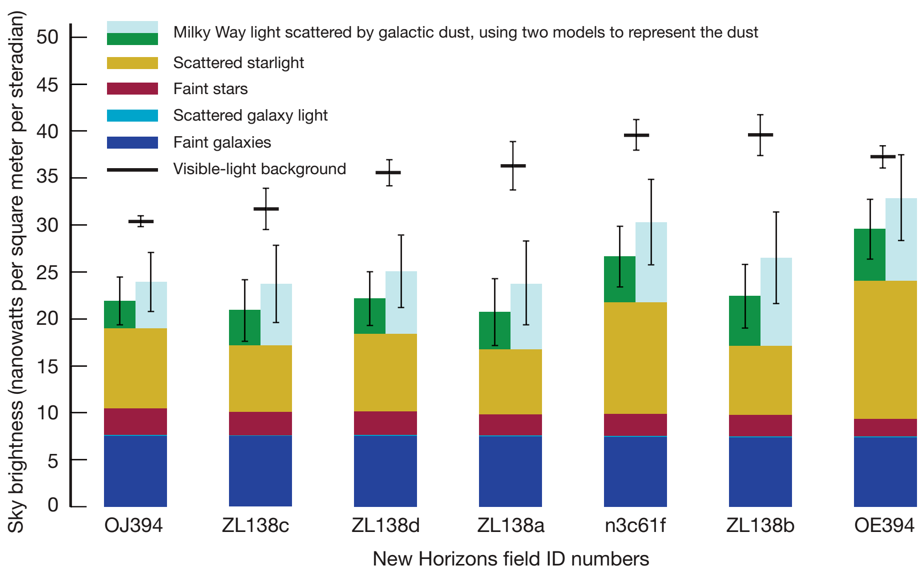
Yet when all the calculations were done, there was still "extra" light they couldn't explain, Lauer and colleagues report in the January 10th *Astrophysical Journal*. "The total unknown amount is more than the integrated flux from all known galaxies," Lauer said at the 237th meeting of the American Astronomical Society.

Some of the excess may yet find a simple explanation. Shuji Matsuura (Kwansei Gakuin University, Japan), who also found an indication of "extra" light with his colleagues in the Cosmic Infrared Background Experiment (CIBER), suggested that the New Horizons team might have underestimated the amount that scattered Milky Way light contributes to the background. "My opinion," he adds, "is that we have to be careful to claim the existence of the diffuse cosmic optical background at this stage."

But if it pans out, the New Horizons result has some interesting implications. The team sees twice as much optical background as predicted by existing galaxy catalogs. Faint galaxies might account for some of the extra light, but other sources could contribute, too. Faint stellar halos around galaxies, "lost" stars torn away during galactic mergers, undiscovered black holes, or even *axions*, a hypothetical dark matter particle (*S&T:* Jan. 2021, p. 16), might be part of the explanation.

■ MONICA YOUNG

Read the full story at https://is.gd/NewHorizonsCOB.



▲ Lauer and colleagues measured the visible-light background (black horizontal lines) in seven regions outside the galactic plane. They then subtracted sources that make and scatter visible light (colored bars). Known sources of light, including the total associated uncertainty shown by the error bars, do not fully explain the background light New Horizons saw.

BLACK HOLES

The Most Distant Quasar and Black Hole Birth

This artist's impression shows the gas-guzzling black hole and the powerful wind it generates.

THE EXISTENCE OF A QUASAR in the infant universe is helping astronomers understand black hole formation.

Feige Wang (University of Arizona) and colleagues report the detection in the January 20th *Astrophysical Journal Letters*: a 1.6 billion-solar-mass black hole just 670 million years after the Big Bang (at a redshift of 7.64), around the era when the first stars were beginning to shine. The discovery leaves astronomers wondering, how did the mass of more than a billion Suns come together into a black hole so early on?

One school (*S&T:* Jan. 2017, p. 24) thinks that black holes come from massive stars. The very first generation of stars — known as Population III stars — would have fit the bill: They had on the order of hundreds of solar masses, burned fast, and died young.

The other school of thought skips stars entirely, instead positing the direct collapse of cold clouds of gas, something not seen now but thought to be possible in the crowded early universe.

The record-breaking quasar may help decide the debate. Even if this black hole were gaining mass at the maximum rate 100% of the time, it would still need to have been huge — at least 10,000 times the Sun's mass — to grow to 1.6 billion Suns by the time it's observed. Wang's team thus rules out a massive star for the formation of this black hole.

"I think these large masses at redshifts greater than 7 put a huge amount of pressure on models that assume Population III seeds," agrees Mitch Begelman (University of Colorado, Boulder), who was not involved in the research.

Besides powering the most distant quasar known, the black hole is also driving a gale of hot gas into the galaxy at 20% the speed of light. The Atacama Large Millimeter/submillimeter array in Chile shows the host galaxy is currently birthing 200 solar masses' worth of stars per year. Future observations will investigate whether the hot gusts could eventually halt the stellar churn.

■ MONICA YOUNG

GALAXIES

Astronomers Spot Galaxies Clustering in Early Universe

A TINY GALAXY CLUSTER was found coming together just 770 million years after the Big Bang. The discoverers say the elongated protocluster consists of two smaller systems of galaxies that will probably merge into one.

Today's clusters contain hundreds of individual members, but billions of years ago protoclusters were just slightly denser regions of space. The protocluster LAGER-z7OD1 has 21 galaxies packed together five times more tightly than galaxies at similar distances.

Weida Hu (University of Science and Technology of China) and coworkers reported the find on January 25th in *Nature Astronomy*, from data collected by the Dark Energy Camera on the 4-meter Blanco Telescope at the Cerro Tololo Inter-American Observatory in Chile. Using a narrowband near-infrared filter, they singled out young galaxies by emission from their ionized hydrogen. This hydrogen emits a specific ultraviolet wavelength known as *Lyman-alpha*, which redshifts to near-infrared as it passes through the expanding universe.

Spectroscopic measurements with the twin 6.5-meter Magellan telescopes at Las Campanas Observatory, also in Chile, confirmed the extreme distance (corresponding to a redshift of 6.93) of 16 of the galaxies.

▶ An artist's impression of a protocluster in the infant universe

Hu and his colleagues expect LAGER-z7OD1 to evolve into a massive cluster measuring about 100 million light-years across and with almost twice the mass of the nearby Coma Cluster.

■ GOVERT SCHILLING

IN BRIEF

NASA Extends Mars, Jupiter Missions

NASA has granted extensions to two key planetary missions: Insight's Mars operations have been extended through December 2022, and Juno's work at Jupiter will go through September 2025. Insight will keep recording the faint rumblings of marsquakes, adding to the more than 480 detected during its primary mission. However, its heat probe, part of the Heat Flow and Physical Properties Package provided by the German Aerospace Center, has been shut down following failed attempts to dig into the Martian surface. Meanwhile, Juno's extension adds another 42 orbits, taking it past Ganymede on June 7th, which will reduce its 53-day orbit to 43 days. Close encounters with Europa will follow in autumn 2022, then a series of Io flybys start at the end of 2023. Juno will face higher radiation as it orbits closer to Jupiter — a prime reason to save these orbits for the end of the mission.

■ DAVID DICKINSON

QUASAR: NOIRLAB / NSF / AURA / J. DA SILVA; PROTOCLUSTER: ESO / M. KORNMESSER

EXOPLANETS

Rocky Planet Found Around 10 Billion-Year-Old Star

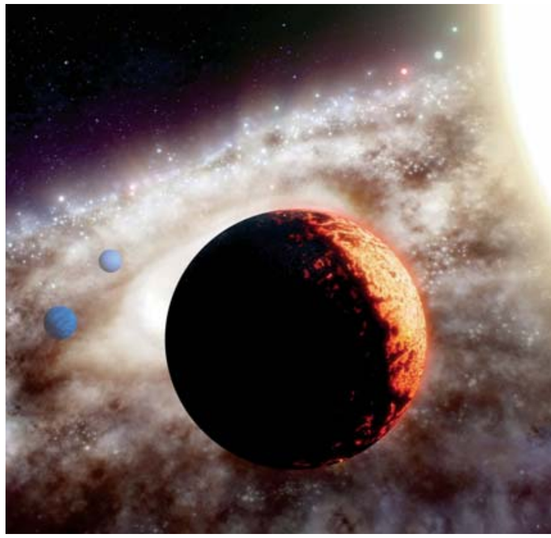
ASTRONOMERS USING the Transiting Exoplanet Survey Satellite have discovered three planets orbiting a star about 10 billion years old — one of them rocky. The star, TOI 561, resides in our galaxy's older and fatter *thick disk*, so its planets have a nice view of the Milky Way's spiral from on high.

The planets have diameters 1.45, 2.9, and 2.3 times Earth's, respectively. The innermost one is a rocky planet, whose average density is similar to our own. But it's on an orbital period of 0.44 day, and it's anything but Earth-like. The dayside surface temperature is around 2500K (4000°F). That's at least twice as hot as Earth's magma, and it's surely molten. What it actually looks like is uncertain because, as lead scientist Lauren Weiss (University of Hawai'i, Mānoa) notes, "It exceeds temperatures where geophysicists have made lava in the lab."

Astronomers have found planets around old stars before, as well as around stars with a paucity of heavy elements. But this planet holds the record as the first confirmed rocky planet found around a thick-disk star.

"We now have evidence that the universe has been forming rocky planets for the last 10 billion years," Weiss says, "more than double the age of our own solar system, and nearly since the origin of the universe itself."

■ MONICA YOUNG



▲ This artistic concept shows the rocky planet circling TOI 561. Two larger and likely gaseous planets are shown at left.

ROCKY PLANET: W. M. KECK OBSERVATORY / ADAM MAKARENKO; WHIRLPOOL GALAXY: SOFIA STREAMLINES: NASA / SOFIA SCIENCE TEAM / A. BORLAFF; BACKGROUND IMAGE: NASA / ESA / S. BECKWITH (STSCI) / HUBBLE HERITAGE TEAM (STSCI / AURA)

Magnetic Whirlpool

NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) has captured a new view of the Whirlpool Galaxy (M51), 31 million light-years away in Canes Venatici. By imaging polarized light, SOFIA's High-Resolution Airborne Wideband Camera mapped out M51's magnetic field. The resulting magnetic streamlines are shown overlaid on the image at right. While radio observations had revealed that the magnetic field lines trace the spiral structure in the inner parts of the galaxy, the SOFIA data show for the first time that the field lines in the outer arms do not follow the same order. Intense star formation in these outer regions may be causing magnetic chaos, and the gravitational tug of neighboring galaxy NGC 5195 probably also plays a role.

■ MONICA YOUNG

GALACTIC

Black Hole Feasts on Star

A DISTANT SUPERMASSIVE black hole is flaring in a surprisingly regular pattern, and astronomers think it betrays the piecemeal devouring of a star.

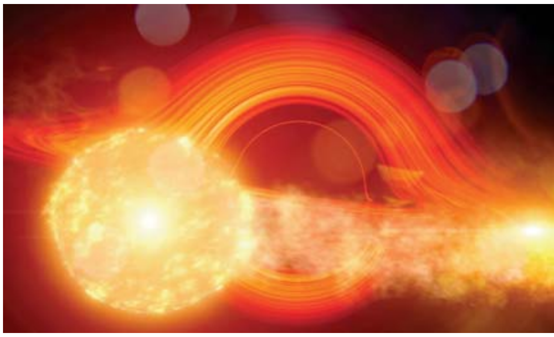
On November 14, 2014, the All-Sky Automated Survey for Supernovae (ASAS-SN), a global network of 14-cm robotic telescopes, detected a flare in the core of a misshapen galaxy 570 million light-years away.

Astronomers initially thought the flare, cataloged as ASASSN-14ko, was a supernova, or maybe the temporary brightening of a supermassive black hole. However, when Anna Payne (University of Hawaiʻi, Mānoa) went back over six years' worth of data, she found similar flare-ups occur every 114 days.

Payne and colleagues observed the days-long flashes with various facilities, including four large amateur telescopes in Australia, South Africa, and Brazil and several X-ray satellites. Payne discussed the analysis at the 237th meeting of the American Astronomical Society (AAS), and the results will appear in the *Astrophysical Journal*.

In a second paper, presented at the AAS meeting and posted on the arXiv preprint server, Michael Tucker (also at the University of Hawaiʻi, Mānoa) and colleagues announced two nuclei at the center of this galaxy, each one hosting a feeding supermassive black hole. The periodic flaring comes from the brighter of the pair. The team suggests the galaxy is in the late stages of a merger, which would explain its irregular shape.

The flares can't come from interactions between the black holes, which are 4,500 light-years apart. Instead, Payne's team envisions a star in an elongated orbit. Every time the star passes near the black hole, it loses about three Jupiter masses' worth of gas, which heats up and flares as it falls into the black hole. The star survives, only to lose another chunk during the next pass.



▲ This artist's concept shows a supermassive black hole tugging the outer layers off a red giant star.

Without knowing what kind of star is involved or how long the flares have been happening, it's hard to tell how long this will last, Payne says. The team plans to keep studying upcoming flares expected in April and August 2021.

■ GOVERT SCHILLING

SOLAR SYSTEM

Amateur Finds Jupiter's "Lost" Moons

AN AMATEUR ASTRONOMER has found four of five "lost" Jovian moons. The feat allows a recalculation of their orbits, leaving only one of Jupiter's 79 known satellites still unaccounted for.

The formerly missing moons are among a group of 23 small Jovian satellites that Scott Sheppard (Carnegie Institution for Science) and colleagues reported in 2003. Many of these were later lost due to uncertain orbits; as of late November 2020, five remained so.

The amateur, who gave his name only as Kenneth, began his quest to find the lost moons using the discovery images stored in the Canadian Astronomy Data Centre's Solar System Object Image Search. Starting from initial orbital information, he ran the clock back to find additional "precovery" images. Once he had found a moon in a precovery image, he then used the position data to extend the orbit back over a longer time period. He could then hunt for additional images.

Kenneth tackled the five moons one by one. Only the last, S/2003 J 10, proved too difficult to recover. The Minor Planet Center has now published Kenneth's reports for the other four: S/2003 J 23, J 12, J 4, and J 2. (Unbeknownst to Kenneth, Sheppard had already recovered S/2003 J 2 and J 23, but his submissions to the Minor Planet Center, along with Kenneth's, were stuck in a processing backlog.)

Sheppard calls Kenneth's recoveries "impressive." Not only are the moons faint, but with their wide-ranging orbits they traverse an area of about 80 square degrees. That's a giant haystack to search for dim needles, especially when the powerful telescopes required to image them have small fields of view.

Most small Jovian moons belong to one of five distinct families, each dominated by one big object that Jupiter probably captured long ago. The Smaller moons are likely fragments broken off the larger main bodies during collisions — rare events now but numerous billions of years ago. Small moons thus help probe the solar system's history.

■ JEFF HECHT

IN BRIEF

Galactic One-Two Punch

The Milky Way may have endured a one-two punch early in its history. A large fraction of the stars in our galaxy's halo are crash debris, scraps from galactic collisions — including many of the ancient balls of stars called *globular clusters*. Astronomers think the largest offender was Gaia-Enceladus (*S&T:* Feb. 2019, p. 13), which might have contributed more than 20 globulars (*S&T:* Mar. 2021, p. 11). But new work by Jeremy Bailin and Ryker von Klar (both at University of Alabama) suggests Gaia-Enceladus was a double whammy. Instead of assuming that globulars' current levels of heavy elements match what was in the gas that formed them, Bailin and von Klar accounted for how levels would have changed as stars within the clusters died and spread their remains around. They discovered that the globulars associated with Gaia-Enceladus split into two distinct chemical groups: There were two galaxies, not one, Bailin reported at the 237th meeting of the American Astronomical Society.

■ CAMILLE M. CARLISLE

NASA GSFC

The Cosmic Conjunction

When the world's got you down, look up and tune into orbital time.

▲ The Great Conjunction of Jupiter and Saturn, as seen just after sunset on December 21, 2020

TOM POLAKIS

JUST AS THE HELLACIOUS year of 2020, so full of loss, conflict, cynicism, and pain, was drawing to a close, we Earthlings were treated to a rare and stunning celestial arrangement as the two bright gas giants Jupiter and Saturn pulled to within a fingernail's width of each other on the night of the winter solstice.

For those of us attuned to the heavens, such a sight is not only a delight in and of itself, but it can pull us out of our quotidian reality. We enter into sky time, recalling other spectacles, other times and places when the stars aligned for us. We remember our favorite eclipses, rare meteor showers, auroral light shows, the few really good comets that have offered themselves to our close inspection, and those bright planetary congregations we've witnessed during our few orbits.

My own wedding came (not by coincidence) on a summer solstice coinciding with a choice conjunction of the crescent moon with two bright planets. For me, every planetary conjunction now has a little of that night in it. Each watcher has their own associations, and these peak sky happenings stitch our life's journeys together at a scale beyond the day-to-day.

These memorable sightings also bind us to human lives before and after our own. My grandmother, who is no longer with us, was not impressed with the apparition of Halley's Comet in 1986. To explain why, she drew me a picture from memory of the truly magnificent appearance in 1910, when she was only 10 years old.

The previous close meeting between Saturn and Jupiter came in 1226 (not counting their discrete 1623 rendezvous, when few likely saw them consorting so near to the Sun). Seen only with naked eyes, that was the last pre-telescopic, pre-Copernican superconjunction. Not too long after that, we learned what the planets really are and, concurrently, that our own world is also a planet that could be seen wandering through the skies of others. With that knowledge, we'll never see a conjunction the same way again.

This orbital dance also connects us to geologic and cosmologic time. It has been proceeding since long before there were humans, or hominids, or mammals, or any creatures with eyes who might have noticed.

Beyond the simple aesthetic enjoyment, why are these cosmic configurations so compelling?

Conjunctions, along with eclipses and cometary apparitions, have long been seen as omens. It's not hard to imagine why. The wandering planets, by nature of their capricious movements, can appear to possess agency and awareness. When they cross paths, it highlights their apparent personalities, almost as if they were greeting one another, or perhaps conspiring. In truth, the awareness exists only down here in the eyes of the beholders.

We don't need to think of such alignments as portents to appreciate the wisdom in the perspective they bring, to delight in the reminder of the rhythmic and harmonious cosmos we occupy, and to feel enmeshed in their movements. After all, it is the shifting parallax of our view from Earth's orbit, the fact that we observe from a moving platform, that makes Saturn and Jupiter seem to rush together and then part so rapidly. This is a dance we participate in.

When the world feels momentarily dark, celestial spectacles can connect us to places and times that transcend our immediate worries and remind us of the wider landscapes we inhabit. Jupiter and Saturn will pass each other this close again on March 15, 2080. I won't get to see that one, but I'm glad some of you will.

■ Astrobiologist DAVID GRINSPOON, an *S&T* contributing editor, is author of *Earth in Human Hands: Shaping Our Planet's Future*.

 by Govert Schilling

COSMIC POW

AIR SHOWER This artist's concept shows an example of the air shower of secondary particles that a high-energy cosmic ray creates when it hits Earth's atmosphere. The ground structure is one of the water tanks that serve as a Cherenkov-radiation detector for the Pierre Auger Observatory in western Argentina.

ER RANGERS

Scientists are deploying vast arrays on Earth to search for the origin of the most energetic particles in the universe.

In an uninhabited part of western China, between the arid Gobi Desert and the mountain peaks of the Tibetan Plateau, a novel radio observatory is taking shape. This spring, a few dozen weird-looking dipole antennas will start "listening" for extremely energetic neutrinos from outer space. Scientists will add thousands of additional units over the next five years, in an area 100 kilometers across. Eventually, the Giant Radio Array for Neutrino Detection (GRAND) will consist of 200,000 antennas in various parts of the world, covering a total area as large as Nebraska. The ultimate goal: solving the riddle of ultra-high-energy cosmic rays.

Cosmic rays are energetic particles — electrons, protons, heavier atomic nuclei, and their antiparticles — that zip through space at near-light speed. Most of them originate in the Sun, in supernova explosions and remnants, or in the vicinity of pulsars. But the origin of the most powerful cosmic rays is one of the oldest and largest mysteries in high-energy astrophysics. Since the charged particles are deflected by cosmic magnetic fields, their arrival directions do not tell you where they came from.

"But we expect that ultra-high-energy cosmic rays are accompanied by extremely energetic neutrinos," says GRAND project manager Charles Timmermans (Radboud University, the Netherlands), "and because neutrinos have no electrical charge, they point back to their source."

AIR SHOWER: A. CHANTELAUZE, S. STAFFI, L. BRET; BACKGROUND LINE TEXTURE: FUNKYPLAYER / SHUTTERSTOCK.COM

Austrian physicist Victor Hess discovered cosmic rays back in 1912, but studying them in detail has been frustratingly difficult. As soon as high-energy particles enter Earth's atmosphere, they collide with nitrogen and oxygen nuclei, producing an avalanche of rapidly interacting and decaying secondary particles. Only by capturing and measuring these fleeting *air showers* can scientists hope to learn more about the primary culprits. "From our data, we can derive the number of secondary particles at ground level, the arrival direction of the air shower, and the total energy," says Antonella Castellina (INFN Torino, Italy), co-spokesperson of the international Pierre Auger Observatory, currently the largest cosmic-ray observatory in the world.

For *ultra-high-energy cosmic rays* (UHECRs), an additional complicating factor is their sheer rarity. Particles with energies above 8×10^{18} electron volts (8 EeV, about 1% of the punch of a high-velocity baseball) only arrive at Earth at a rate of one per square kilometer per year. Little wonder that the origin of UHECRs is still pretty mysterious, even though the first one was detected almost 60 years ago, in 1962. "Finding the sources is by far the biggest challenge," says theorist Luis Anchordoqui (City University of New York).

Not that scientists are completely in the dark about the origin of UHECRs. In 2017, the Pierre Auger collaboration presented convincing evidence that they originate from beyond the Milky Way, as most researchers already suspected on theoretical grounds. Because of their high energy, UHECRs experience a smaller deflection by magnetic fields than lower-energy cosmic rays — in general, less than 25°. Looking at the arrival directions of more than 30,000 of these "baseball particles" over a period of 12 years, scientists found that about 6.5% more UHECRs are coming from one half of the sky than from the opposite half. This anisotropy is not aligned with the galactic center, as you might expect in the case of a galactic origin, but with the slightly lopsided distribution of external galaxies within 150 million light-years or so.

Energetic air-shower particles pass through the tanks at velocities that are higher than the speed of light in water.

One year later, the team announced a possible association of even more energetic UHECRs (above 4×10^{19} eV) with relatively nearby starburst galaxies (galaxies with an exceptionally high star-formation rate) — in particular, NGC 4945 in the constellation Centaurus, NGC 253 (Sculptor), M83 (Hydra), and NGC 1068 (Cetus). "At present, it's just a strong hint," says Castellina — the statistical significance of the correlation isn't yet large enough to claim a discovery. More data are crucial to obtain a higher degree of confidence, she explains. "We keep observing."

A Sea of Water Tanks

Located in the Pampa Amarilla northeast of the Argentinian town of Malargüe, the Pierre Auger Observatory (named after the French physicist who pioneered air-shower observations) covers an area of 3,000 square kilometers — about the size of Rhode Island. Its some 1,660 surface detectors, spaced about a mile apart, consist of tanks that look like giant Jacuzzis, each holding 12,000 liters of purified water. Sensitive silicon photomultipliers register the faint Cherenkov radiation produced when energetic air-shower particles pass through the tanks at velocities that are higher than the speed of light in water — a

▶ **TEAM EFFORT** Outreach coordinator Greg Snow (1954–2019) stands with the final tank of the 1,600 originally deployed, signed by collaboration members. Later, the array team installed additional tanks, part of a more densely spaced section to enable detections at lower energies.

▼ **PIERRE AUGER** Long-distance view of a line of the observatory's Cherenkov water tanks (small white structures).

phenomenon comparable to the sonic boom of a fighter jet breaking the sound barrier.

Meanwhile, from four locations around the perimeter of the observatory, a total of 27 wide-field telescopes with 3.6-meter segmented mirrors keep an eye on the sky above the pampa, looking for the ultraviolet fluorescence caused by the interaction of the air-shower particles with atmospheric nitrogen atoms. The Pierre Auger Observatory started operating in early 2004 while still under construction and was officially inaugurated in November 2008. "Our stations have recorded many millions of signals to date," says Castellina. "At energies above 3×10^{18} eV, where our detector is fully efficient, the number of extensive air showers is on the order of 15,000 per year."

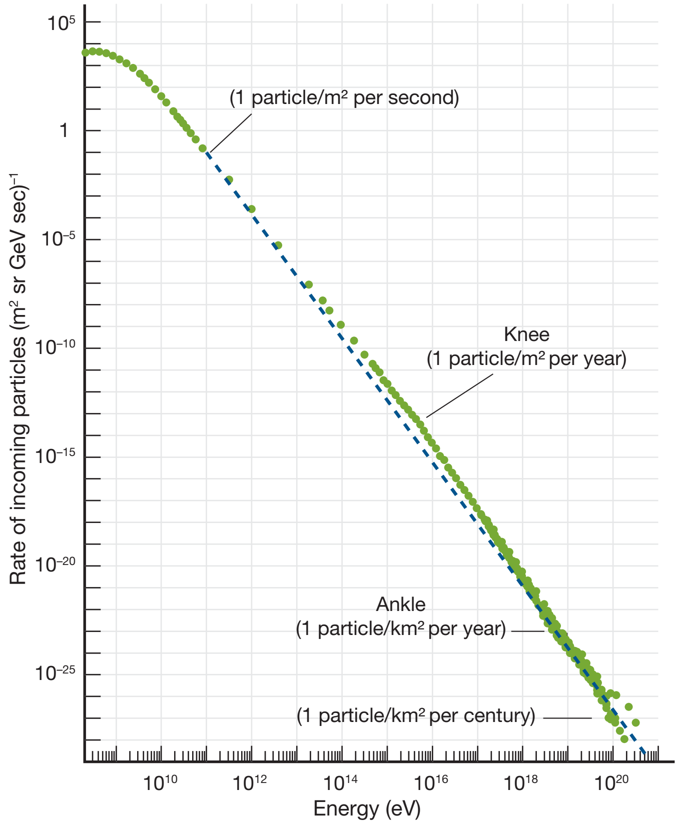
Using data from the surface detectors, scientists can reconstruct the spatial orientation and the spread of the air shower, as well as the number of secondary particles that reach Earth's surface. From the UV observations of the fluorescence detectors, they estimate the total energy of the primary cosmic-ray particle, while the altitude at which the fluorescence trail reaches its peak brightness indicates the incoming particle's nature: Protons and electrons penetrate to lower altitudes than heavier nuclei with the same energy.

Unfortunately, the fluorescence detectors can only operate during cloudless and moonless nights — about 15% of the time. That's where radio observations come in — they don't care about weather or daylight. As Castellina explains, there are two ways in which particle showers produce radio waves. The more prominent source is electrons and positrons (anti-electrons) produced by the decay of secondary cosmic-ray particles: When they are deflected by Earth's magnetic field, they emit radio pulses. But relativistic charged particles moving through the atmosphere also emit a cone of radio waves known as Askaryan radiation, after the Soviet-Armenian physicist who predicted the effect in 1962.

Test observations with the Auger Engineering Radio Array (AERA) — a network of more than 150 simple dipole radio antennas — have demonstrated that astronomers can also use radio detections to estimate the energy of primary cosmic rays. That's why engineers are now installing 1,660 radio antennas (one at every surface detector) as part of an ongoing upgrade of the observatory, known as AugerPrime. The upgrade also includes 1,660 flat particle detectors known as *scintillators*, each with an active surface area of 3.2 by 1.2 meters, that will help characterize the secondary particles in the air showers. These in turn provide more information on the nature of the primaries. The AugerPrime deployment has been delayed by the COVID-19 pandemic, but it should be completed in 2022.

Hotspot Connection

In the Northern Hemisphere, the smaller Telescope Array project in western Utah is also undergoing an upgrade, quadrupling its current dimensions (some 750 square kilometers) to a size comparable to Pierre Auger's. However, the Telescope



▲ **COSMIC RAYS** The flux of cosmic rays bombarding Earth as a function of their energy per particle. Scientists think those above the "knee" come from within the Milky Way, while those of higher energies come from outside our galaxy. Ultra-high-energy cosmic rays lie around the "ankle" or beyond.

GREGG DINDERMAN / S&T; SOURCE: WILLIAM HANLON / UNIV. OF UTAH

Array lacks Cherenkov water tanks; it just consists of hundreds of scintillators and three fluorescence detector stations.

"It's not easy to compare the results of the Pierre Auger Observatory and the Telescope Array," says theorist Anchordoqui. "They are different experiments with different properties, and they use different analysis techniques." Still, scientists from both projects are working together to combine the two data sets.

Interestingly, the Telescope Array has detected a 40°-wide UHECR hotspot in the sky centered in Ursa Major, possibly associated with the starburst galaxy M82. If confirmed, it would support the possible link between UHECRs and nearby starburst galaxies found by the Pierre Auger collaboration. "Everything seems to be closing together," Anchordoqui says, "although it's still unclear what makes these handful of starburst galaxies so special. There are many dozens of other galaxies at similar distances that do not appear to contribute as strongly to the observed UHECR flux."

Central black holes can't be the answer, he adds, since they are found in almost every galaxy. Anchordoqui's favorite explanation is galactic superwinds — powerful gaseous outflows that result from huge numbers of supernova explosions. Indeed, M82 and NGC 253 show clear evidence of such superwinds. Shock fronts in the outflows could accelerate particles to ultra-high energies.

Solving the mystery of ultra-high-energy cosmic rays has been hampered by a somewhat unexpected property of these baseball particles: At higher energies, they contain a higher proportion of heavier nuclei. Pierre Auger data indicate that the proportion of protons (hydrogen nuclei) eventually falls off to some 20%; most of the UHECRs are nuclei of carbon, nitrogen, oxygen, silicon, or even iron. Because of their larger (positive) electrical charge, these nuclei are easier to accelerate to near-light speed, even though they are more massive. But for the same reason, they are also easier for magnetic fields to deflect, making it harder to precisely trace them back to their source.

Follow the Fluorescence

To firm up the UHECR/starburst galaxy correlation, astrophysicist Angela Olinto (University of Chicago) says researchers need to gather more data at the highest possible energies. "You need to be more sensitive, which means larger. However, 3,000 square kilometers is already quite a lot, so how do you get there? The answer is: Go into space." While Pierre Auger and the Telescope Array can only monitor a relatively small part of the atmosphere, an orbiting ultraviolet space telescope could survey huge portions of Earth's nightside for the fluorescence trails produced by air showers.

An orbiting ultraviolet space telescope could survey huge portions of Earth's nightside for the fluorescence trails produced by air showers.

The idea was first proposed some 40 years ago by American physicist John Linsley, who discovered the first UHECR in 1962. However, NASA's plan for an Orbiting Wide-angle Light-collectors mission (OWL) failed to materialize, and a competing European/Japanese mission was likewise aborted after many delays and financial setbacks. At present, the only operational instrument looking for fluorescence trails from space is a small UV telescope known as Mini-EUSO (for Extreme Universe Space Observatory), which was installed at the International Space Station in August 2019.

Olinto is the principal investigator of a major new initiative called POEMMA, for Probe of Extreme Multi-Messenger Astrophysics. Her team first proposed the billion-dollar

JOHN MATTHEWS / UNIVERSITY OF UTAH

▲ **TELESCOPE ARRAY** This solar-powered scintillation detector measures the strength and direction of air-shower particles created by incoming cosmic rays. The setup is how it appeared in 2014, when the collaboration announced its hotspot detection.

space mission for the study of ultra-high-energy cosmic rays to NASA in 2016. In 2019, the researchers submitted a detailed design study for review by the 2020 Decadal Survey on Astronomy and Astrophysics of the National Academies, which is expected to report its recommendations this spring. If the proposal receives a high ranking and NASA gives the green light, POEMMA could launch by the end of the decade, according to Olinto.

POEMMA consists of two identical spacecraft circling Earth in the same orbit, some 300 kilometers behind each other. The stereo vision of its two eyes — 4-meter wide-angle telescopes equipped with sensitive ultraviolet cameras — would enable a full 3D reconstruction of any fluorescence trail in the atmosphere. "What we need is a lot of events with directions," says Olinto, "and over time, POEMMA will observe large swaths of the Earth's nightside. Within five years or so, it should be possible to map the sources of UHECRs."

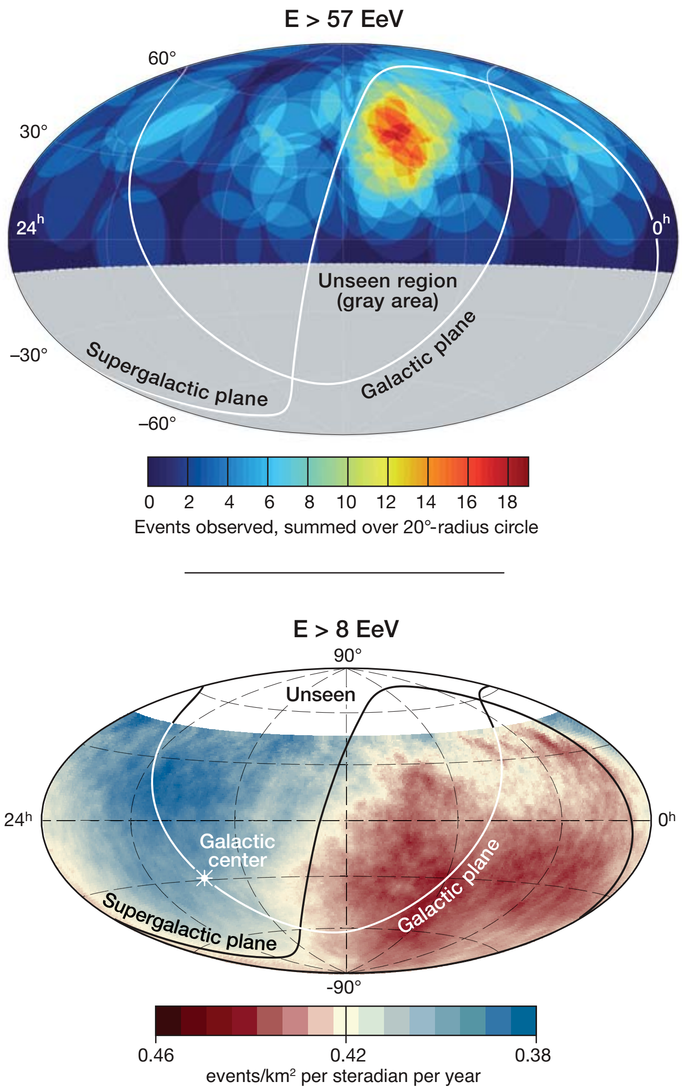
Geography to the Rescue

By then, however, the UHECR riddle may have been solved by GRAND, the prototype of which is now taking shape in western China. Just like the new radio antennas of Pierre Auger, GRAND will also detect air showers produced by cosmic-ray particles, but its ultimate goal is to hunt for extremely energetic neutrinos. "These high-energy neutrinos have never been observed before," says Timmermans, "but we're very confident they must exist, although they're apparently quite rare."

No matter how cosmic-ray particles are accelerated to UHECR levels, explains Timmermans, you expect them to incidentally crash into atomic nuclei in the ambient interstellar medium — probably close to their source, where densities are much higher than in intergalactic space. Through $E = mc^2$, the sheer energy of these collisions is converted into a wide variety of new particles, including uncharged neutrinos. According to theoretical calculations, these neutrinos carry some 5% of the energy of the original cosmic-ray particle. In other words, a burst of UHECRs of 10^{20} electron volts should be accompanied by neutrinos of a few times 10^{18} eV.

Because magnetic fields don't deflect neutrinos, any high-energy neutrino arriving here on Earth points directly back to its origin. Unfortunately, not all of the particles will come from pinpoint sources: UHECRs can also create high-energy neutrinos by interacting with the cosmic background radiation, which is all over the sky. But any neutrinos produced together with the UHECRs will betray where the most energetic particles in the universe originate, with a precision of better than half a degree. "It would be great to really discover one or more discrete sources on the sky," says astroparticle physicist Sijbrand de Jong (Radboud University, The Netherlands), who pioneered the Auger radio observations and is also a member of the GRAND collaboration.

But how do you detect these high-energy neutrinos? That's where the Tibetan Plateau mountains come in. Somewhat counterintuitively, the most energetic neutrinos are more likely to interact with normal matter than their lower-energy siblings — because of their higher energy, they have a larger *cross section*, as physicists say. While low-energy neutrinos easily pass through a planet like Earth, the particles that GRAND is after have trouble penetrating a few tens of kilometers of solid rock. So if their source is low above the horizon — hidden from view by the mountains, as seen from GRAND — they will enter the mountains from behind and most likely interact with a nucleus somewhere in the rock. These interactions produce short-lived particles that may emerge from the near side of the mountain range, in full view of the GRAND radio antennas.



▲ **ORIGIN HINTS** In the Northern Hemisphere, the Telescope Array has detected more extremely energetic cosmic rays coming from a hotspot centered in Ursa Major *(top)*. Operating in the Southern Hemisphere, the Pierre Auger Observatory has seen more cosmic rays (including those of slightly lesser energy) coming from one half of the sky than the other *(bottom)*. Unfortunately, the two experiments see different parts of the sky and have different energy cutoffs, so it's difficult to compare their data. (The supergalactic plane is the plane of nearby galaxy clusters.)

TELESCOPE ARRAY HOTSPOT: R. U. ABBASI ET AL. / *ASTROPHYSICAL JOURNAL LETTERS* 2014 (790:L21); COSMIC DIPOLE: PIERRE AUGER COLLABORATION

If the incoming high-energy neutrino is an electron neutrino, the interaction produces an electron, which will never leave the mountain at all. In the case of a muon neutrino, a negatively charged muon is produced — the heavier cousin of the electron. Such energetic muons will emerge from the mountain and zip through the atmosphere undetected.

However, in the case of a tau neutrino, the interaction yields an even more massive tau lepton, or tauon. "Tau leptons have a lifetime of about a trillionth of a second," says de Jong, "but because of a relativistic effect known as *time dilation*, they can cover tens of kilometers before they decay into a shower of other particles." These other particles include electrons and positrons, which can be detected by the radio waves they emit when deflected by Earth's magnetic field.

So here's the idea. Like the AERA array in Argentina, GRAND will be able to detect the radio emission of all kinds of air showers. But if the shower is a "horizontal" one, coming from the direction of the Tibetan Plateau mountains, it cannot be due to an incoming cosmic-ray particle or a high-energy gamma ray: Charged particles and photons are not able to penetrate kilometers of rock. Instead, the culprit must be a neutrino, and at least some of the highest-energy neutrinos are expected to be generated in the same extragalactic sources that also produce ultra-high-energy cosmic rays.

GRAND will observe at low radio frequencies between 50 and 200 megahertz, using thousands of antennas separated by about 1 kilometer. Each station consists of three butterfly-shaped dipoles at right angles to each other, to also measure the polarization of the radio waves. And if the first, 10,000-square-kilometer version in China (GRAND10K) is successful, the plan is to expand the observatory to a whopping 200,000 square kilometers all across the globe. Adding similar fields elsewhere in the world will increase the sky coverage and the detection rate. "All you need is a radio-quiet region with nearby mountains," quips de Jong.

Argentina, with the Andes range along its western border, is an obvious choice, according to Timmermans, but his team is also eyeing northern Canada (close to the Rocky Moun-

CHARLES TIMMERMANS

tains) and Russia (east of the Ural range). "The Transantarctic Mountains would also work," he says, "although deploying tens of thousands of radio antennas in Antarctica is going to be expensive." Currently, the full-scale version of GRAND is budgeted at somewhere between $150 and $200 million — a lot of money for a ground-based facility, but significantly cheaper than a space mission like POEMMA.

Timmermans and de Jong are very hopeful that GRAND eventually will detect discrete sources of extremely high-energy neutrinos. If they do, it would be bad news for Anchordoqui's superwind model. If UHECRs are accelerated in galactic superwinds, as he believes, the acceleration takes place in the tenuous halos of galaxies, where densities are probably too low to produce large numbers of high-energy neutrinos. "If GRAND finds discrete sources of high-energy neutrinos, the superwind scenario cannot be correct," Anchordoqui says, "and UHECRs must be accelerated in the cores of galaxies." In that case, scientists will have to revisit the question of why only some galaxies produce UHECRs.

But Anchordoqui isn't convinced that GRAND will have a serious impact on revealing the sources of UHECRs. "My personal opinion is that the radio technique is not yet mature enough," he says, "so I think AugerPrime is more likely to make the big discovery."

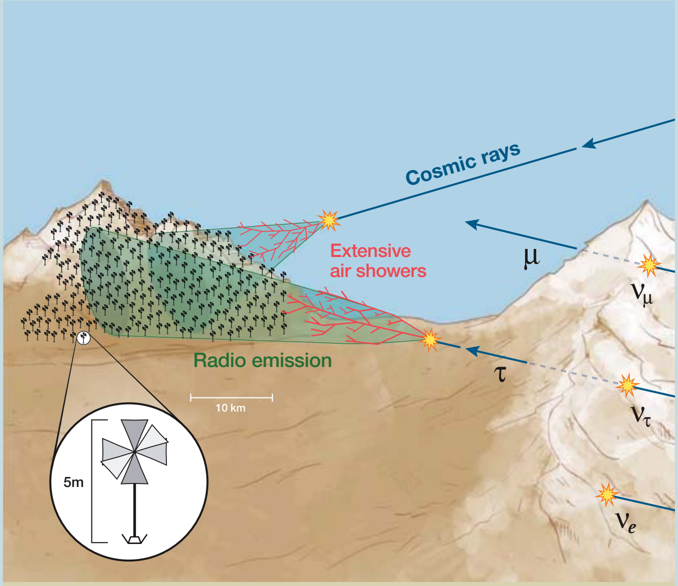
According to Timmermans, however, that won't happen before 2025, and it will depend on how long it takes for the individual detections to add up into clear, localized signals. "If AugerPrime hasn't found discrete sources by 2030," he says, "I believe that GRAND will have the best chances of achieving the breakthrough."

Meanwhile, if the POEMMA mission gets the green light, its observations may well yield an independent answer by the mid-2030s. One way or the other, the elusive energetic particles probably won't stay a riddle for much longer.

■ Contributing Editor **GOVERT SCHILLING** is a science writer who lives in The Netherlands. He has written dozens of books and is currently writing a book on dark matter.

GRAND SITE: CHARLES TIMMERMANS; HOW GRAND WORKS: GRAND COLLABORATION

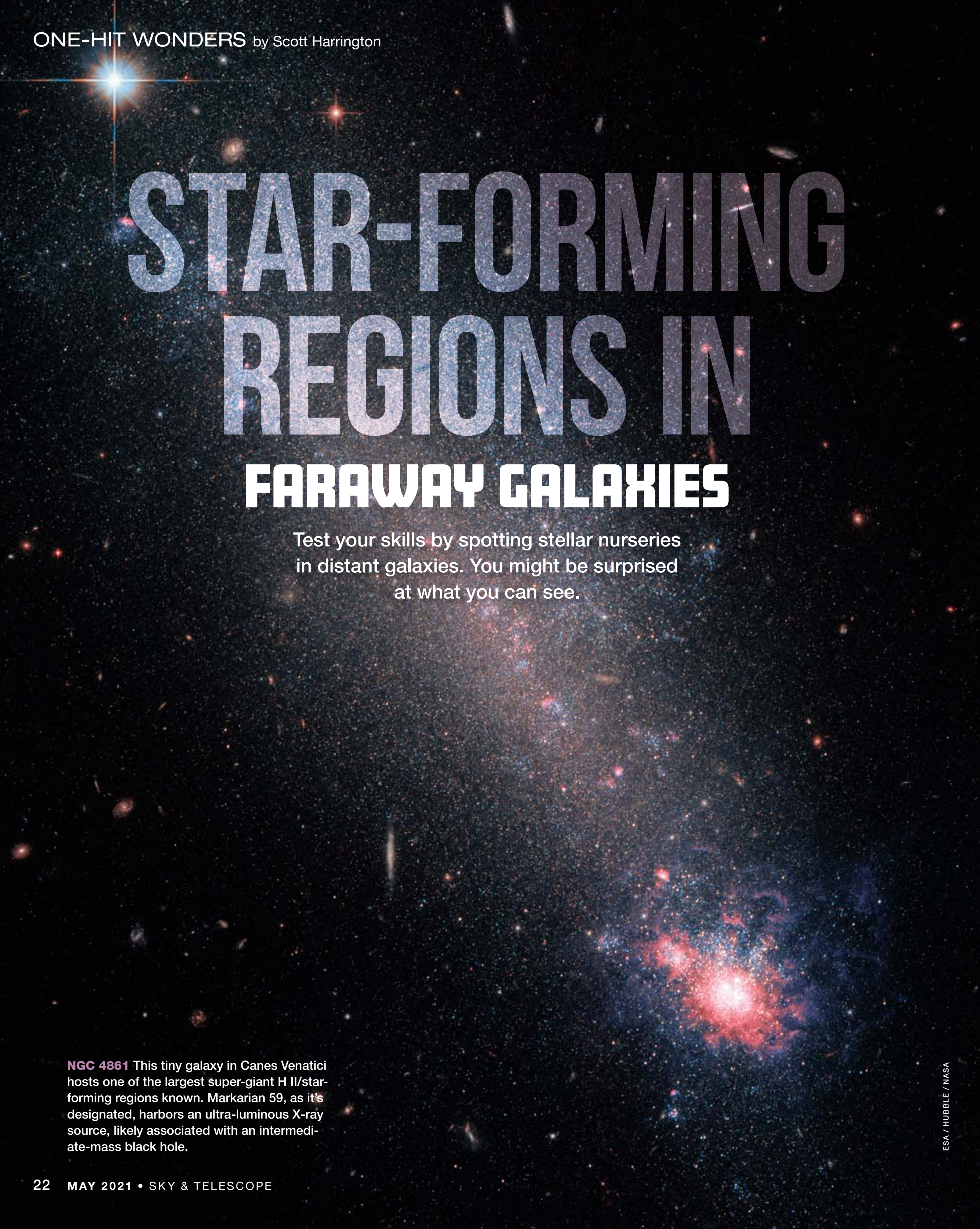
◀ **GRAND FUTURE** *Far left:* This windswept site in western China is the home of the growing Giant Radio Array for Neutrino Detection. Standing at the site are Xiang-Ping Wu and Huang Yan (National Astronomical Observatories of China). *Near left:* The setup for site survey operations. Scientists used easily moved antennas to measure background noise.



▲ **GRAND** The Giant Radio Array for Neutrino Detection will eventually use thousands of radio antennas to detect the signal of cosmic rays and tau neutrinos. Unlike muon or electron neutrinos, tau neutrinos will interact with atoms in neighboring mountains to create a detectable particle shower. The antennas have a triple bow-tie design, with three perpendicular arms. (Note that the mountain-facing slope the antennas are deployed on will be gentler than shown here.)

STAR-FORMING REGIONS IN FARAWAY GALAXIES

Test your skills by spotting stellar nurseries in distant galaxies. You might be surprised at what you can see.



NGC 4861 This tiny galaxy in Canes Venatici hosts one of the largest super-giant H II/star-forming regions known. Markarian 59, as it's designated, harbors an ultra-luminous X-ray source, likely associated with an intermediate-mass black hole.

ESA / HUBBLE / NASA

You don't have to be an amateur astronomer for long before you learn this: When springtime rolls around, the most sought-after deep-sky objects lie *outside* the Milky Way. I'm talking about galaxies, of course.

Often we're content to casually inspect these vast wonders, but I'm going to challenge you to go even deeper and look for super-giant H II/star-forming regions (H II/SFR). These are immense stellar nurseries where new stars are born and the hydrogen cloud surrounding them glows from the ionizing ultraviolet radiation of the hot, massive O- and *B*-type stars within. The nearest one to us is the Tarantula Nebula, visible naked-eye in the neighboring Large Magellanic Cloud (*S&T:* Nov. 2017, p. 24).

Seeing such features might sound daunting for galaxies beyond our Local Group, but it's really not — I've observed many in my 10-inch Schmidt-Cassegrain telescope. I'll even start with one H II/SFR that's so bright you'll be kicking yourself if you've never looked for it! So let's begin in the far north and work our way south.

For most people, the dwarf irregular galaxy **NGC 2366** can be hard to find simply because it lies in the dim constellation Camelopardalis. For me, it's even harder because the fork arms of my Schmidt-Cass get in the way! So, I find it's easiest to first locate the binocular-bright galaxy NGC 2403. From there it's only a 3° hop north-northwest to the magnitude-5.6 star HD 58425 and then another 0.8° to our quarry.

Sweeping around with an eyepiece yielding close to a 1° field at 73×, my eye quickly catches sight of a dim glow 3.5′ × 1′ in size and elongated north-northeast to south-southwest. At its southern end is a soft-looking, 12.5-magnitude star that forms a narrow diamond pattern with two stars about 4′ north and a 10th-magnitude star a farther 3′ north. Bumping the magnification all the way to 322× reveals that the soft-looking "star" is actually a high surface brightness knot 7″ across and elongated east to west.

Known as Markarian 71 (Mrk 71), this knot is actually a massive H II/SFR that spans roughly 30 times the width of the entire Orion Nebula and contains a pair of *super star clusters*, massive clusters of very young stars that may eventually evolve into globulars. I've been able to see it in my 10-inch with the aperture stopped down to just 50 mm with an off-axis mask — and that's before adding an O III or UHC filter!

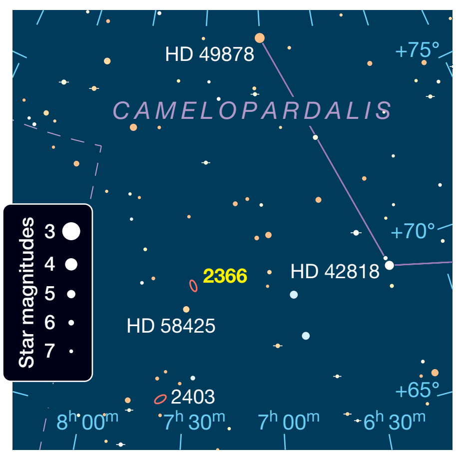
Not surprisingly, it was Mrk 71 and not the rest of the galaxy that caught William Herschel's eye when he discovered NGC 2366 in 1788. However, it wasn't until 1935 that Mrk 71 was first studied. Today, NGC 2366 and others like it are classified as *tadpole* (formerly *cometary*) *galaxies* because they exhibit dense, luminous "heads" and dimmer trailing "tails."

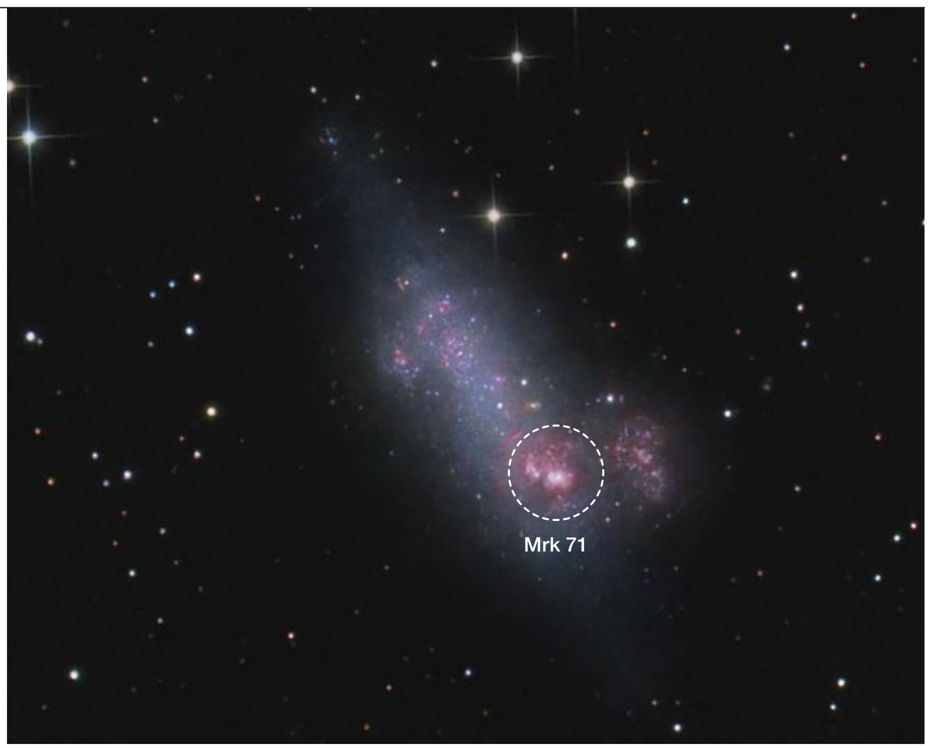
Going to the Dogs

Heading farther south into galaxy-rich Canes Venatici you'll find three more of the galaxies on our tour. The first and easiest to locate is the asymmetrical barred spiral galaxy **NGC 4618**, which is visible in 8×56 binoculars almost midway between Beta (β) Canum Venaticorum and M94. Low power in my 5.1-inch (130-mm) reflector reveals an 11th-magnitude star 4′ to its south and the smaller, 12.4-magnitude galaxy NGC 4625 only 8′ to its north-northeast.

At 153× in my 10-inch, NGC 4618 appears as a soft-looking elliptical glow 3′ across with a bright, broad core

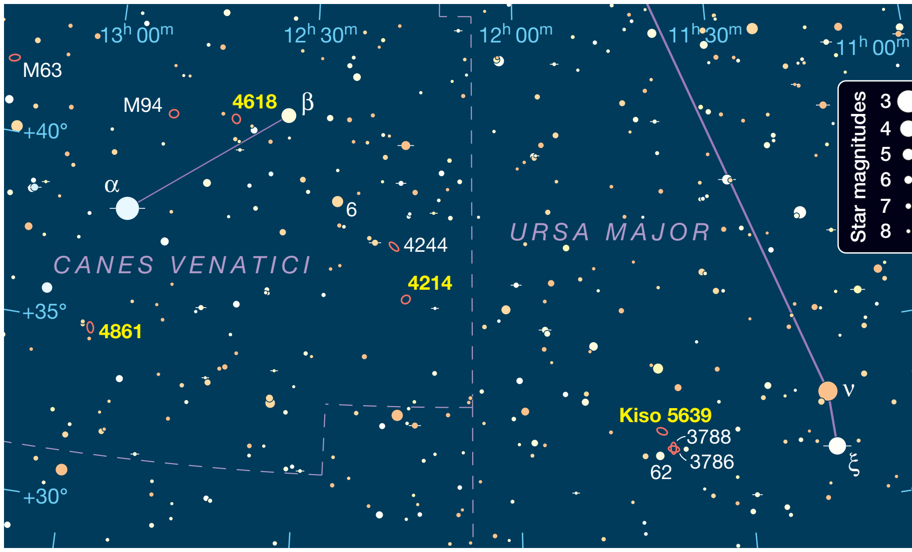
▶ **NGC 2366** Look for this dwarf galaxy in the sparse and dim constellation Camelopardalis, the Giraffe. Nestled in the galaxy is the bright H II/star-forming region, Markarian 71, which in turn harbors two super star clusters that go by many names, including Knot A and Knot B. One reason Mrk 71 is the second brightest of its kind in the Northern Celestial Hemisphere is because its host galaxy only lies 10 million light-years away.





MICHAEL SINISCALCHI

that's offset to the north and strongly elongated northeast to southwest. With averted vision, the hazy glow of the galaxy's disk extends nearly halfway to the 11th-magnitude star. Images show this is due to the galaxy's bright arm, which is evident in the eyepiece as a broad curve that's slightly brighter than the disk. The arm appears attached to the northeast end of the core and sweeps counterclockwise before disappearing on the galaxy's western side. Upon closer inspection, I can glimpse an extended diffuse spot on the arm's outside edge as it swings closest to that 11th-magnitude star.



In the Hubble Space Telescope (HST) image on page 25, this knot — which carries the designation IC 3668 — is well resolved into individual stars. What I'm seeing, then, is an older H II/SFR in which the nebula has mostly dissipated, revealing a wealth of hot, massive *O*- and *B*-type stars. In my scope it appears distinctly nonstellar.

Lying just 3.5° south-southeast of 3rd-magnitude Alpha (α) CVn is another tadpole galaxy. This one is an even more amazing enigma for the visual observer! At 73× in my 10-inch, **NGC 4861** is visible 15′ southwest of a pair of 7th-magnitude stars that are 4.8′ apart and aligned nearly north-south. The galaxy is easy to overlook, appearing only as a dim streak spanning a 2.5′ gap between two stars of roughly 13th magnitude. Upon closer inspection at 264×, the dimmer (I estimate magnitude 13.3) and more southern of the two stars begins to appear nonstellar. It's hard to believe until you've seen the HST image (page 22), but this "star" is actually a highly luminous and compact H II/SFR knot known as Markarian 59.

Surprisingly, Mrk 59's true nature was suspected as early as 1855, just 70 years after William Herschel discovered the host galaxy. That's when R. J. Mitchell, an assistant observing with the 72-inch reflector of William Parsons, the third Earl of Rosse, recorded ". . . [NGC 4861] has a plain star in north extremity and either a star or what looks more like a bright little knot involved in south end." It wasn't until 1974, however, that Mrk 59 was identified as a super-giant H II region. It's now one of the largest known at some 8,000 light-years across and has an ultra-luminous X-ray source associated with it.

I've looked for NGC 4861 in my 5.1-inch and found its dim streak just barely detectable at 59×. But I've seen Mrk 59 in my 10-inch with a 75-mm off-axis mask. If you want to see the H II/SFR but are having trouble making out its host galaxy, try blinking the field with either an O III or UHC filter. Mrk 59, like Mrk 71, is among the few extragalactic H II regions that respond well to filters.

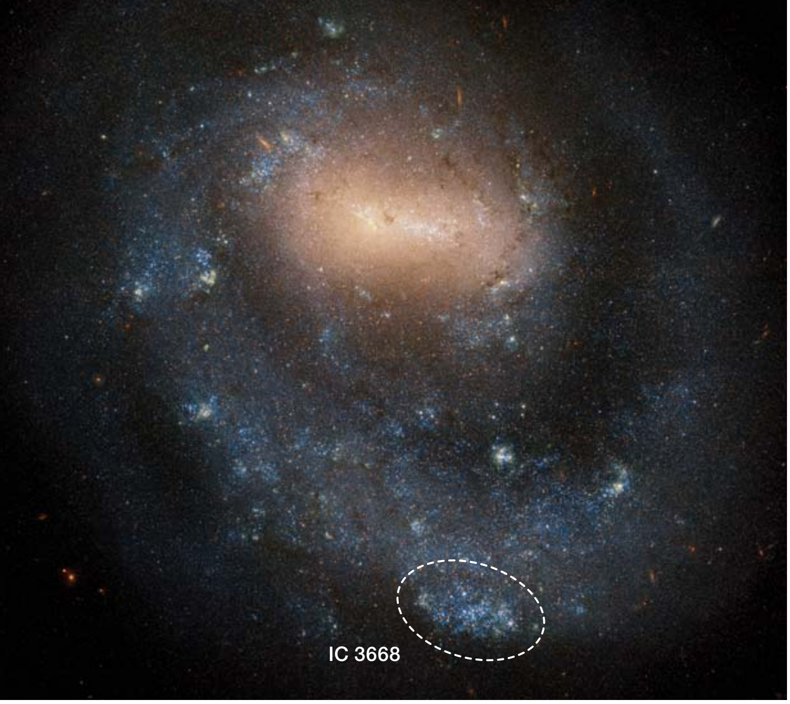
Staying in Canes Venatici, return to Beta CVn and drop 2.8° south-southwest to 5th-magnitude 6 CVn. Continuing in the same direction for another 3.4° will bring you to the dwarf starburst galaxy **NGC 4214** and safely past the clutches of the much more arresting edge-on galaxy NGC 4244.

NGC 4214 is the only galaxy on our tour that I've seen in my 7×35 binoculars. At 73× in my 10-inch, my first impression is that of a 2.5′ × 2′ soft disk that has an intensely bright but irregular central band running northwest to southeast. Inside this band is a strongly condensed core that shines at about magnitude 13.5. There is a scattering of five 14th- and 15th-magnitude stars to the galaxy's northern and eastern edges, along with an 11.8-magnitude star only 4.5′ to the southeast. At 153× the shape of its bright, elongated center vaguely reminds me of a shrimp. It appears even more irregular along its length — it bulges to the northeast, and a small bright section of about magnitude 14 is seemingly detached from its southeastern end. At 264×, its center appears mottled while the detached section forms an arc that bulges west. By adding a UHC filter, the whole length of the central bar responds favorably, revealing an emission component.

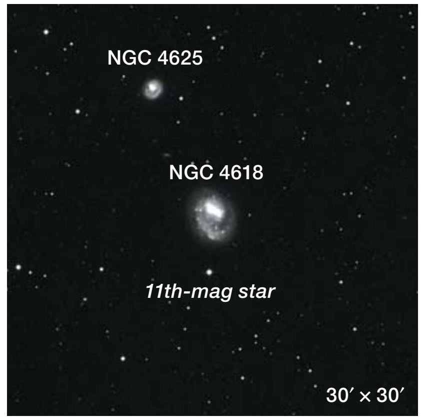
As seen in the HST image on page 25, NGC 4214 has a confusing jumble of H II complexes and knots running down its middle. Professional astronomers label the large central H II complex NGC 4214-I and the smaller detached complex NGC 4214-II. They further break NGC 4214-I into two substructures (I-A and I-B). Region I-A is the H II region in which a massive, young super star cluster has evacuated the gas at its center. Known as I-As, it lies among a rich spray of *O*-type stars and contains several hundred *O*-type and Wolf-Rayet stars of its own. My big surprise came when I realized that I-As is the condensed core I saw!

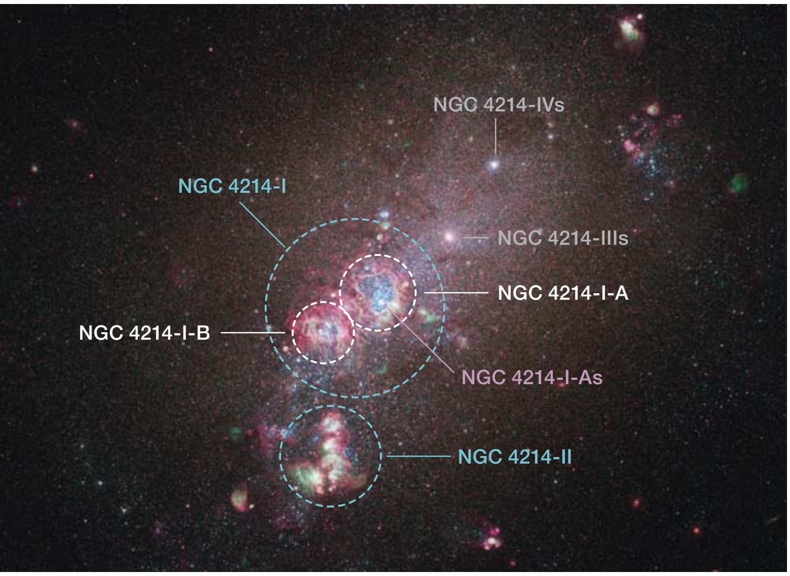
Smaller NGC 4214-II consists of about half a dozen H II knots involved with three massive OB associations, which are a little older than the ones in NGC 4214-I. If you have the opportunity to observe this galaxy with a large telescope, look for two super star clusters of roughly 16th and 17th magnitudes just north of its core.

NGC 4618 HST: ESA / HUBBLE / NASA / I. KARACHENTSEV; NGC 4214 HST: NASA / ESA / HUBBLE HERITAGE TEAM / STSCI / AURA / ESA / R. O'CONNELL / WFC3 SCIENTIFIC OVERSIGHT COMMITTEE; SKETCH: SCOTT HARRINGTON; KISO 5639 HST: NASA / ESA / D. ELMEGREEN / B. ELMEGREEN / J. ALMEIDA, C. MUNOZ-TUNON / M. FILHO / J. MENDEZ-ABREU / J. GALLAGHER / M. RAFELSKI / D. CEVERINO; DSS: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY (2)

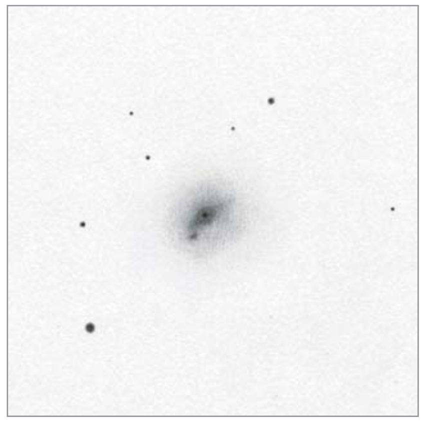


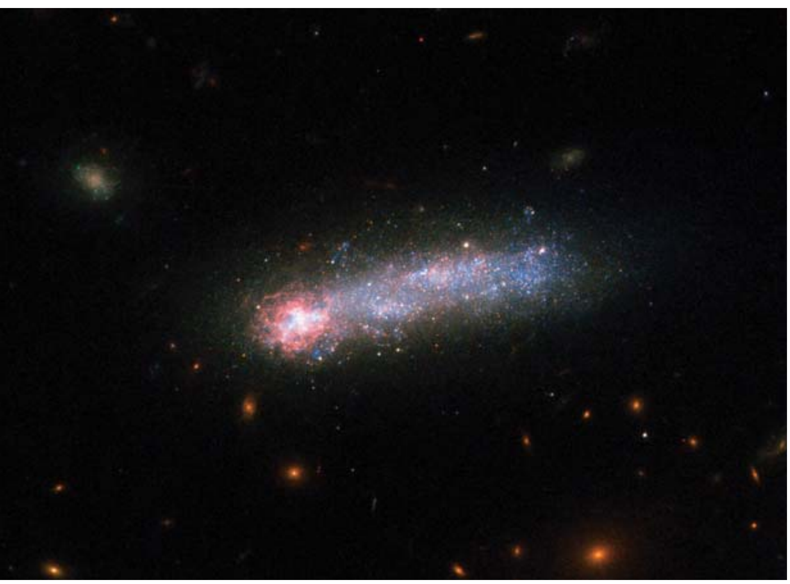
◀▶ **NGC 4618** About halfway between Beta CVn and the face-on spiral M94 you'll find NGC 4618, a barred spiral galaxy that curiously has only one arm curling around its center. See if you can spot the OB association on the southern edge of the galactic arm.



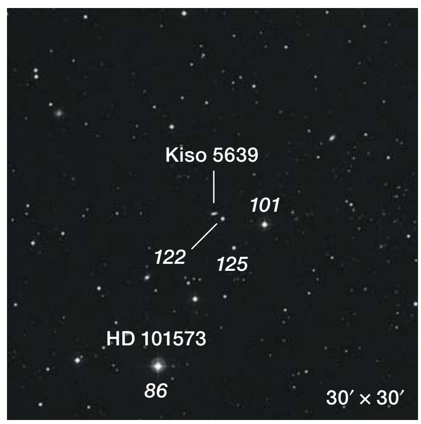


◀▶ **NGC 4214** In the southwestern corner of Canes Venatici is the dwarf galaxy NGC 4214. The furious winds of young, massive stars have carved out the heart-shaped cavity at the center of this galaxy. The sketch shows the view as seen using 153× on the 10-inch Schmidt-Cass.



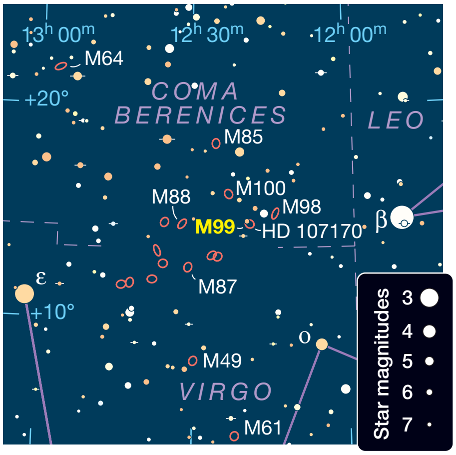


◀▶ **KISO 5639** Hopping across the border into Ursa Major takes us to Kiso 5639, also known as LEDA 36252. Astronomers studying the Hubble Ultra Deep Field have found that tadpole galaxies, such as Kiso 5639, while rare now, were fairly common in the early universe. This suggests that galaxies likely go through a "tadpole" phase during their evolution.



Far Out

Our next target is the tiny 16th-magnitude galaxy **Kiso 5639**, which lies in the far southeastern corner of Ursa Major. In fact, it's so small that it was only first detected in a survey for emission-line galaxies in the early 1980s.



To locate Kiso 5639, start at the rearmost leg of the Great Bear and its naked-eye paw stars Nu (ν) and Xi (ξ) Ursae Majoris. From there slide 5° east to 6th-magnitude 62 UMa. At 73×, my nearly 1° field can encompass this star, the interacting galaxy pair NGC 3786 and NGC 3788 (Arp 294) only 26′ to its west-northwest, and the location of Kiso 5639 just 41′ to its north. Even at 153×, however, all I can find at Kiso 5639's location is a 3′-wide, nearly equilateral triangle of magnitude 10.1, 12.2, and 12.5 stars. Only after I increase the magnification to 322× can I intermittently detect a stellar spot 1′ east-northeast of the magnitude-12.2 star.

Kiso 5639 is also classified as a tadpole galaxy, and it isn't hard to see why in the HST image on page 25. There it displays a thick but faint streak 22″ long running east to west with a high surface brightness H II/SFR on its eastern end. So it turns out I'm not seeing the tadpole's "body" at all. Instead, I'm glimpsing the massive H II region forming its "head" — an astounding fact given that the galaxy lies 80 million light-years away!

Our next target is one of the brightest spirals in the Virgo Cluster and probably the most frequently observed galaxy on our tour. That doesn't necessarily mean, however, that you've noticed the star-forming region that it harbors! To find **Messier 99**, start at 2nd-magnitude Denebola in the tail of Leo and slide 6.5° east to the 5.1-magnitude star 6 Comae Berenices. You'll find the galaxy lies just 50′ southeast of 6 Comae and in the same field as the 6.5-magnitude star HD 107170.

At 73× in my 10-inch, the galaxy is a soft, 4′-wide glow with a bright, offset center that gradually brightens to a starlike core. With averted vision I can detect two of its three strongest spiral arms at this magnification. At 153×, after moving HD 107170 out of the field, I can trace its asymmetrical southern arm until it starts curving north. I can also see a 13.5-magnitude star 2′ to the galaxy's southeast and a 14.1-magnitude star to its northeast. Upping the magnification to 264×, the spiral arms become very tenuous, but a nonstellar spot is now noticeable with averted vision 1.8′ east of the core.

Cataloged HK 1 in a 1983 paper by astronomers Paul Hodge and Robert Kennicutt, this is a remarkable H II/SFR

▲▶ **M99** *(Top)* The only Messier object in our collection, M99 is a grand design spiral, displaying long and clearly defined spiral arms, akin to our own Milky Way. You'll find this galaxy in Coma Berenices, in the northwestern corner of the Virgo Cluster. *(Above)* Using his 25-inch f/4 reflector, French amateur Bertrand Laville was able to easily see M99's three largest arms and HK 1, shown also in the HST image at right.

simply because it appears nonstellar despite being at a distance of nearly 50 million light-years. In fact, I was surprised by how easy it was to see on my first attempt and have since estimated its magnitude at 15.2. Mysteriously, Lord Rosse only drew HK 1 as a star on a drawing he made after turning his 72-inch reflector to the galaxy in 1846.

Deep South

To find our next galaxy, we need to travel far below the celestial equator into northern Centaurus. **NGC 5398** lies about 6° southeast of the bright galaxy M83, but it's best found by star-hopping north 3.5° from 2nd-magnitude Theta (θ) Centauri. Be forewarned, though: I found this to be the hardest galaxy on our tour because of its low altitude, lack of nearby bright stars, and low surface brightness.

With a nearly 1° field at 73× in my 10-inch, I'm able to find the correct location with the aid of a ½°-wide Digitized Sky Survey image (like the one on page 28), but the galaxy remains invisible. By using a little more magnification (91×)

M99: ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA / SKETCH: BERTRAND LAVILLE

ESA / HUBBLE / NASA / MATEJ NOVAK

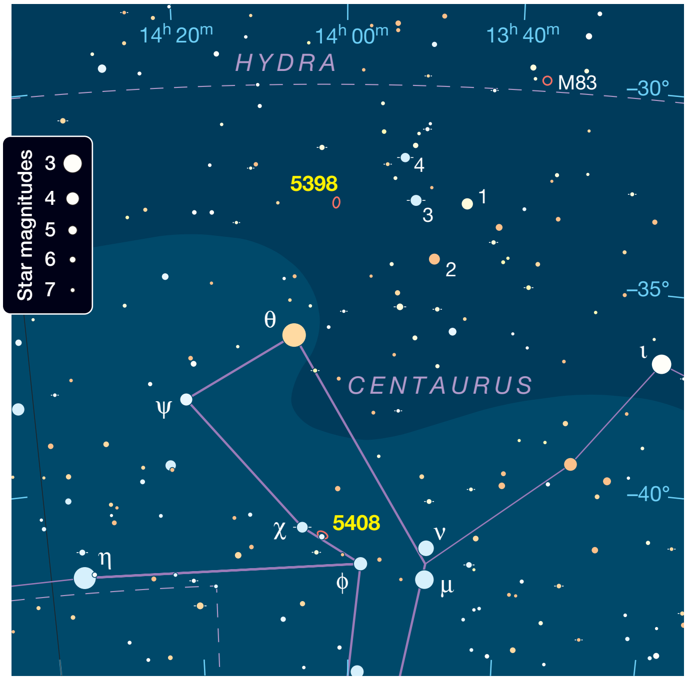
and averted vision, however, I can just tease out its soft, roughly 10″-wide core only 3′ southeast of a 3′-tall isosceles triangle of 12th-magnitude stars. At 153×, I can make out an exceedingly faint disk about 1′ across with a 13.6-magnitude star 2′ to the southwest. Upping the magnification to 264× and using averted vision, I'm able to see what looks like a second core just 32″ from the main core and in the direction of the 13.6-magnitude star. Their proximity to one another, similar brightness, and the haze of the galaxy's disk make concentrating on just one with averted vision difficult.

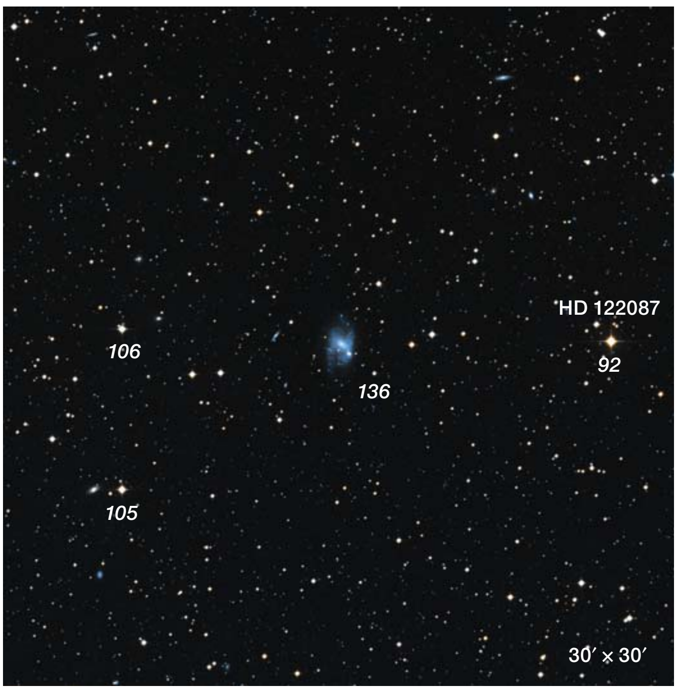
In images of the galaxy, the offset "core" I'm seeing turns out to be a massive, isolated H II/SFR region. That's quite impressive when you consider that NGC 5398 is a barred spiral 28 million light-years away. A 1976 paper on emission-line objects discovered at the Cerro Tololo Inter-American Observatory (CTIO) in Chile also labels it Tol 89.

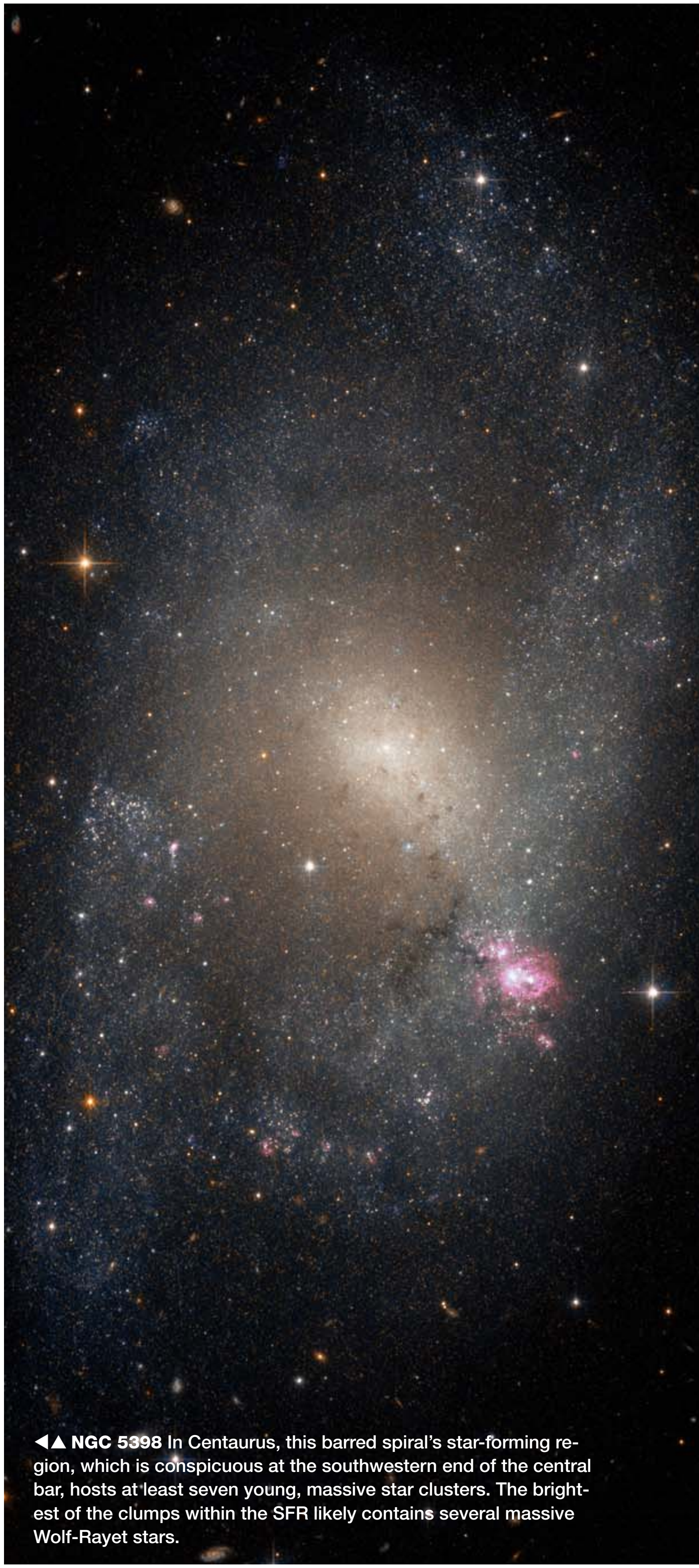
While our final galaxy, **NGC 5408**, resides even deeper in Centaurus than our last, it's not one you should miss! Seeing it will take planning, though, because it lies 8.3° below NGC 5398. From my latitude (in northern Arkansas) it culminates at an elevation of only 12.5°, and for an observer at 40°N, it reaches no higher than 8.6°.

The easiest route to NGC 5408 is to find Theta Centauri again and drop straight south 4.8° to magnitude-4.3 Chi (χ) Centauri. From there it's just a short ½° slide west-southwest to a magnitude-6.1 star. At 73×, that star forms a 3′ wide equilateral triangle with magnitude-10.6 and -10.1 stars to its north.

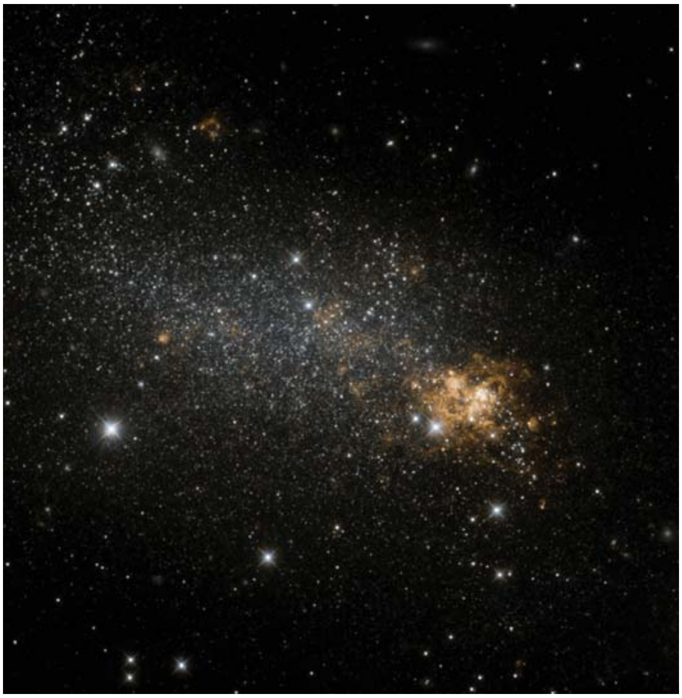
Even on exceptional nights, I can't make out the galaxy at 73×, but 153× allows me to detect it as a faint, ghostly glow stretched 1.5′ parallel to the north side of the equilateral triangle. At that magnification, I find that a nonstellar spot at its western end is slightly more noticeable than the overall galaxy. At 322×, the galaxy all but vanishes, while the nonstellar spot becomes elongated east to west. On images,

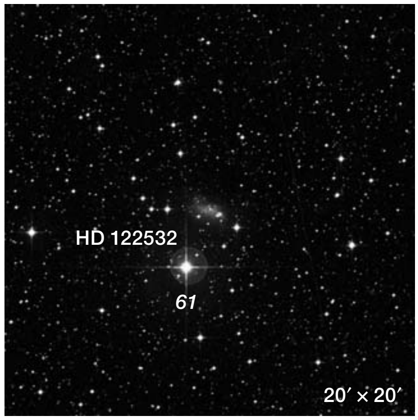






◀▲ **NGC 5398** In Centaurus, this barred spiral's star-forming region, which is conspicuous at the southwestern end of the central bar, hosts at least seven young, massive star clusters. The brightest of the clumps within the SFR likely contains several massive Wolf-Rayet stars.





▲▶ **NGC 5408** Going deeper into Centaurus leads us to this irregular galaxy, whose prominent H II region was long mistaken for a planetary nebula. Just to the lower left of the H II region is the X-ray source NGC 5408 X-1, likely powered by a rare intermediate-mass black hole.

this spot turns out to be a prominent grouping of at least two large H II/SFRs that harbor several super star clusters.

NGC 5408 is a dwarf starburst galaxy located 16 million light-years away in a group dominated by NGC 5128 (Centaurus A). It's had a confusing history after John Herschel's discovery in 1834, with his only description being "extremely faint, extended." That's because in the late 1960s, astronomer-astronaut Karl Henize noticed the galaxy's H II/SFR in a large objective-prism survey of the southern sky and classified it as an "emission-line star." Jürgen Stock and Herbert Wroblewski then designated it a planetary nebula (StWr 4-9) in their 1972 paper, but they did so using only objective-prism plates that didn't show the galaxy at all. At the same time, another study using visual-light images taken with the 1.5-meter Cassegrain reflector at CTIO described it as a massive H II complex at one end of NGC 5408. The same 1976 paper mentioned earlier confirmed this finding, and the H II complex was designated Tol 116. Despite such evidence, though, researchers continued publishing papers declaring it a planetary nebula. One of these was Luboš Kohoutek's 1978 supplement to the *Catalogue of Galactic Planetary Nebulae*, in which he assigned it the label PK 317+19.1.

Things began to change in 1982 when a study using the Einstein Observatory, the first fully imaging X-ray telescope put into space (*S&T:* Aug. 2019, p. 14), detected an ultraluminous X-ray source next to the so-called planetary nebula! That discovery garnered the dwarf galaxy some much needed scrutiny, but it still took another five years for its planetary nebula status to be dropped.

Well, we've reached the end of our tour, but we've only touched on the wealth of extragalactic H II regions that are visible with moderate-size telescopes. So, the next time you view a galaxy, make sure to take a closer look for any H II regions that may await you there.

■ **SCOTT HARRINGTON** is an astronomer in his 20s who is always thrilled when he sees a new deep-sky object in only handheld binoculars. Links to his various works can be found at **astronomy-mall.com/Adventures.In.Deep.Space**.

Extragalactic Pickings

Object	Feature Name	Distance (Ml-y)	Surface Brightness	Mag(v)	Size	RA	Dec.
NGC 2366	Mrk 71	10	14.5	11.1	8.1′ × 3.0′	$07^h 28.9^m$	+69° 13′
NGC 4618	IC 3668	24	13.5	10.8	4.2′ × 3.4′	$12^h 41.5^m$	+41° 09′
NGC 4861	Mrk 59	35	14.2	12.3	4.2′ × 1.6′	$12^h 59.0^m$	+34° 52′
NGC 4214	NGC 4214 II	10	13.9	9.8	8.0′ × 6.6′	$12^h 15.6^m$	+36° 20′
Kiso 5639	—	80	—	—	0.4′ × 0.1′	$11^h 41.1^m$	+32° 26′
M99	HK 1	50	13.2	9.9	5.4′ × 4.7′	$12^h 18.8^m$	+14° 25′
NGC 5398	Tol 89	28	13.7	12.2	2.8′ × 1.7′	$14^h 01.4^m$	–33° 04′
NGC 5408	Tol 116	16	12.4	11.6	2.0′ × 1.2′	$14^h 03.4^m$	–41° 23′

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.

QHYCCD's Newest Planetary Camera

We test a versatile, high-speed color video camera designed for planetary imaging.

◀ The QHY5III462C comes with a USB 3.0 cable, a UV/IR blocking filter, an IR850 near-infrared filter, an adjustable parfocalizing ring, and a 6-pin autoguider cable. All you need to supply is a suitable telescope and a computer. All photos by author unless otherwise noted.

QHY5III462C

U.S. Price: $299 (camera), $349 (expansion kit)

What We Like

Small, sensitive pixels

Lightning-fast downloads

What We Don't Like

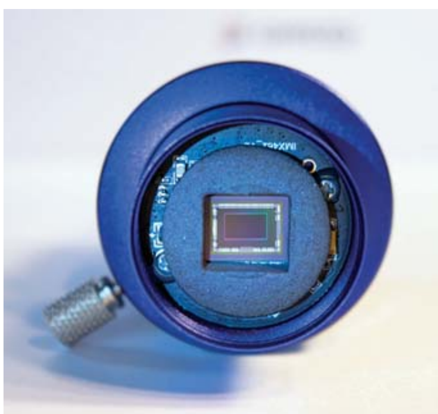
Washed-out color

Difficult to keep dust off sensor

FOR NEARLY TWO DECADES "lucky imaging" has been the tried-and-true route to recording the most detailed images of the Sun, Moon, and bright planets. Key to the technique's success is the use of high-speed video cameras that record as many frames as possible in a short period, along with software to cull, register, and stack the sharpest frames. The resulting images often show more details than can be gleaned with the eye alone. Best of all, it's fairly easy to do it yourself.

QHYCCD, a Chinese manufacturer specializing in astronomical cameras for both deep-sky and planetary imaging, recently announced a new high-speed model geared specifically to those with an interest in near-infrared imaging. The QHY5III462C is a color CMOS camera with a 6th-generation, back-illuminated Sony IMX462 sensor, engineered with deeper photosites that permit greater sensitivity to the longer wavelengths of light found at the red and near-infrared end of the spectrum, between 800 and 1,000 nanometers. This has a few interesting ramifications, as we'll see shortly. We borrowed one late in 2020 to see how well it performs.

The camera is housed in the QHY5-series body, which is no bigger than a typical 25-mm, 1¼-inch eyepiece. In fact, the 7.94 × 3.18-centimeter (3⅛ × 1¼-inch) body is designed to fit directly into a standard 1¼-inch-format focuser, allowing it to reach focus with most any telescope. The Sony IMX462 detector is a fairly small 1/2.8-format with a 1,920 × 1,080 array of 2.9-micron-square pixels. The camera includes a removable clear filter with C-mount threads, a parfocalizing ring, 1¼-inch threaded UV/IR blocking and IR850 filters, a 2-meter USB-3.0 cable, and an autoguider cable. QHYCCD also sent us the optional



◀ The QHYCCD camera's 2-megapixel color sensor measures 6.46 millimeters from corner to corner and is mounted precisely 12 mm behind its front flange.

$349 expansion kit, which contains an additional front window with UV/IR-blocking and C-threads, a 2.5-mm f/1.2 C-mount lens, and an 890-nm Methane band (CH_4) filter.

A Versatile Detector

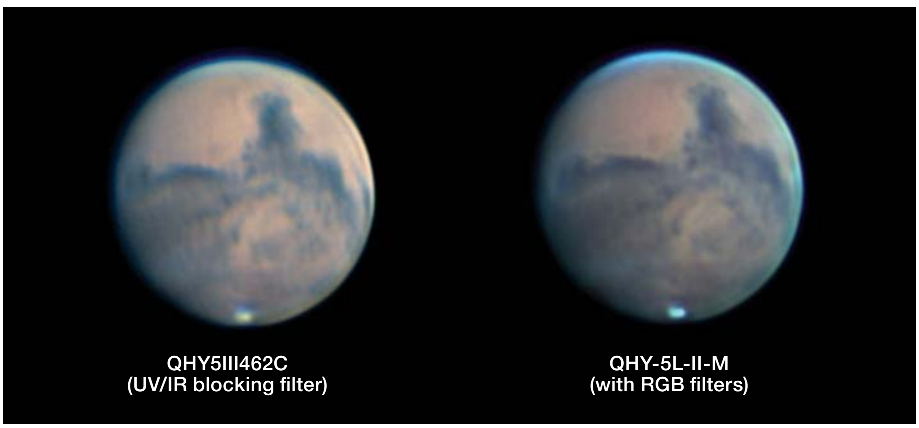
The QHY5III462C uses a Bayer matrix of color filters over the individual pixels to produce a color image. In practice, this means the pixels are divided into three interwoven "grids." A quarter of the pixels have red filters over them, another quarter have blue filters, and the remaining half have green filters. Software separates the image data into the respective colors then fills in the checkerboard-like gaps in each channel to create the final color image, in a process known as *interpolation*. This action produces slightly less spatial resolution compared to an image created with a monochrome sensor used with individual color filters. Thankfully, modern interpolation algorithms make the differences between the two arangements inconsequential.

One advantage a high-speed, one-shot-color video camera has over a monochrome sensor used with color filters is that the recorded video sequences require about one-third less storage space than the tri-color method. The QHY5III462C actually produces monochrome video files that don't become color until processed. And while the camera can record "debayered" video, data captured this way reduces the overall frame rate because it is attempting to download 3× more information than with the raw video.

The Sony sensor in the QHY5III462C is different than most others in that it uses organic dye filters that are claimed to be very efficient at transmitting visible wavelengths and are completely transparent at near-infrared wavelengths. QHYCCD lets you take advantage of this unique characteristic by including both the UV/IR blocking filter and an 850-nanometer near-infrared pass filter. When imaging through the UV/IR filter, you get a natural color image.

With the infrared filter in place, it blocks visible wavelengths while transmitting only wavelengths higher than 850 nm. The resulting video image appears monochromatic due to the transparency of the filters at these longer wavelengths, permitting users to record near-infrared data that don't require interpolation when stacking the results. This makes the camera especially useful for planetary imagers interested in recording observations beyond the visible spectrum. It also helps when imaging through poor seeing, as longer wave-

▲ The camera fits directly into any 1¼-inch-format focuser and includes a parfocalizing ring that lets you set the camera to approximately the same focus point as the eyepiece you use to center your target. The round port on the rear of the camera accepts the autoguiding cable that connects to your mount, allowing the camera to also be employed as a very sensitive autoguider. In fact, the camera's near-IR sensitivity makes it particularly well-suited for use in Innovations Foresight's ONAG on-axis guiding system (**innovationsforesight.com**).



▶ *Top:* The image at left taken with the QHY5III462C is virtually indistinguishable from the results achieved at right with a monochrome QHY 5-L-II-M camera and color filters. Mars was 18.6 arcseconds when the author recorded it through a 12.5-inch reflector on the evening of November 9, 2020.

▶ *Bottom left:* While images captured with the QHY5III462C were highly detailed, colors tended to be muted compared to images recorded with a monochrome camera and a set of color filters. Boosting the saturation level in post-processing software by about 25% corrected the discrepancy.

▶ *Bottom right:* When the included IR850 filter is employed, images appeared monochrome and don't require debayer interpolation during post-processing.

lengths are less affected by atmospheric turbulence than shorter ones.

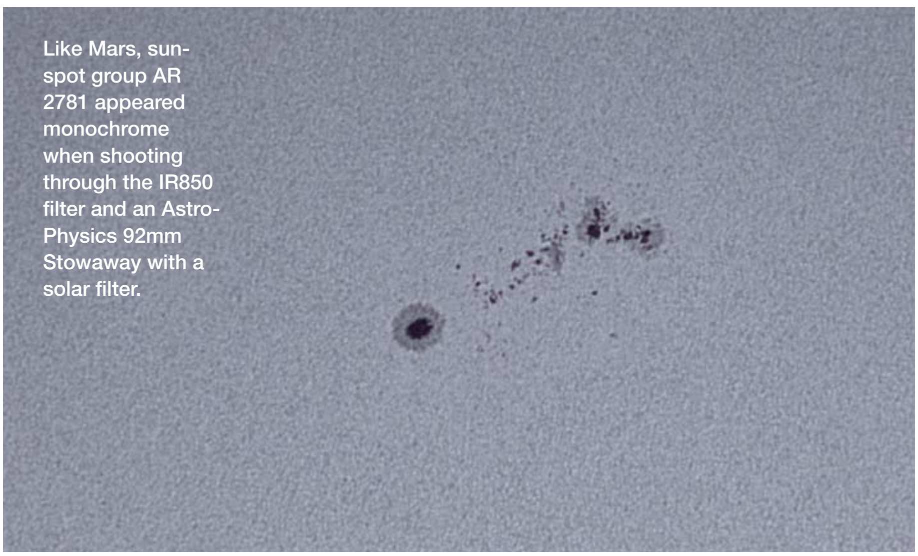
As for speed, this little camera has it — and lots of it. Through its USB 3.0 interface, the QHY5III462C can transfer an eye-popping 135 full-resolution frames per second, and at even faster speeds when using a smaller region-of-interest (ROI) crop of the sensor, meaning the camera only downloads the area specified in your control software. This translates into a lot of frames in a very short amount of time — sometimes on the order of several hundred per second! This is a crucial advantage because all planets rotate, and some (Jupiter and Saturn) do so at such a fast rate that you need to limit video recordings to roughly a minute at a time to avoid smearing fine details. Still, you'll need to make sure your control computer has a very fast hard-drive write speed.

QHYCCD provides a link to download the camera drivers and *SharpCap* control software from its website. Both the drivers and software installed on my PC laptop without a hitch. *SharpCap* gives adequate camera control, though I preferred to operate the camera with the third-party free program *FireCapture* (**firecapture.de**) a robust program written for dedicated planetary astrophotographers. The camera outputs several file formats, including AVI and SER video, as well as individual FIT, TIF, PNG, or JPG frames, all of which are compatible with most popular image-stacking programs, including *RegiStax 6* and *Autostakkert!3*.

At the Telescope

I used the QHY5III462C in late 2020 when Mars was just past opposition and dominating the evening sky. My 12.5-inch f/5.1 Newtonian reflector fitted with a Tele Vue 4× Powermate allowed me to achieve an adequate image scale, thanks to the camera's very small 2.9-micron pixels, which make this easier than with cameras having larger pixels. I also compared my results to images shot with an older QHY5L-II-M monochrome camera with color filters. However, the 5L-II-M has slightly larger 3.75-micron pixels and captures at a much slower rate through its USB 2.0 interface.

Even at f/21, Mars isn't very large, so I usually employed an ROI of 640 × 480 pixels. A 1-minute video typically resulted in a whopping 14,820 frames recorded, with an average of 246 frames per second, compared with the 135-fps limit when using the whole sensor. Impressive! Although a filter wheel isn't typically necessary when imaging with a color camera, I added the UV/IR blocking and IR850 filters to my 5-position filter wheel to quickly swap between the two. The results were just as advertised — the image through the IR850 filter on screen was essentially black-and-white, and the video frames didn't require interpolation when stacking.



Like Mars, sunspot group AR 2781 appeared monochrome when shooting through the IR850 filter and an Astro-Physics 92mm Stowaway with a solar filter.

▲ The expansion kit for the QHY5III462C includes a replacement window with UV/IR blocking, a 2.5-mm f/1.5 all-sky lens, and a 1¼-inch 890-nm CH_4 (methane) filter, which is useful for recording deeper features within Jupiter's atmosphere.

When compared to images taken through the older monochrome camera equipped with color filters, the QHY5III462C resolved the same level of detail as the 5L-II-M camera. The only noticeable difference was that the color was markedly muted when compared to the filtered monochrome results. Boosting the saturation level by about 25% in Adobe Photoshop made the results virtually indistinguishable, as the comparison on page 31 shows. This was the case with all the objects I targeted.

Since the QHY5III462C is geared towards producing high-resolution images of the planets, its 1,920 × 1,080-pixel-array doesn't provide enough coverage to record the entire Moon (or Sun, through a safe solar filter) in a single frame with anything larger than a 300-mm lens. But the camera does take excellent high-resolution close-ups of crater fields in any telescope, and users can easily produce high-resolution mosaics of the entire Moon with a little planning. I was impressed with the results I got when targeting the Moon with a 92-mm Astro-Physics Stowaway refractor on cold January nights. The camera had no problem achieving its stated 135 frames per second maximum output when imaging the Moon at f/25.

I also targeted the Sun through the refractor equipped with a Herschel Wedge and the IR850 filter to capture satisfying views of sunspot group

▲ When paired together with the expansion kit's UV/IR-blocking window and 2.5-mm lens, the QHY5III462C makes a very capable all-sky camera that can be employed to monitor sky conditions from indoors or to capture meteors.

AR 2781 in early November 2020. Much like the experience shooting Mars, images through the near-infrared filter and Herschel Wedge were sharp and showed fine details, such as solar granularity on the photosphere.

Additional Accessories

I had hoped to try out the additional 890-nanometer Methane (CH_4) filter included with the camera. This filter is used to record features deeper within the atmosphere of Jupiter (and to a lesser extent Saturn, Uranus, and Neptune), though typically it requires long exposures with other popular cameras.

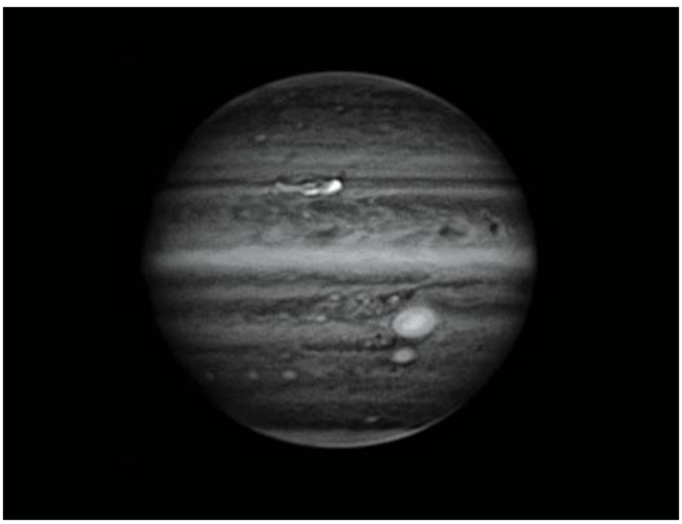
At the time of this review, Jupiter and Saturn were both too far past opposition to target from my observing site in New Hampshire, but expert planetary imager Christopher Go has used this camera and filter combination with excellent results from his site in the Philippines. As Go notes, the camera and CH_4 filter provide more than 3× the brightness of other camera/filter combinations currently on the market. This translates into a brighter image, which in turn reduces the exposure length needed to adequately record methane features in Jupiter's atmosphere (see image at bottom left).

The blocking filter window combined with the 2.5-mm wide-angle (though not quite all-sky) lens lets users monitor sky conditions at a remote facility, or even capture aurorae and meteors. The lens is easy to focus, and the setup worked well when controlled with the included *SharpCap* software. The camera is limited to exposures of up to 900 seconds (15 minutes), but in practice users will never need more than a few seconds exposure in all-sky mode.

The QHY5III462C planetary camera is an excellent device that I found to be much more versatile than typical color planetary cameras. Its extended red sensitivity makes it an excellent choice for planetary enthusiasts with a particular interest in monitoring Jupiter and the other gas giants. The addition of both a UV/IR blocker as well as a near-IR filter further extends the camera's usefulness to attract the attention of planetary imagers like myself who typically use monochrome cameras and color filters.

■ Associate Editor **SEAN WALKER** sometimes laments living so far north when the planets are often so far south on the ecliptic.

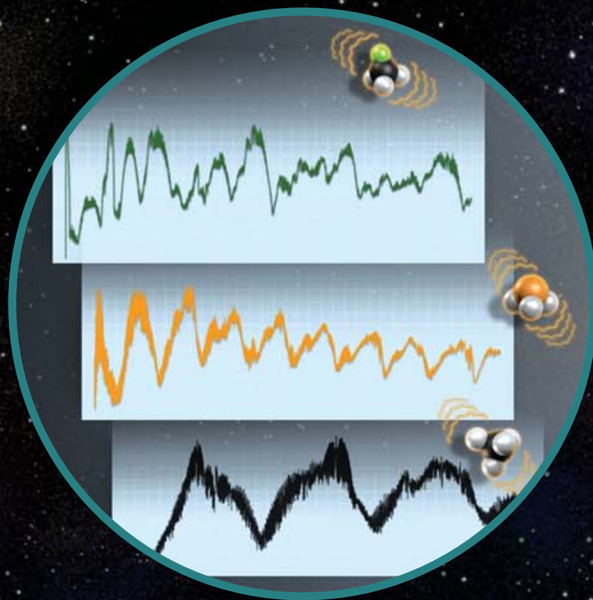
▼ *Left:* The extended near-IR sensitivity of the QHY5III462C becomes apparent when imaging Jupiter at 889 nanometers, where regions beneath the planet's upper cloud layer appear bright. Exposures of a fraction of a second are possible with this combination, whereas exposures with other cameras typically measure a second or more — a notable disadvantage under less-than-perfect skies. *Right:* While primarily intended for imaging the planets, the QHY5III462C is capable of producing excellent close-ups of lunar craters.



METHANE JUPITER: CHRISTOPHER GO

Building a Better Biosignature

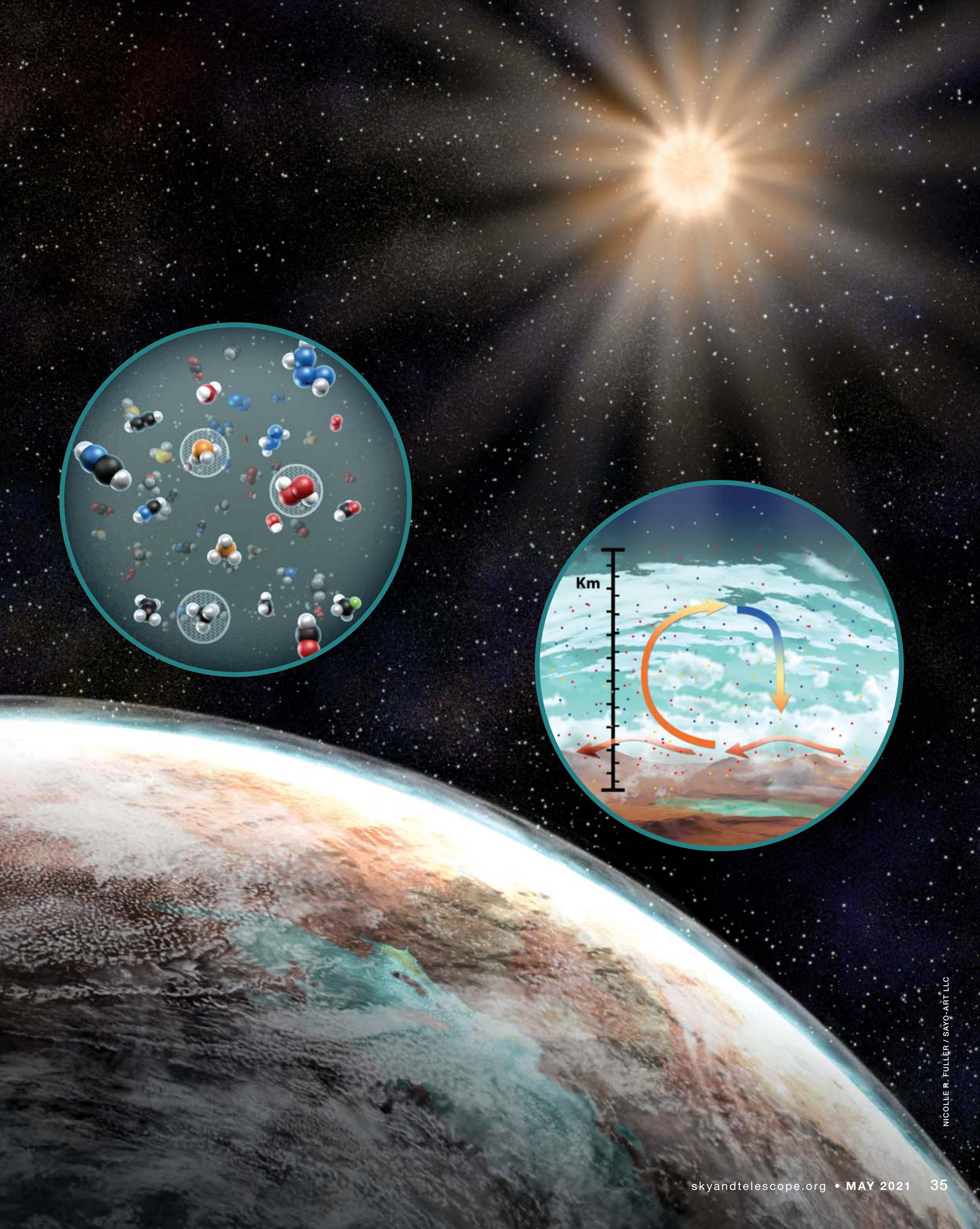
Finding signs of alien life requires more prep work than you might think.



Every genre has its tropes, and science fiction is no exception. Stories set in space often center around the discovery of strange new worlds, and the narrative tradition in these situations usually demands that someone "scan for signs of life." It's quite simple, really: An order is given, a touchscreen touched, and an answer promptly received.

If you've ever wondered at this fictive sleight-of-hand, and whether such remote sensing is even possible, you're in good company. Astrobiologists all across the world are laboring to transform this pretend practice into a real science. We are a long way from, "Alexa, check for life signs on Kepler-186f." But someday, we may know enough about the clues life creates to estimate what portion of our galaxy's terrestrial worlds, if any, are life-bearing.

The key for remote sensing is *biosignatures*. A biosignature is something — whether a substance, a pattern, or even an object — that (probably) had to be made by life in order to exist. It is not life itself, but something made by life, a kind of fingerprint.



NICOLLE R. FULLER / SAYO-ART LLC

In looking for biosignatures on distant worlds, astrobiologists are mostly focusing at the moment on chemical compounds in a planet's atmosphere. Find the right molecules in the proper context, and it could be circumstantial evidence for life.

But to get to this point, astrobiologists must first construct a methodology for identifying reliable, resilient, and detectable biosignatures. That might sound boring, but it's crucial: We can't find life's fingerprints if we don't know what to look for or how to interpret it once we find it. Hints of methane on Mars (*S&T:* Jul. 2019, p. 9) and the recent tentative detection of phosphine in the clouds of Venus (*S&T:* Mar. 2021, p. 9) remain contentious in part because we don't fully understand what could create these signals. As exciting as it is to reach out into the solar system and the galaxy, the work of understanding what we find begins back here on Earth, with fundamental research in three fields: quantum chemistry, molecular biology, and atmospheric science.

A Work in Progress

There are probably plenty of exo-Earth candidates in our line of sight. And the next generation of instruments will give us unprecedented views of these worlds' atmospheres. But before we get too excited about any potential biosignatures, we need a better understanding of the basic nature and behavior of molecules under a wide range of temperatures. This is the purview of quantum chemistry, the first pillar of the biosignature framework. Scientists do this work both in the lab and computationally.

Biology is the next pillar. Specifically, we need to know all the gases that all the various lifeforms on Earth produce. There are a few groups tackling this monumental task, utilizing both analog methods (graduate students) and machine learning to scroll through a vast agglomeration of scientific literature and compile useful databases.

Then comes atmospheric science, which takes a litany of chemical information from the above-mentioned efforts and

Key Constituents of Earth's Atmosphere, Relative Abundances

Molecule	Ground-truth Earth	Galileo Value	Thermodynamic Equilibrium
N_2	0.78	--	0.78
O_2	0.21	0.19 +/- 0.05	0.21 (ignoring the crust's under-oxidized state)
H_2O	0.03-0.001	0.01-0.001	0.03-0.001
CH_4	1.6×10^{-6}	$3 \pm 1.5 \times 10^{-6}$	$<10^{-35}$

▲ **TOO MUCH METHANE** These data from a 1993 paper by Carl Sagan and others highlight the disparity between the methane level expected in a steady-state atmosphere and that found in Earth's atmosphere. Methane should not survive more than a decade or so in our oxygen-rich atmosphere without being replaced, they noted.

EXO-EARTHS
Based on Kepler data, astronomers estimate that there should be four rocky planets in the habitable zones around *G* and *K* dwarfs within 30 light-years of the Sun.

plugs it into a computer code that simulates how everything would behave in a planetary context. This allows scientists to model gases' abiotic production, abundances, lifetimes, movements, and altitudes.

The first time these specialties were brought together to look for signs of life from space, the effort was a stunning success. The year was 1990, the spacecraft was NASA's Galileo, and the planet, Earth. (We'd stacked the deck.) At a distance of about 1,000 kilometers (600 miles), Galileo detected an unstable combination of methane and oxygen in our atmosphere, which researchers interpret as one of Earth's particular life signs. A similar chemical cocktail on another world might also be a biomarker.

But 30 years later, astronomers are still trying to understand the total context and composition of Earth's biosphere, both in the present and throughout geologic time — and then use that to aid in the search for life elsewhere.

"It's not just about finding liquid water, or oxygen, or even methane and oxygen together," Sarah Rugheimer (Oxford University, UK) says. "There's the whole planet to consider, and with that comes so much potential for false positives. On top of all this is the fact that we don't really understand exotic chemistry very well, which I think is what Venus is showing us."

Venus has taken center stage in the biosignatures hunt thanks to the 2020 announcement by Jane Greaves (Cardiff University, UK) and others that there's phosphine in the cool cloud deck of our sister planet. On Earth, phosphorus and hydrogen don't tend to get together to make phosphine unless life forces their hand. On Jupiter and Saturn, the chemical forms thanks to the extremely hot, high-pressure environments deep below. But the conditions on our planet's evil twin are nothing like those distant cousins, the gas giants. So, could phosphine form on Venus abiotically? We don't know yet because, until recently, we had no reason to find out.

Quantum Chemistry, Lab Edition

There is a bias in exoplanet data towards very hot worlds — worlds like WASP-79b, a gas giant where the clouds are 1500°C (2700°F). This is because both of the most successful detection techniques used by astronomers (radial velocity and transit) tend to find planets very close to their stars.

The transit method allows us to observe the way the starlight changes when the planet passes in front of its host. The specific wavelengths that the planet's atmosphere absorbs give us information about the chemicals therein. But interpreting these data has proven difficult.

"Historically, almost all the databases for absorption spectroscopy are confined to room temperatures and pressures," says engineer Christopher Strand (Stanford). "This is because the main driver of previous research was atmospheric studies of Earth."

Stanford's High Temperature Gasdynamics Laboratory hopes to rectify this gap in our knowledge. Typically, it does research for the aerospace industry. But the group's facilities turned out to be perfect for replicating and studying high-temperature exoplanet atmospheres, Strand says.

One important piece of equipment is *shock tubes*. A shock tube is a long steel pipe — between about 8 and 61 meters (25 and 200 feet), depending on the facility — that is divided into sections and capped at both ends. A thin diaphragm separates the sections. One side is pressurized to the point that the diaphragm ruptures. When that happens, a shock wave forms and travels down the tube to the low-pressure gas at the other end, compressing and heating it. Lasers then shoot through the compressed gas, and the gas molecules absorb some of the light. How strongly the gas absorbs photons of different wavelengths depends first on the molecules' structures and second on the gas's temperature, pressure, and composition.

Such experiments provide ground-truth tests for theoretical predictions of spectra, derived from complex adaptive algorithms. "There are groups that are simulating billions upon billions of [spectral] lines ab initio," Strand says. "And this is very useful. But are these calculations correct? I know from experience that low-temperature models do not accurately reflect what actually happens at high temperatures."

Astronomers are still trying to understand the total context and composition of Earth's biosphere.

Still, although lab experiments are a common-sense way to discover where our assumptions fail, charting the vast number of possible reactions between all the molecules in existence at every temperature and pressure is impossible. Safety is one problem. Phosphine, for example, is highly toxic and dangerous to work with. Funding is another problem. This is why the majority of our spectral information is predicted with machine learning instead.

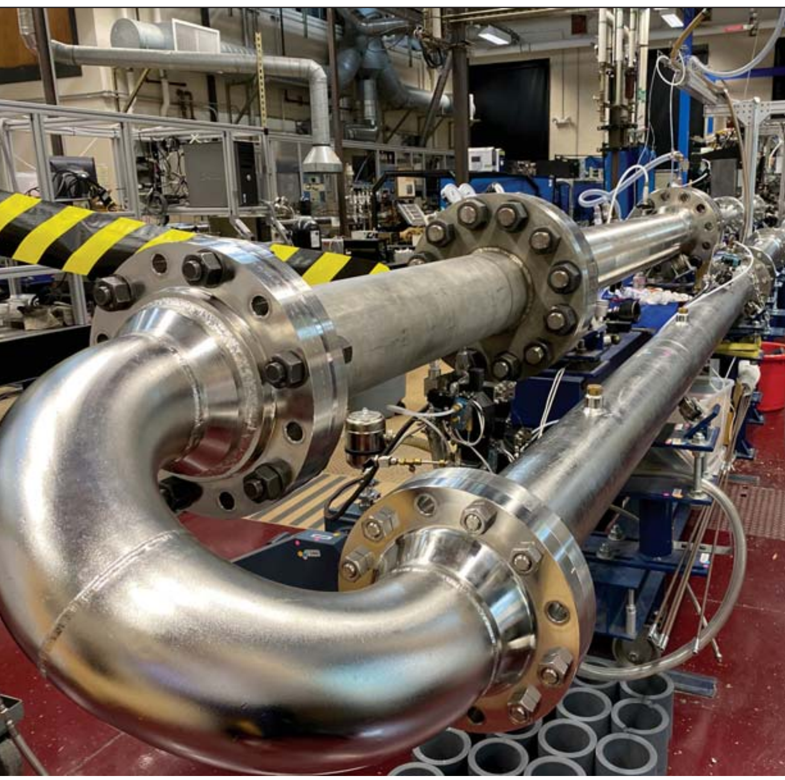
Quantum Chemistry, Office Edition

One such project, ExoMol at University College London, has produced data on more than 80 simple molecules since 2011. Headed up by Jonathan Tennyson and Sergey Yurchenko, the group's aim is to create highly descriptive, open-source listings of all the important molecules and their spectra that astronomers might see on extrasolar planets and cool stars.

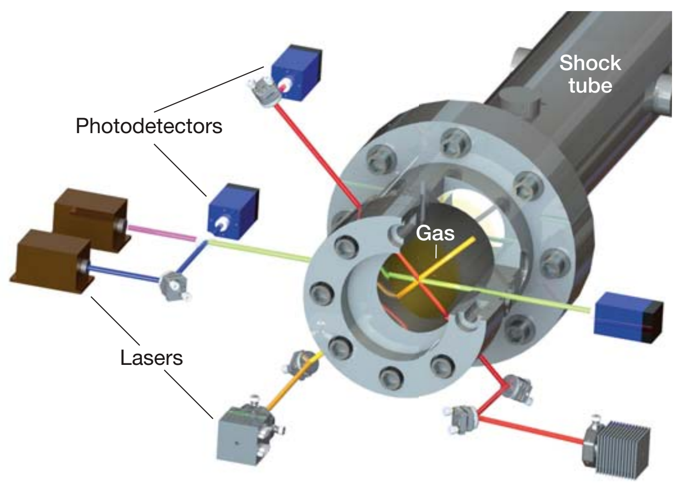
"We use existing experimental data to compute from what we call first principles," Yurchenko says. "We try to describe a molecule's motion, and then eventually, conclusions can be drawn about spectroscopy."

The best understood molecules, the ones with the most accurate and trustworthy data, are those that are simple and common on Earth — things like water, oxygen, carbon diox-

LAB: CHRISTOPHER STRAND



◀▼ **SHOCK TUBE** *Left:* The longest shock tube in Stanford's High Temperature Gasdynamics Lab curls around itself to fit its 23.2-meter (75.6-ft) length into the lab. Near the camera is the high-pressure section. At the far end is the optical table with lasers that pass through the gas. *Below:* This schematic by Stanford graduate student Nico Pinkowski shows the laser setup. Semiconductor lasers (gray and brown boxes) each send a beam of a specific infrared wavelength through optical ports in the shock tube. High-speed infrared photodetectors (blue boxes) determine how much of each beam the gas absorbs. From these measurements, researchers infer the gas's absorption properties.



ide, and methane. They have the longest, most comprehensive experimental record, and their biosignature potentials are relatively well understood.

When it comes to expanding beyond these molecules, most astrobiology research leans on *extremophiles* as aliens-by-proxy. Extremophiles are microorganisms that live in conditions deadly to "normal" lifeforms — environments with extreme temperatures, chemical concentrations, or pH levels. One example is anaerobes, which either don't need oxygen or would die if it's present. Venus's atmosphere has very little free oxygen, so any life there would be anaerobic. Phosphine is a byproduct of anaerobic bacteria here on Earth. And as scientists know of no abiotic production method for phosphine on rocky worlds, it is potentially a very good biosignature.

Clara Sousa-Silva (now Center for Astrophysics, Harvard & Smithsonian), one of the researchers on the phosphine study, completed her PhD at UCL. While working for ExoMol, she built a template of more than 16 billion different spectral permutations for phosphine, each of which could be a signal a telescope might pick up, depending on the planet's conditions. The uncertainties about our neighbor's atmosphere are huge, however. If you shift the gas content, mixing, and altitude of the models just a tiny bit, one chemical fingerprint starts to look very much like another. This is one of the reasons other researchers suspect the group actually detected something else in Venus's clouds, perhaps sulfur dioxide.

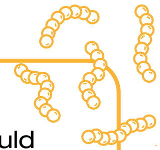
It's All About the Gas

The All Small Molecules project (ASM) at MIT is a database of more than 16,000 molecules meant to guide research on biosignature gases. Sara Seager started it in the early 2010s with William Bains and Janusz Petkowski, and they published the list in 2015. The project was a tacit admission that until we have full workups on all the small molecules produced by life, we do not have even the most basic foundational knowledge with which to gauge whether a particular detection is a biosignature or not. So they set out to organize what *is* known into a kind of Webster's Dictionary for astrobiologists.

"Life on Earth produces thousands upon thousands of different volatile gases," Petkowski says. "So, what we tried to do with ASM is to come up with an exhaustive list of all these gases, which then could be assessed in terms of their biosignature potential."

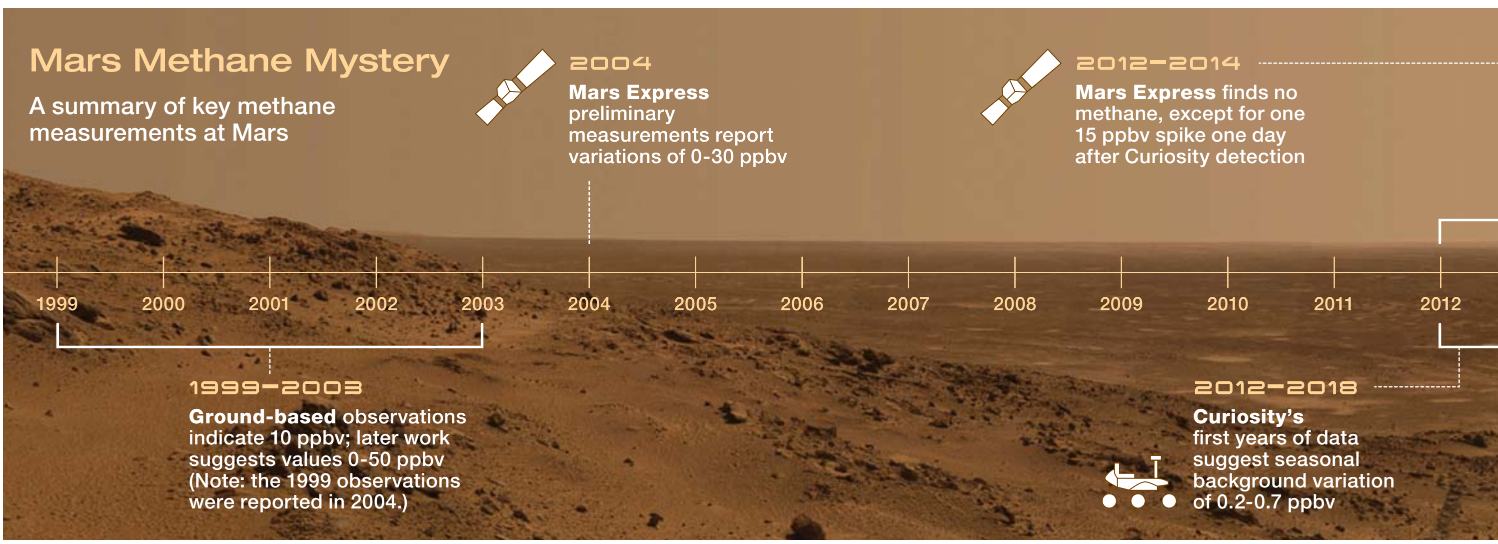
Unlike ExoMol, which produces spectral information that is generally useful to astronomy, the ASM database was built explicitly to aid in the search for extraterrestrial life. Most of the information it contains was not created by the team but collected by trawling existing literature. Certain large gaps in our knowledge have emerged, such as microbial byproducts. It turns out that biologists don't do a lot of fundamental research into trace gases produced by microbes unless they pose a threat to human life. This is how we know about the bacteria that produce phosphine: The toxic gas was popping up in water treatment and sewage plants, and people wanted to know why.

An offshoot project called RASCALL (Rapid Approximate Spectral Calculations for All) aims to take this work a step further and obtain spectra for all of the ASM molecules. This contribution will still not be as good as a laboratory measurement, like what Stanford's Gasdynamics Lab does, or a full ab initio quantum chemical calculation, like what ExoMol does. But that's okay. RASCALL and ASM are not trying to create knowledge, but rather to collect what is already known into a



ANAEROBES

Organisms that don't need oxygen or would die in its presence might sound alien, but these anaerobic organisms are more common on Earth than you might think. Examples include *E. coli* and *Vibrio cholerae* (which causes cholera). They're also widespread in your mouth and lower gastrointestinal tract.



ANAEROBES: OLEKSANDR PANASOVSKYI / THE NOUN PROJECT; TIMELINE: TERRI DUBÉ / S&T; SOURCE: ESA; MARS LANDSCAPE: NASA / JPL / CORNELL useful reference for the community.

"Our database is a tool for modeling planetary atmospheres," Petkowski says. "Volatile gases react with other atmospheric components. Some will not be detectable, because they will be destroyed by atmospheric radicals and UV. Our goal was to find if there are groups of gases that are better candidates to be remotely detected than others. The creation of this database is just the first step on that road."

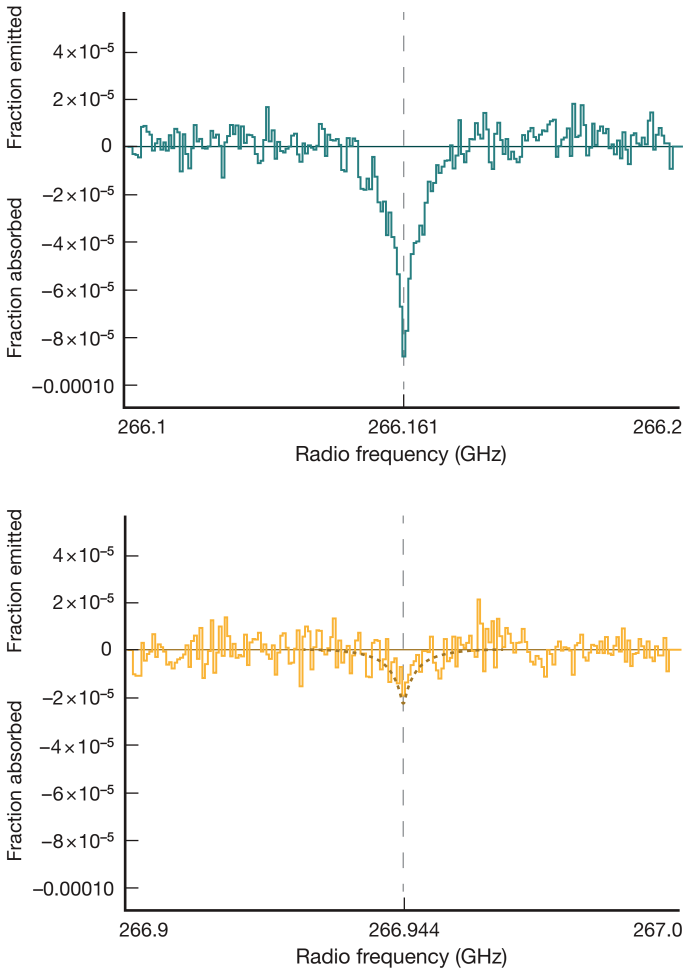
Cloudy with a Chance of Phosphine

The third pillar of the biosignature framework is atmospheric science, a broad and highly computational specialty that looks at the physics, chemistry, and dynamics of planetary atmospheres. Scientists build environmental simulations starting with physical and chemical rules, then input observations and other facts about the world in question. Then they "press go" and watch what happens to their toy planet. Do the results align with the real world, or does everything fall apart?

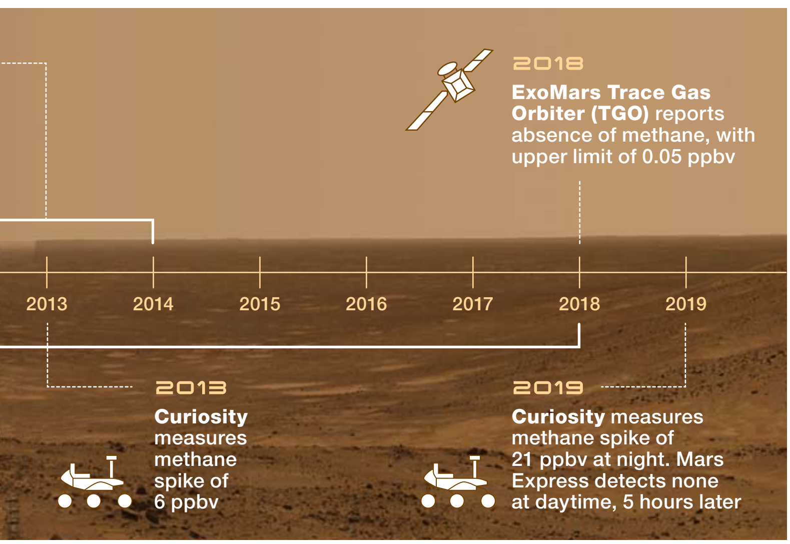
Through a process of trial and error, these simulations help us to understand both local phenomena like weather and even global phenomena, such as the lifetime of methane and oxygen in Earth's atmosphere. Models that focus on chemistry allow scientists to make predictions about what might be causing unexpected gas emissions. But even a detection of methane and oxygen in thermodynamic disequilibrium on a rocky world in a star's habitable zone wouldn't necessarily "prove" anything. After all, there might be completely abiotic ways to produce this that we are unaware of.

Sukrit Ranjan (now at Northwestern University) had the task of figuring out how well phosphine could survive in Venus's hot and acidic atmosphere. First, he took everything known about Venus's surface, subsurface, and atmospheric composition (which is far from complete). He then introduced disruptive simulations of things like volcanic eruptions and meteorite impacts to the model. In theory, these events could create phosphine. But they didn't make enough.

GREGG DINDERMAN / S&T, SOURCE: J. GREAVES ET AL. / ARXIV 2011.08176



▲ **A SIGN OF PHOSPHINE?** These plots are two narrow slices of Venus's spectrum, taken by ALMA and fixed from an earlier version. Jane Greaves and her team took targeted observations of Venus at multiple frequencies, one centered where they would expect to see absorption from phosphine *(bottom)*, and another where they should see the more familiar signal of the water isotope HDO *(top)*. The observed bands were too narrow to include many other molecules, but the absorption features (dips at centers of plots) appeared right where expected for both molecules. Finding HDO's absorption line where they expected it gives the researchers confidence that they're correctly identifying PH_3. The PH_3 line also matched the predicted phosphine spectrum (dotted line), calculated from lab measurements and scaled to the conditions in Venus's atmosphere. The V-shape for both absorption features is spreading caused by the molecules' motion in the planet's atmosphere.



"We tried to see if abiotic mechanisms could explain the presence of phosphine at the inferred abundances," Ranjan says. "But we couldn't account for it."

The phosphine detection itself is tentative, and a recent fix of the primary data out of ALMA has reduced astronomers' confidence in the observation. But even if future in situ observations verify the sighting, this doesn't mean we've discovered alien life.

The phosphine debate may have a similarly drawn-out fate as methane on Mars. Methane is easily destroyed by sunlight and should be fairly short-lived on the Red Planet. Astronomers reported in the early 2000s they'd detected the molecule there, and the Curiosity rover has caught seasonal whiffs on the surface. But more than a decade after the first detection, the highly sensitive ExoMars Trace Gas Orbiter found nothing in the upper atmosphere, inciting intense debate.

The uncertain fate of biosignatures discovered right next door doesn't bode well for finding clear-cut biosignatures on exoplanets, which will suffer from much poorer and more ambiguous data and have no possibility for validation by a spacecraft visit.

A Footprint Doesn't Look Like a Boot

There are two main criticisms of remote biosignature detection research. The first criticism concerns the prevailing method. Simple molecules are easy to make. Even if we are building a framework for detection, wherein all the context of a world and multiple gases are laid out in inexplicable disequilibrium, a certain disconnect remains. Life is ultimately distinguished by its processes, not its products. So the question arises: Mightn't we focus on ways of detecting *complexity*, whether in essence or in action? Lee Cronin (University of Glasgow, UK) thinks so.

"Simple molecules can be good hints if they can be linked with a life-like process," Cronin said. "But we need a way to detect, just for example, complex molecules remotely that could not have formed on their own. Only when we can detect molecules that have high information content can we say that we have detected life unambiguously."

The remote observation of more concrete biomarkers such as complex molecules, cellular structures, stable isotope patterns, and surface evidence, is beyond our current technical abilities. These may very well be the way alien life is ultimately found. In the meantime, we are left to infer life from small molecules.

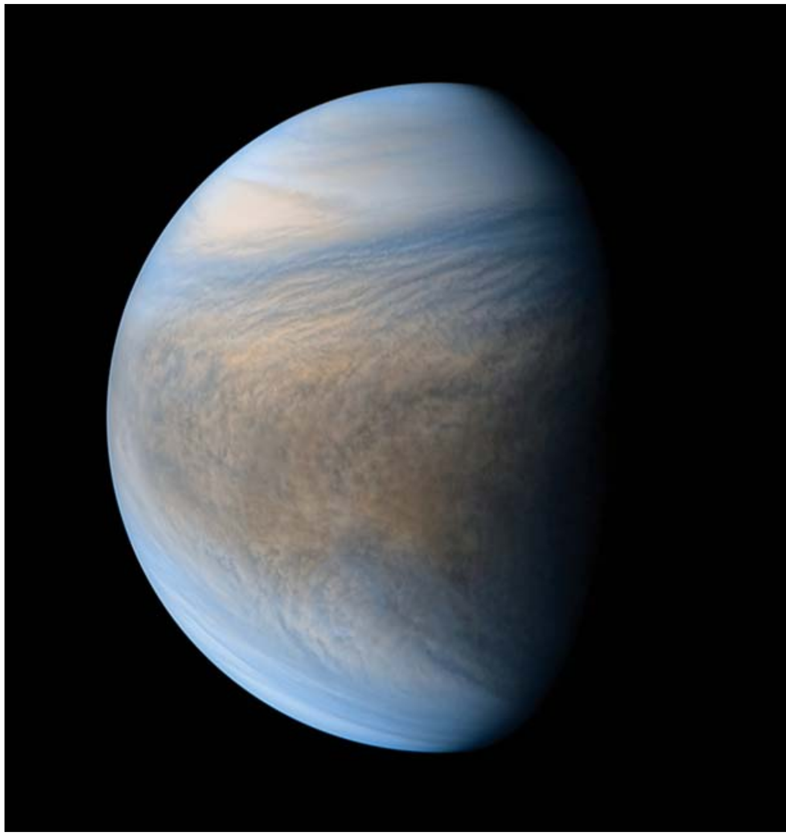
But there is reason to hope for answers from this method. Eventually. Assuming all the next-gen telescopes work, and the community cracks on with building a good framework for remote detections, a new field will soon arise: comparative exoplanet science.

"For now, we are only capable of detecting atmospheric features of various gases, like, for example, water on gas giants," Petkowski says. "If we can get enough data on rocky planets, then maybe we will be able to actually see a trend! Like, for example, how many contain carbon dioxide in their atmospheres? How many of them actually contain oxygen?"

The second criticism of remote-sensing efforts is a more philosophical one: All these wonderful worlds are out of reach. Even if we did detect oxygen on an Earth-twin in the liquid-water zone of a main-sequence star, we may never be able to know for certain whether it harbors life. So what is the point, then, of finding an exo-Earth if we can never go there? What is the point of having statistical evidence of alien life that we can never be certain of?

This critique gets to the heart of human nature. We want to *know*. One of the big mysteries in astronomy is whether Earth is unique, ordinary, or somewhere in between. Chances are, this question won't be answered in a "Eureka!" moment. Instead, as biosignature science matures, we will slowly inch towards enlightenment, rocky planet by rocky planet. We will learn how common certain atmospheric compositions are for terrestrial worlds in the habitable zone. And this, not a weird whiff of gas, will probably be the first true hint as to how common life is in the universe.

■ **ARWEN RIMMER** is a freelance writer and musician in Cambridge, England.



▲ **VENUS IN UV** This composite image combines two images from the Japanese Akatsuki orbiter and reveals motions in Venus's atmosphere. Venus is particularly interesting in ultraviolet: A mysterious "UV absorber" in the planet's cloudtops soaks up a wide swath of ultraviolet and visible wavelengths and may even influence wind speeds. Since the UV absorber's discovery several decades ago, some scientists have speculated that it might be an unknown lifeform. Others think it's likely a sulfur-oxygen compound.

ACID CLOUDS

Venus's clouds are approximately 85% sulfuric acid and only 15% water. Droplets there are 100 billion times more acidic than the most acidic environment on Earth.

3 DAWN: Look toward the south-southeast before sunrise to see the last-quarter Moon and Saturn about 6° apart. Jupiter gleams left of the pair.

4 DAWN: The Moon, Jupiter, and Saturn form a wide triangle above the southeastern horizon.

6 MORNING: While the Eta Aquariids are often one of the best showers for the Southern Hemisphere, viewers in the southern U.S. may nevertheless catch some of its meteors before the waning crescent Moon rises a little before 4 a.m. local daylight time.

12 DUSK: Scan low in the west-northwest right after sunset to spot a thin sliver of lunar crescent less than a degree from Venus. You'll need a clear view to the horizon (see page 46 for more). Binoculars will help.

13 DUSK: A more conspicuous lunar crescent now sits about 3° from Mercury. Look toward the west-northwest to catch the pair before they set.

15 DUSK: Higher in the west, watch as the Moon and Mars hang in Gemini shortly after sunset, with around 2° between them.

16 DUSK: Find the waxing crescent Moon, still in Gemini, now some 3° from Pollux.

17 DUSK: The Moon visits Cancer and is positioned around 2° from the Beehive Cluster (M44).

19 DUSK: Look high in the southwest to see the first-quarter Moon in Leo, a bit less than 5° from the Lion's lucida, Regulus.

23 DUSK: As the Moon continues its passage along the ecliptic, this evening finds it in Virgo with some 7° separating it from Spica.

26 DAWN: A total lunar eclipse is visible for parts of the Americas and large swaths of the Pacific; turn to page 48 for details.

26 EVENING: The nearly full Moon rises in the southeast in tandem with Antares, the red giant in Scorpius. They're about 6° apart.

27 DUSK: Look toward the west after sunset to see Mars and Pollux emerge from the gloaming as twilight deepens, and watch as the pair sinks toward the horizon. Planet and star will be within 6° of one another until early June.
— DIANA HANNIKAINEN

▲ NASA's Cassini spacecraft took one last look at Saturn and its rings in September 2017, two days before self-destructing in the planet's atmosphere. Turn to page 58 to read more about the astronomer who inspired the naming of the mission. NASA / JPL-CALTECH / SPACE SCIENCE INSTITUTE

MAY 2021 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart

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

NASA / LRO

MOON PHASES

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

LAST QUARTER

May 3
19:50 UT

NEW MOON

May 11
19:00 UT

FIRST QUARTER

May 19
19:13 UT

FULL MOON

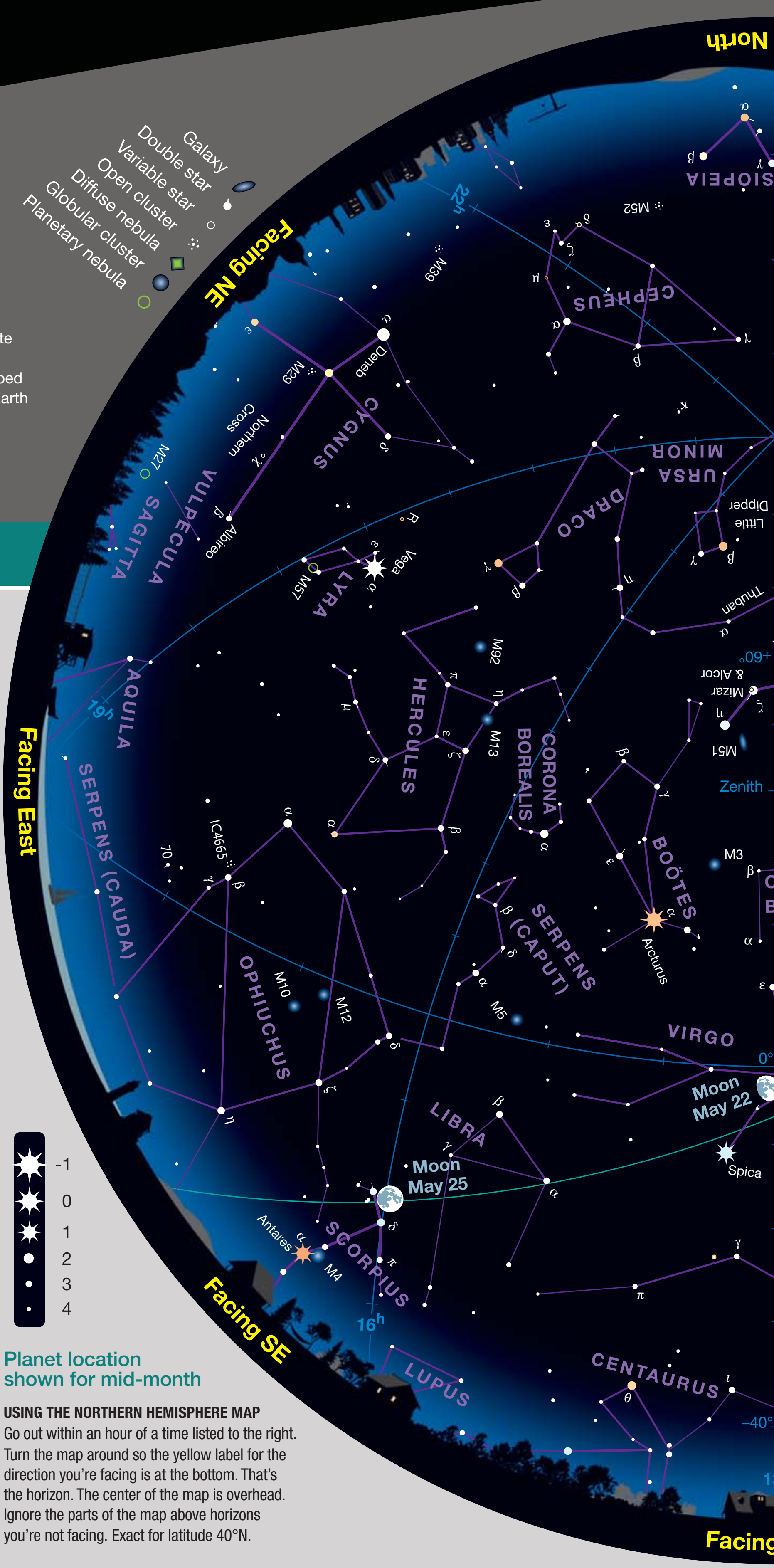
May 26
11:14 UT

DISTANCES

Apogee	May 11, 22ʰ UT
406,512 km	Diameter 29′ 24″
Perigee	May 26, 02ʰ UT
357,312 km	Diameter 33′ 26″

FAVORABLE LIBRATIONS

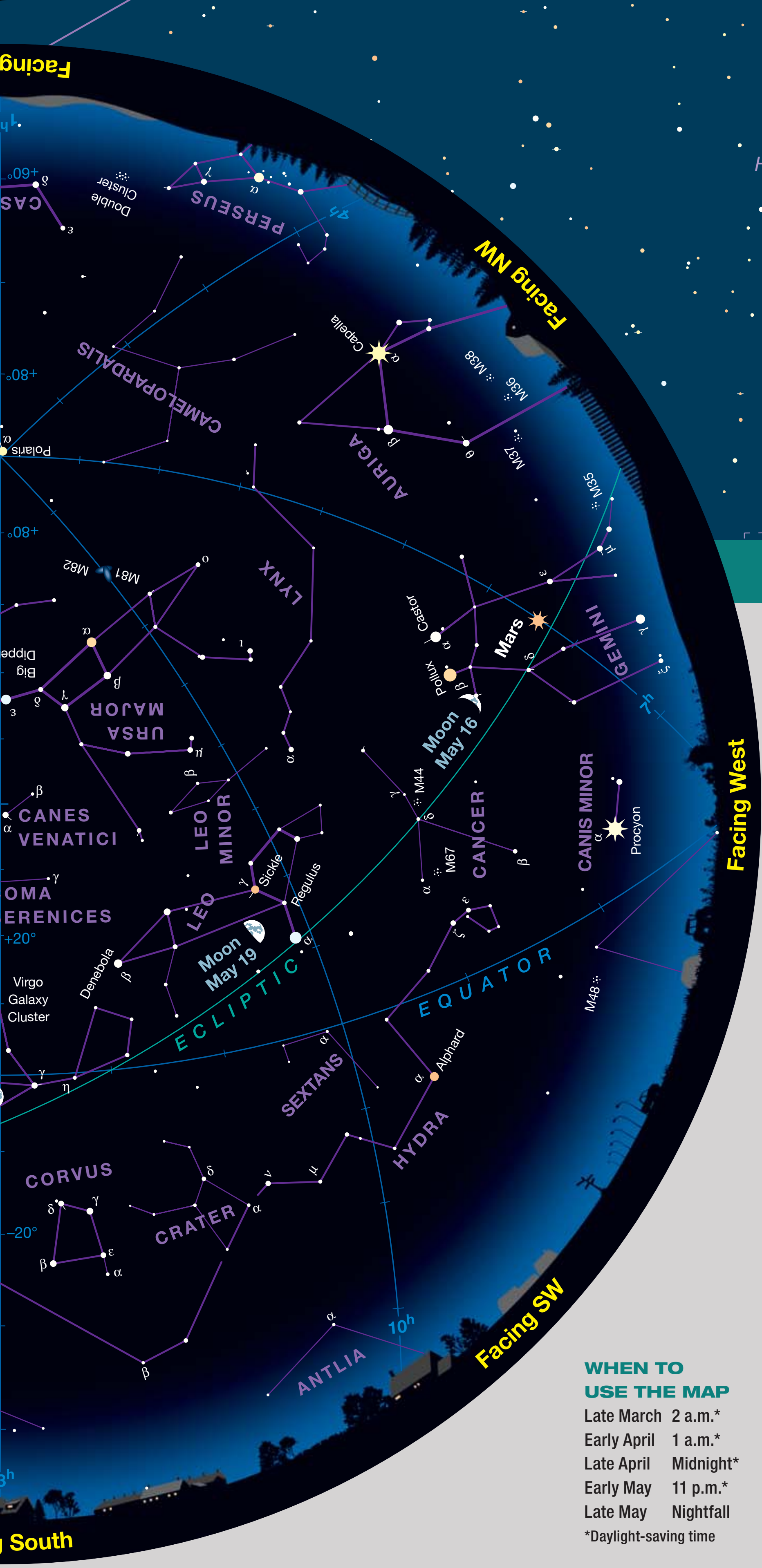
- Phocylides Crater — May 25
- Short Crater — May 26
- Mare Undarum — May 27

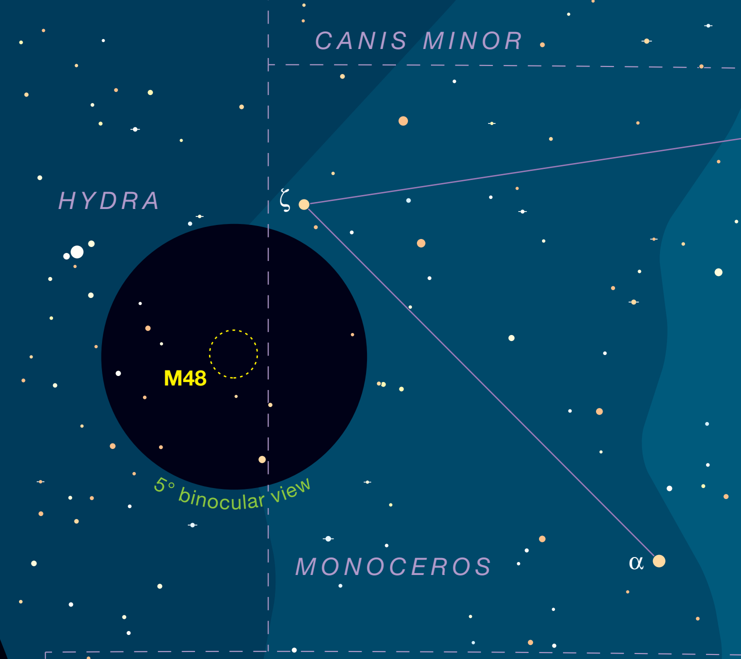


Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

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





Binocular Highlight by Mathew Wedel

Farewell Winter, Hello Future

This is my 60th Binocular Highlight column. I've had this gig for five years now, which is hard to believe. When I first started here, I made a little deal with myself to stay away from the Messier objects as much as possible. I figured that would push me to go find new stuff — and it did! It's been one of the best things about writing this column: I have a professional responsibility to go out often, and to be omnivorous in my observing.

Still, a Messier every now and then is no catastrophe. One of my favorites is **M48**, an open star cluster in the constellation Hydra, the Water Snake. It's a truly breathtaking sight, sprawling across almost a full degree. The cluster is chock-full of stars, but none of them is very bright, mostly 9th and 10th magnitude and dimmer. The stars appear dim because they are so distant, roughly 2,500 light-years from the Sun. A telescope will crack M48 wide open, but I prefer the view in binoculars, when by some alchemy of sky and eye this big fuzzy patch suddenly resolves into a host of tiny points of light.

M48 was the last stop on my very first article for *Sky & Telescope*, a binocular tour of the winter Milky Way in the December 2015 issue. Ever since then I've thought of it as the last herald of winter. Here's a neat observation for this time of year: As Sirius sinks to the west, Vega rises in the northeast, like sentinels trading off at shift change. Summer ushering winter out the door, while spring soars overhead.

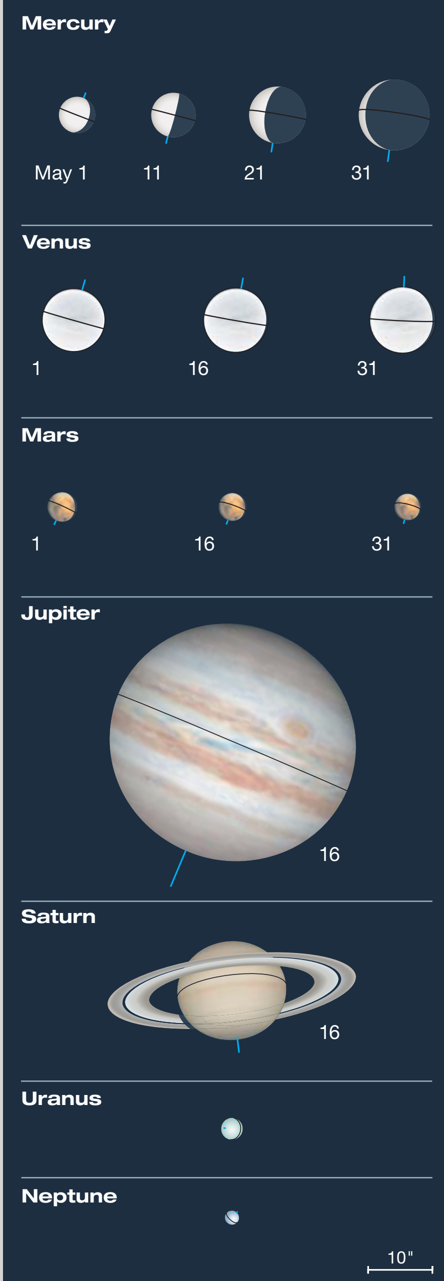
After five years, I thought I'd be farther along. Instead, I feel like I'm just getting started. There's so much left to see. I hope you'll join me on the quest.

■ **MATT WEDEL** estimates that he'll only need a couple more centuries before he can declare his work for this column complete.

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



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

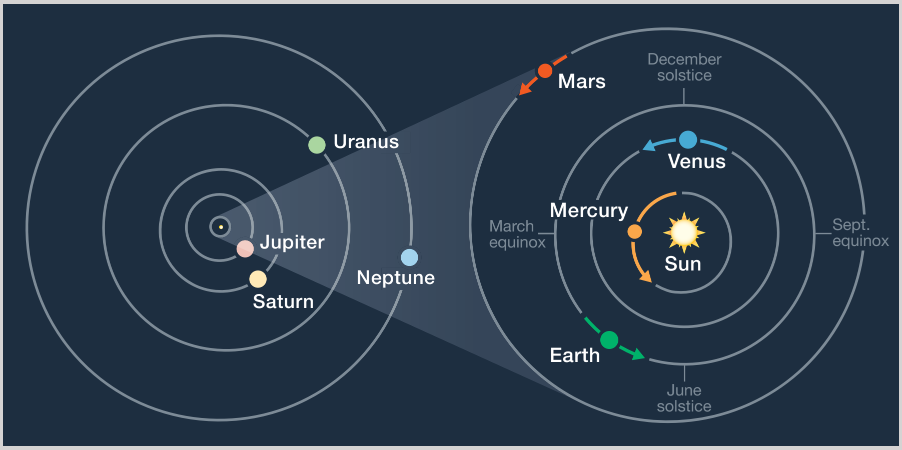
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during May. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** is visible at dusk through the 27th • **Venus** is visible at dusk all month • **Mars** is visible at dusk and sets around midnight • **Jupiter** and **Saturn** rise after midnight and are visible through dawn all month.

May Sun & Planets

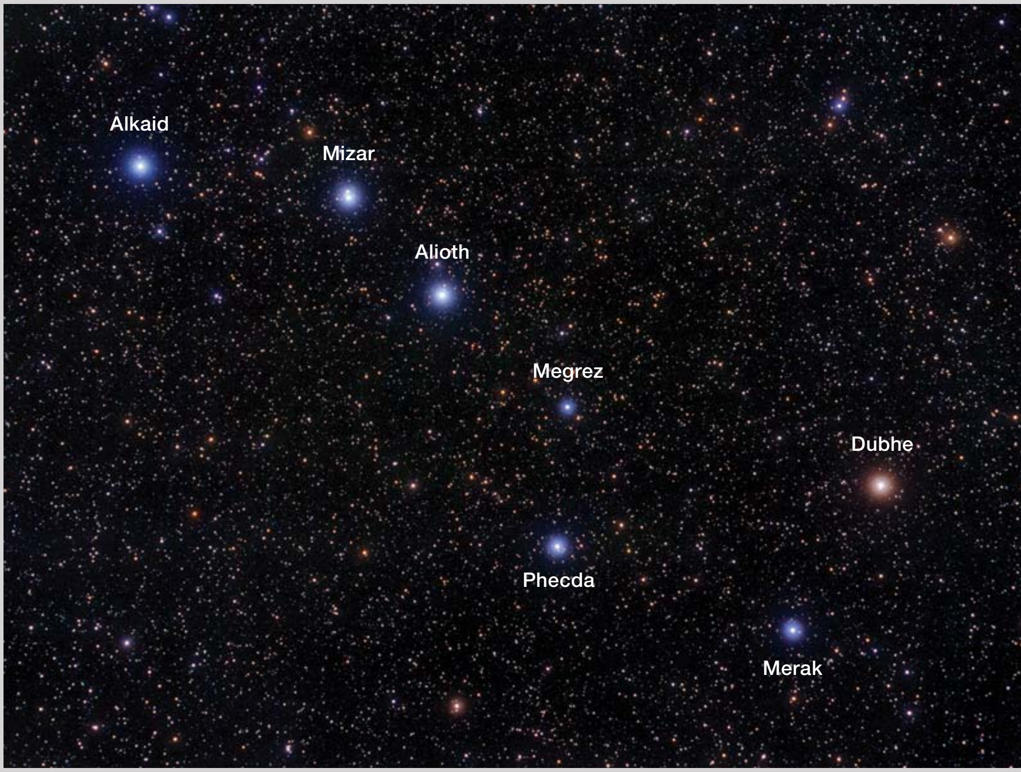
	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	2^h 32.6^m	+14° 59′	—	–26.8	31′ 45″	—	1.008
	31	4^h 31.3^m	+21° 52′	—	–26.8	31′ 33″	—	1.014
Mercury	1	3^h 24.3^m	+20° 10′	13° Ev	–1.1	5.7″	83%	1.188
	11	4^h 35.2^m	+24° 28′	21° Ev	–0.3	6.9″	53%	0.970
	21	5^h 21.6^m	+25° 06′	22° Ev	+0.8	8.8″	28%	0.760
	31	5^h 35.6^m	+23° 14′	15° Ev	+2.8	11.0″	9%	0.610
Venus	1	3^h 09.6^m	+17° 20′	9° Ev	–3.9	9.8″	99%	1.698
	11	3^h 59.9^m	+20° 38′	12° Ev	–3.9	9.9″	98%	1.678
	21	4^h 51.8^m	+22° 59′	14° Ev	–3.9	10.1″	97%	1.653
	31	5^h 45.0^m	+24° 15′	17° Ev	–3.8	10.3″	95%	1.623
Mars	1	6^h 18.8^m	+24° 49′	54° Ev	+1.6	4.6″	93%	2.021
	16	6^h 58.9^m	+24° 10′	48° Ev	+1.7	4.4″	94%	2.138
	31	7^h 38.6^m	+22° 53′	43° Ev	+1.7	4.2″	95%	2.245
Jupiter	1	22^h 02.0^m	–12° 51′	72° Mo	–2.2	37.4″	99%	5.268
	31	22^h 14.3^m	–11° 51′	98° Mo	–2.4	41.1″	99%	4.801
Saturn	1	21^h 01.8^m	–17° 31′	88° Mo	+0.7	16.7″	100%	9.956
	31	21^h 03.3^m	–17° 29′	116° Mo	+0.6	17.5″	100%	9.471
Uranus	16	2^h 35.8^m	+14° 49′	14° Mo	+5.9	3.4″	100%	20.735
Neptune	16	23^h 34.1^m	–4° 00′	63° Mo	+7.9	2.2″	100%	30.376

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.



Anatomy of the Amazing Big Dipper

There's more to this distinctive collection of stars than meets the eye.



▲ **TEMPORARY DIPPER** The Big Dipper is the most recognizable part of the constellation Ursa Major, the Great Bear. Five of the Dipper's stars are moving through space together, but two (Alkaid and Dubhe) are not. As a result, over the coming millennia the iconic shape of the Dipper will eventually become unrecognizable.

AKIRA FUJII

The Big Dipper is the most famous asterism. It's so eye-catching that few of us focus on the individual stars that make it up. However, there's much to see and to learn about them.

The Big Dipper is part of the larger, official constellation Ursa Major, the Great Bear. Most constellations have stars with Greek letter designations that are sequenced in order of diminishing brightness, with Alpha being brightest, Beta second brightest, and so on. However, the Greek letters in the Big Dipper are arranged by position from the lip of the dipper bowl, around the bottom of the bowl, and out to the end of the handle. Thus, starting from the lip of the bowl, the stars are Alpha Ursae Majoris (Dubhe), Beta (Merak), Gamma (Phecda or Phad), Delta (Megrez), Epsilon (Alioth), Zeta (Mizar), and Eta (Alkaid or Benetnasch).

Given that the Greek letters are out of order, what are the relative brightnesses of the seven Big Dipper stars? Most people who've casually observed the pattern would probably say they're all roughly the same brightness. That's almost true. Six of the stars differ by little more than half a magnitude. Interestingly, these six fall into two brightness batches. The brighter batch includes Dubhe and Alioth at magnitude 1.8, Alkaid at 1.9, and Mizar at 2.2. That's the lip of the bowl and the three stars of the handle. The fainter batch (if you can call two stars a "batch") is Merak at magnitude 2.3 and Phecda at 2.4, which form the bottom of the bowl. Of course, at nightfall in April and May the Big Dipper rides high above Polaris and is oriented upside-down, so the bottom of the bowl is on top.

So what about the seventh, dimmest star of the Big Dipper? That's Megrez. It shines at only magnitude 3.3 — almost a full magnitude dimmer than the faintest of the other six. In fact, there are five stars in other parts of Ursa Major that are equal to or brighter than Megrez. Its dimness is easily overlooked because it's positioned right in the middle of the Big Dipper, quietly forming the link between the three handle stars and the rest of the bowl.

Most asterisms are not true clusters. Instead, they're random line-of-sight patterns in the sky comprised of stars that are often at different distances from Earth. However, in the case of the Big Dipper, the middle five stars really do seem to be the remaining core of a once rich and tight star cluster, now known as the Ursa Major Moving Group. These Dipper stars (along with a handful of additional, fainter ones) are still travelling through space together at similar distances, approximately 80 light-years away. The two stars that aren't part of this collection mark opposite ends of the Big Dipper. Dubhe and Alkaid are 120 and 104 light-years away, respectively, and heading in different directions from the main cluster quintet. As a result of this arrangement, over the course of a few tens of thousands of years, the Dipper will have a markedly different shape than it does today.

A final wonderful difference between the disparate sets of Dipper stars is their spectral types. The cluster five are all between *A*0 and *A*3 (tinted bluish white), while Alkaid is a *B*3 (hotter, bluer) star and Dubhe is a cooler, noticeably orange *K*0 star.

■ **FRED SCHAAF** observes the night sky from the oak-pine fringe of the New Jersey Pinelands National Reserve.

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

Mercury's Big Month

The innermost planet has its best showing for 2021 *and* meets up with Venus.

MONDAY, MAY 3

May is **Mercury** month. If the innermost planet has always eluded your gaze, this current apparition offers an excellent opportunity to rectify that. The first event of the May Mercury Show is this evening's close call with the Pleiades cluster in Taurus. As twilight fades, look to the west-northwest to spot the planet shining brightly at magnitude –0.9.

Although Mercury rapidly climbs higher over the coming weeks, it loses much of its luster at the same time. The tiny world should be easy to fish out of the horizon-hugging murk, but you might need your binoculars to pull in the Pleiades and get a really good look at this pretty conjunction. This evening Mercury will be a little more than 2° from Alcyone, the 2.8-magnitude star marking the cluster's center. If the weather doesn't cooperate don't fret: Mercury is almost as close to Alcyone the following evening and remains in the same 5° binocular field as the Pleiades until the 6th.

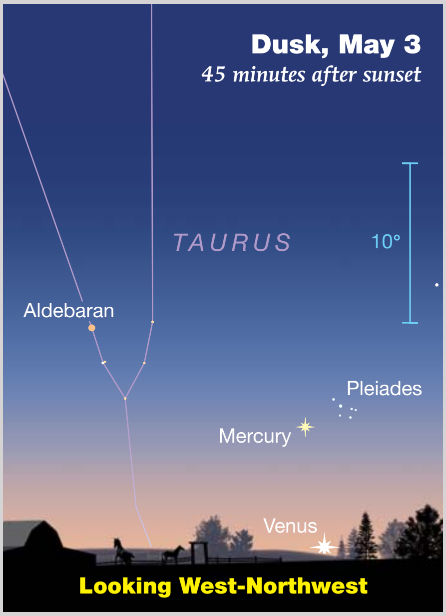
WEDNESDAY, MAY 12

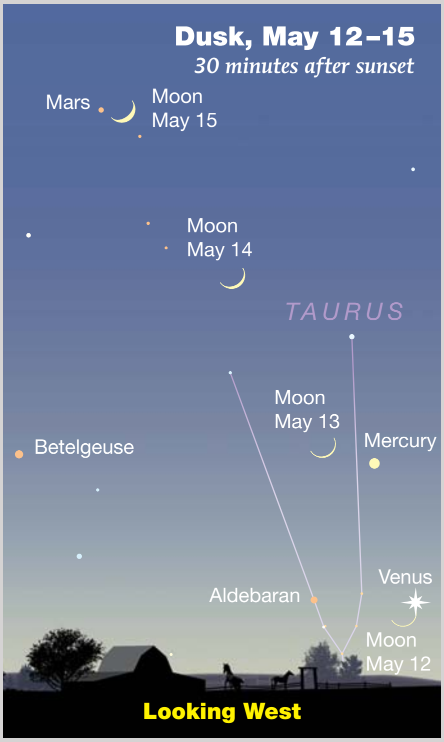
It's hardly an original observation, but pairings involving the **Moon** and **Venus** are among the most arresting sights in naked-eye astronomy. More often than not, when the night sky's two brightest objects get together it's a circle-the-date event. And the closer they are, the better. At dusk today, the Moon will pass closer to Venus than at any other time this year — you don't want to miss out! At 8 p.m. EDT, just 43′ (about 1½ Moon diameters) separates brilliant Venus from the razor-thin lunar crescent. And how thin is "razor-thin"? This evening the Moon is little better than 1% illuminated and only 29 hours past new. Unfortunately, neither object is ideally placed. They're low in the west-northwest in bright twilight and set just one hour after the Sun. However, if you have an unobstructed horizon, you'll have little difficulty spotting the pair soon after sundown, or even *before* if you use binoculars to scan the horizon.

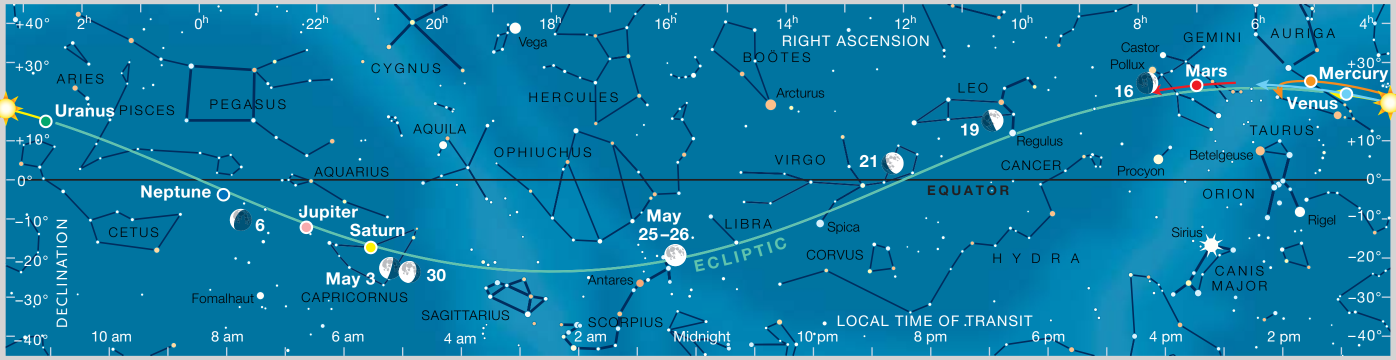
▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west). European observers should move each Moon symbol a quarter of the way toward the one for the previous date; in the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your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

THURSDAY, MAY 13

After its close encounter with Venus, the Moon's eastward movement along the ecliptic brings it alongside **Mercury** this evening. Having faded to magnitude 0, Mercury is much, much fainter than Venus, which gleams at magnitude –3.9. Despite the huge brightness mismatch, this conjunction will be easier to observe than the previous evening's. Not only are Mercury and the Moon some 10° higher than Venus this evening, but the lunar crescent is also 24 hours fatter and now more than 4% illuminated. And the Moon is also visible in a darker twilight sky, making earthshine much easier to see. The one notable negative, however, is that the two objects are much farther apart — the Moon is roughly 3° left of Mercury. That's still close enough for both to comfortably fit in the field of view of ordinary binoculars.



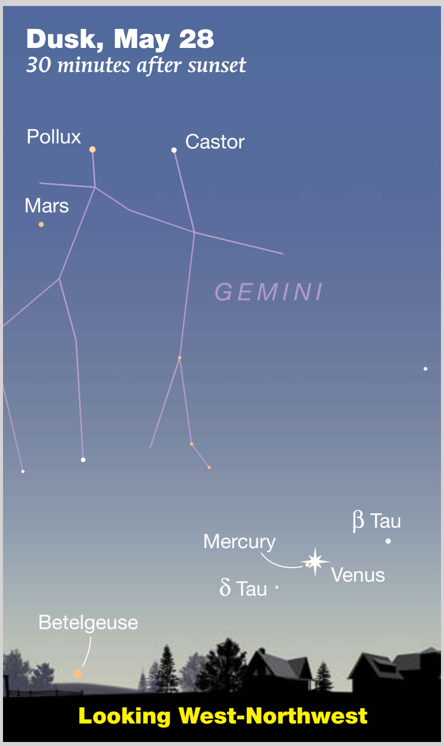




▲ The Sun and planets are positioned for mid-May; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

SATURDAY, MAY 15

Having taken a night off from visiting planets, the **Moon** now encounters **Mars**. Of the three mid-May conjunctions, this is the easiest to view but perhaps the least compelling. That's because Mars shines a relatively dim magnitude 1.6. Offsetting the planet's dimness is the Moon's proximity. At its absolute closest (shortly after 11 p.m. PDT), the waxing crescent is only 39′ to the right of Mars. However, that view is reserved for observers on the West Coast. But even from the East Coast, the Moon and Mars are separated by just 1½° as they sink toward the northwestern horizon.

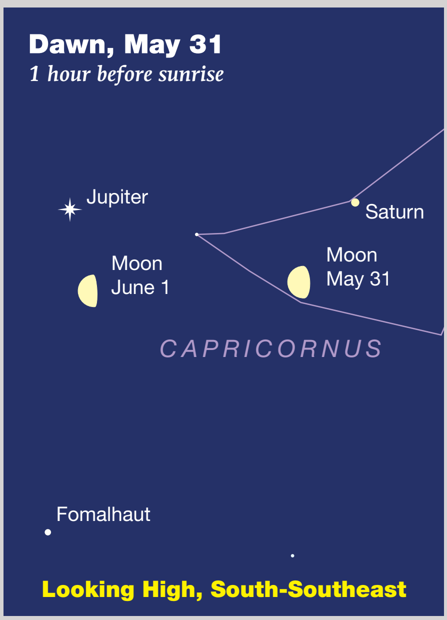


WEDNESDAY, MAY 26

Today's full **Moon** is doubly special. Not only is it a perigean full Moon (popularly known as a "supermoon"), but it also passes through Earth's shadow, resulting in the first total lunar eclipse since January 2019. (Turn to page 48 for complete details.)

FRIDAY, MAY 28

The month's marquee **Mercury** event takes place at dusk today. The fast-moving little world reached greatest elongation on the 17th and has been plunging sunward ever since. This evening its descent brings it within whispering distance of **Venus**. At its closest (at 11:10 p.m. EDT), Mercury is less than ½° from the Evening Star. On the surface, this sounds as if it should be a spectacular sight. However, Mercury has dimmed to magnitude 2.3. That's still modestly bright, but the little planet is badly outshone by beaconlike Venus, which is an astonishing 300 times brighter! Interestingly, the two inner planets have roughly the same apparent diameter — both span a little more than 10″. Despite its smaller physical size, Mercury is presently 2½ times closer than Venus. And, as telescopes will reveal, Mercury presents a tiny crescent while Venus's disk is nearly full.



MONDAY, MAY 31

The month wraps up with a pretty predawn gathering that includes the **Moon** (naturally), **Jupiter**, and **Saturn**. A generous span of 18° separates the two planets, with the waning gibbous Moon positioned in between, roughly 5½° below and left of Saturn. Jupiter gleams at magnitude –2.4 from the western edge of the big but dim constellation Aquarius, while Saturn is a +0.6-magnitude addition to neighboring Capricornus. Both planets are high enough at dawn for enjoyable views in telescopes — Saturn climbs to the meridian just around the time brightening twilight erases it from naked-eye view.

■ Consulting Editor **GARY SERONIK** has been watching the planets for more than 200 Mercurian years.

A Brief Total Lunar Eclipse

Get ready to watch the Moon pass through Earth's shadow.

▲ **TOTALITY AGAIN** *Sky & Telescope* Consulting Editor Gary Seronik captured this triptych portrait of the most recent total lunar eclipse, which occurred on the night of January 20–21, 2019. Like this month's eclipse, during the 2019 event the Moon passed north of the center of Earth's umbral shadow, resulting in the northern limb being markedly brighter than the southern edge of the lunar disk.

Finally. After four penumbral eclipses in 2020, on May 26th we can enjoy the first total lunar eclipse in more than two years. But this is a short and sweet event.

When the Moon passes directly through the center of Earth's umbral shadow, totality can last up to 1¾ hours. However, during this month's eclipse the Moon barely edges inside the umbra, spending only 18.4 minutes there before coasting back into the much lighter penumbra.

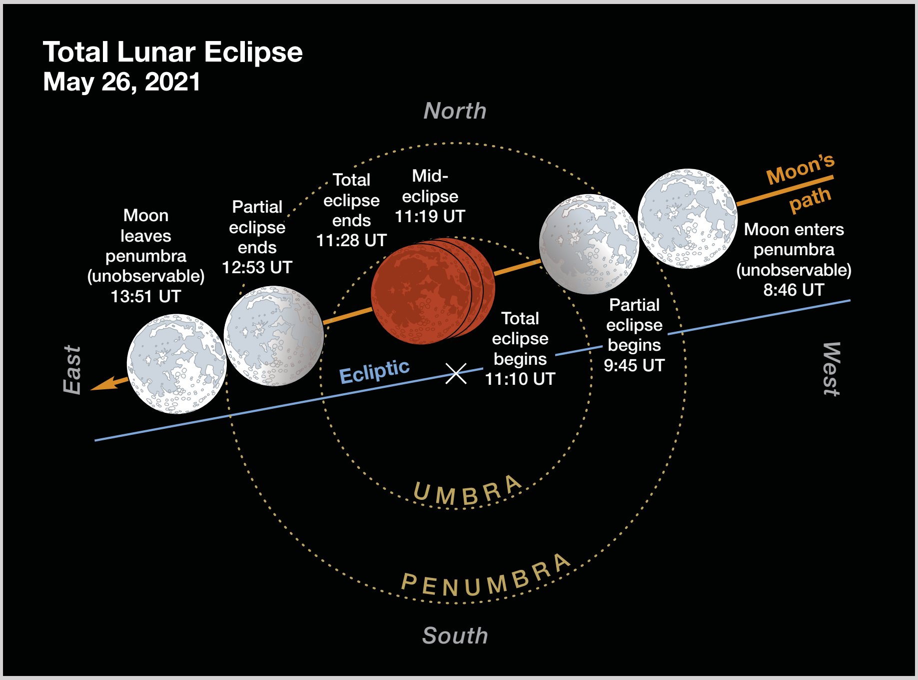
The fraction of the lunar disk immersed in the umbra is described by the *magnitude* of the eclipse — the greater the magnitude, the longer the eclipse. A total eclipse has a magnitude of 1 or greater, and a deep eclipse — when the Moon passes through the center of Earth's shadow — has a magnitude around 1.8, meaning that the Moon lies 1.8 lunar radii inside the umbra at mid-eclipse. With a magnitude of 1.0095, the May event is clearly a squeaker. This also means totality will likely be relatively bright, because the Moon's northern limb never strays far from the umbra-penumbra border.

May's lunar eclipse happens to coincide with a *perigean full Moon*, known popularly as a "supermoon." Perigee occurs on May 25th at 9:53 p.m. EDT, about 9½ hours before mid-eclipse. The full Moon's average apparent diameter is 31′, but during this perigean totality it will be 33.6′ across — about 8% larger. Ironically, the extra-large Moon fills up more of the umbra, further contributing to the brevity of totality.

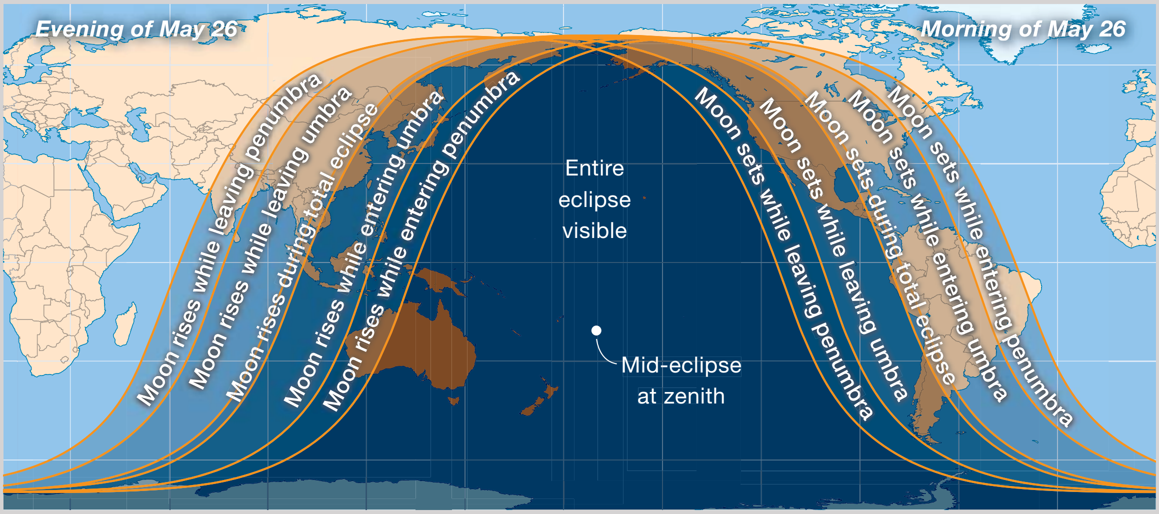
Even though the Moon appears unusually large during the eclipse, the difference won't be noticeable to most observers. Indeed, the best way to appreciate its size will be to take a photo during the eclipse, then take another one 6 months later during the November 19th near-total eclipse, when the Moon's apparent diameter is just 29.8′. Side by side, the two photos will clearly show the difference.

As indicated on the map on page 49, totality is visible from the western half of North America, western South America, East Asia, and Australia. Across the continental U.S. and Canada, the Moon will hang low in the southwest, so be sure to find a location with an open view in that direction to make the most of this event.

Views improve the farther west you



MOON PATH DIAGRAM: LEAH TISCIONE / S&T; SOURCE: USNO



go. Along the East Coast of the U.S., only the early penumbral phase will be visible. Observers in the Midwest will see about half the lunar disk in the umbral shadow before the Moon sets at sunrise. From Los Angeles, the Moon exits the umbra while it's still a comfortable 14° above the horizon around the start of dawn. During the eclipse, the Moon beams from the head of Scorpius, roughly midway between the compact globular cluster M80 and the 2.6-magnitude double star Graffias, Beta (β) Scorpii.

While viewing the eclipse, be alert for starlike flashes of light resulting from meteoroid impacts on the Moon's surface. A number of amateurs spotted an impact flash near the lunar limb, less than half a minute into totality during the January 21, 2019, eclipse. If you have a video camera, consider dedicating a second telescope to recording potential impacts.

A lunar eclipse is a wonderful, slow-moving event that anyone can enjoy with or without optical aid. Sunlight refracted by the atmosphere around the circumference of Earth bathes the deep partial and total phases in coppers, yellows, and reds. Some sunlight also passes through the ozone layer in the upper stratosphere. Ozone absorbs red light and colors the outermost, fuzzy fringe of the umbra blue. Use binoculars or a telescope a few minutes before and after totality to see this feature best.

Capturing Mercury

THIS MONTH MERCURY has its best evening apparition of the year for observers at mid-northern latitudes. Although the planet is brighter at the start of May, its greatest elongation occurs on the 17th when it stands about 11° above the west-northwestern horizon 45 minutes after sunset. Through a telescope Mercury's phase changes from a waning gibbous early in May, to a thin crescent by month's end.

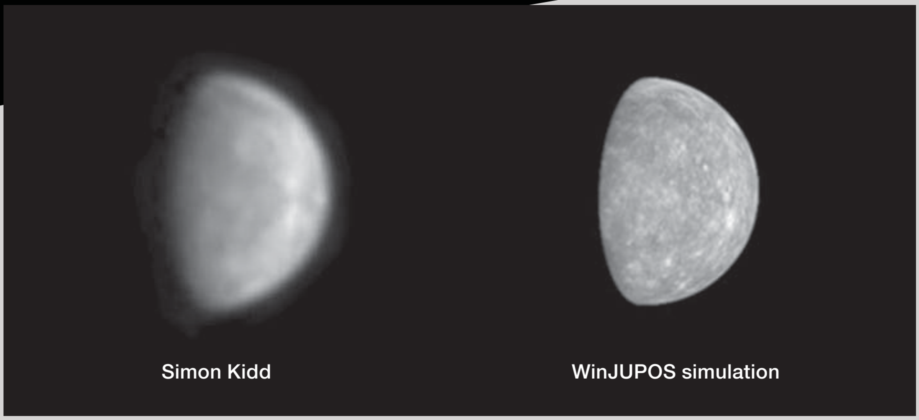
Despite being the only planet other than Mars (and Earth, obviously) with a visible surface, seeing anything more than Mercury's phase has always posed a challenge. One reason is that the little planet's disk is never larger than 12.9″, and that happens only when it's a very thin crescent — not exactly an ideal phase for surface studies. At 50% illumination (a good compromise between apparent size and phase), the planet is still just 7″ across and requires high magnification to examine. Unfortunately, that requirement runs headlong into a second problem. Even under ideal circumstances Mercury never strays more than 28° from the Sun. Forever low at dusk or dawn, it's often severely affected by atmospheric turbulence and dispersion. Many observers simply give up and move on.

However, there are ways to get around these limitations. First, try observing the planet in the daytime when it's positioned much higher in the sky. Second, employ orange or red eyepiece filters to steady the image and improve contrast. Since Mercury lies east of the Sun during this apparition, it's well placed from late morning through late afternoon.

To locate the planet during daylight, you can use a Go To scope (aligned the previous night) or the tried-and-true method of using setting circles on an equatorial mount to offset from the Sun's position. Look up the Sun's right ascension and declination using the table on page 44, or by consulting a computer program. Do the same for Mercury. Then, attach a safe solar filter at the objective end of your telescope and focus on the solar disk. Adjust

▲ **TWILIGHT DELIGHTS** A thin lunar crescent paired up with Mercury at dawn in October 2015. Mercury puts in an excellent appearance at dusk during the first three weeks of May. On the 13th it's joined by the two-day-old Moon in a delicate conjunction low in the northwest during evening twilight.

ECLIPSE MAP: LEAH TISCIONE / S&T; SOURCE: USNO; MERCURY AT DAWN: BOB KING



▲ **MERCURY PAIR** Simon Kidd made this remarkable photo of Mercury (left) with a C14 telescope equipped with a ZWO ASI224MC camera and 742-nm infrared (IR) filter on June 25, 2018. Compare it to the WinJUPOS simulation based on MESSENGER imagery. Kidd captured at least a half dozen rayed craters and several intercrater plains in his image.

your setting circles to agree with the R.A. and Dec. of the Sun's position, then shift your mount so that Mercury's coordinates are displayed. Even if you're not precisely polar aligned, the offset between Mercury and the Sun is small enough that the planet should lie within the field of view of a low-power eyepiece. Remove the solar filter and examine the planet at the highest magnification conditions will allow.

French amateur Michel Legrande calls Mercury "a difficult planet." He goes on to add, "experience has taught me to observe as often as possible . . . the eye, like a muscle, must be trained." He uses an 8.26-inch (210-mm) f/6 homebuilt Newtonian reflector and magnifications between 140× and 200× for his Mercury observing.

Amateur and professional astronomers have recorded vague streaks and spots for decades. Now, thanks to detailed images from NASA's MESSENGER mission, we can correlate what we see in our telescopes with features depicted in the photos. Amateurs have had even better success capturing Mercurian detail in daylight with digital cameras equipped with red or infrared filters. Using the free WinJUPOS program (downloadable at **jupos.org**), images or sketches can be compared to the planet's appearance to confirm and identify specific features such as bright rayed craters and dark, volcanic plains.

Simon Kidd of Cottered, England, who uses a C14 Schmidt-Cassegrain telescope and a 742-nm infrared filter to image the planet, offers this advice: "Don't give up, even if the conditions are only average. There are bound to be a few good frames if you capture 100,000 or so in one run. Keep the exposure really short — a few milliseconds maximum."

For additional information about observing and photographing Mercury, visit the ALPO Mercury Section website at **https://is.gd/ALPOMercury**.

Selected Jupiter Mutual Satellite Events

Date	Time (UT)	Event	Mag change
May 1	7:39 – 7:41	Europa eclipses Io	0.9
May 11	9:06 – 9:15	Europa eclipses Ganymede	0.3
May 20	7:56 – 8:01	Io eclipses Europa	0.4
May 27	10:12 – 10:17	Io eclipses Europa	0.5

Action at Jupiter

BY MID-MAY JUPITER rises around 2 a.m. local daylight-saving time and ascends to an altitude of nearly 30° in the south-southeast by the time morning twilight brightens the sky. On the 15th, the planet displays a disk 39″ across and beams at magnitude –2.3.

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

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

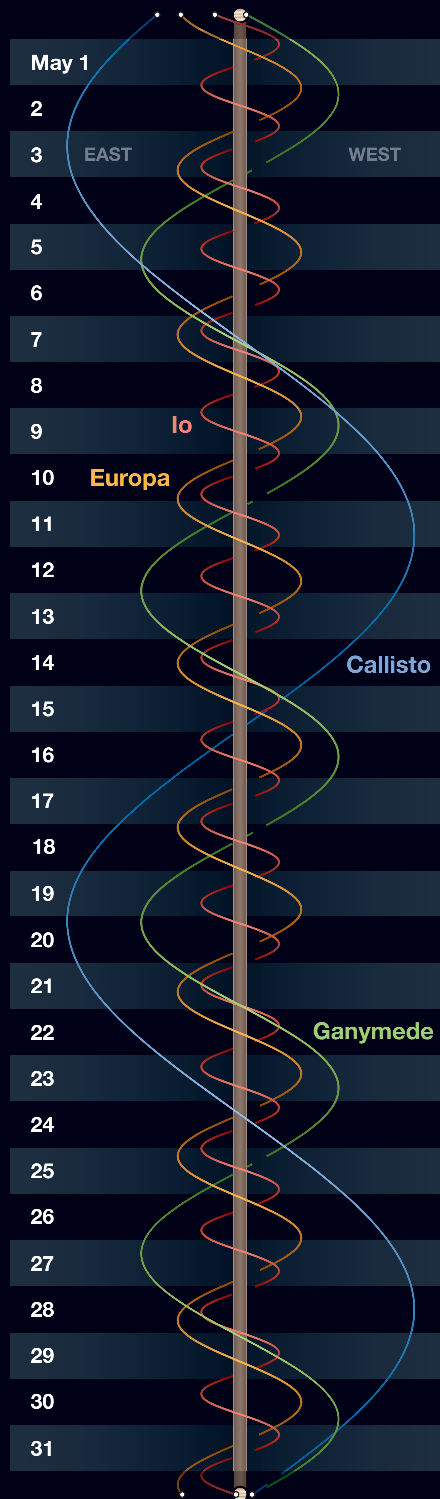
These times assume that the spot will be centered at System II longitude 358° on May 1st. If it has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 358° and 1²/₃ minutes later for each degree more than 358°.

Phenomena of Jupiter's Moons, May 2021

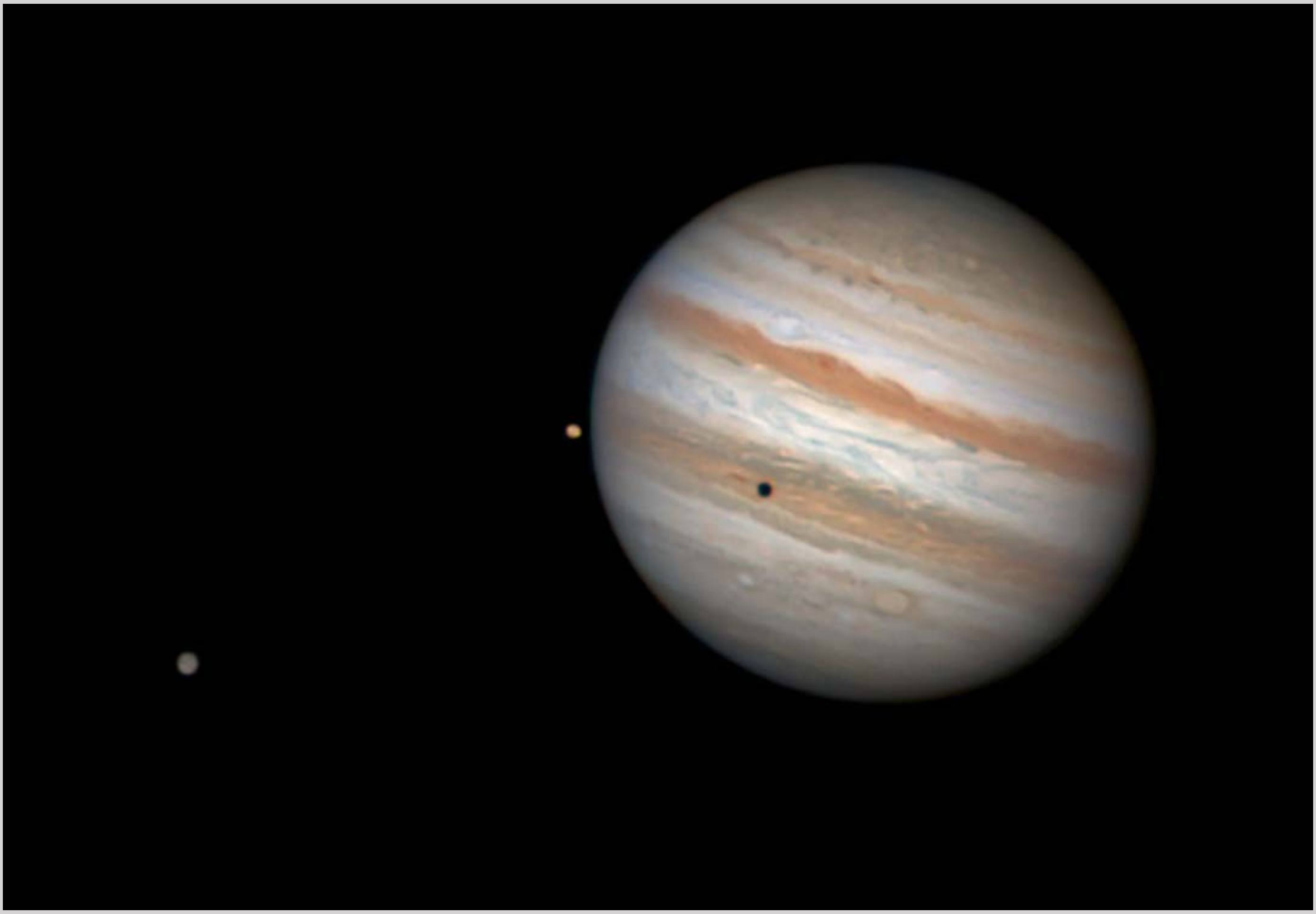
May 1	0:38	II.Sh.I
	3:13	II.Tr.I
	3:30	II.Sh.E
	6:04	II.Tr.E
	11:12	I.Ec.D
	14:48	I.Oc.R
May 2	8:21	I.Sh.I
	9:38	I.Tr.I
	10:38	I.Sh.E
	11:55	I.Tr.E
	18:46	II.Ec.D
May 3	0:17	II.Oc.R
	5:41	I.Ec.D
	9:17	I.Oc.R
	16:44	III.Ec.D
	20:23	III.Ec.R
	22:01	III.Oc.D
May 4	1:40	III.Oc.R
	2:50	I.Sh.I
	4:07	I.Tr.I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

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 4 hours ahead of Eastern Daylight Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Jupiter's Moons



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



SEAN WALKER / S&T

Spurious Shadows

Don’t be fooled by these Jovian moon mirages.

▲ Unlike the anomalous views described in the article, the shadow of the Galilean moon Io appears here as an actual, ink-black spot on the giant planet’s cloudtops.

The ceaseless dance of Jupiter’s four largest moons is one of the most compelling spectacles accessible to backyard astronomers. The configurations of the Galilean satellites differ markedly not only from night to night, but from hour to hour. The jet-black shadows they cast onto Jupiter’s cloud canopy can be seen through even a humble 60-mm refractor.

For more than two centuries, credible observers have also infrequently noted anomalous companion satellite shadows. In the second (1868) edition of his classic observing handbook *Celestial Objects for Common Telescopes*, the Reverend T. W. Webb recounted that early in the 19th century Sir James South witnessed a satellite shadow present “attended by a faint duplicate by its side.”

The puzzling phenomenon was even captured photographically in 1963 by Philip Glaser. Taken through an 8-inch Newtonian, Glaser’s convincing photos recorded a companion shadow that persisted for several minutes.

A 144-year-old account by the French artist and astronomer Étienne Trouvelot remains one of the most compelling descriptions of this perplexing occurrence:

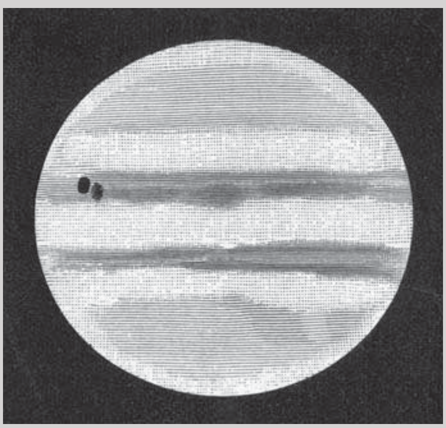
> On April 24th, 1877, at 15h. 25m. the shadow of the first satellite [Io] was projected on the dark band forming the northern border of the equatorial belt, the shadow being then not far from the east limb. Close to this shadow, and on its western side, it was preceded by a secondary shadow, which

> was fainter, but had the same apparent size . . . I watched closely this strange phenomenon, and at 16h. 45m., when the shadow had already crossed ¾ of the disk, it was still preceded by the secondary, or mock shadow, as it may be called; the same relative distance having been kept all the while between the two objects, which had therefore travelled at the same rate. It is obvious that this dark spot could not be one of the planet's markings, since the shadow of the first satellite moves more quickly on the surface of Jupiter than a spot on the same surface travels by the effect of rotation . . .

Trouvelot attributed the mock shadow to a translucent upper cloud deck where ". . . semi-transparent vapors receive the shadow of a satellite at their surface, while at the same time part of this shadow, passing through the semi-transparent vapors, may be seen at the surface of . . . a layer of opaque clouds situated at some distance below the surface."

In the 1870s, British astronomer Charles Edward Burton frequently scrutinized Galilean moon shadows at high magnifications through 7-to-12-inch Newtonian reflectors. The shadows usually appeared "beautifully round, and very sharp at times," but sometimes they looked "slightly lozenge-shaped, or irregularly elliptical." Burton's trigonometric calculations, based on the obliquity of the line of sight, indicated that if these anomalous appearances were caused by shadows falling on upper and lower cloud layers as Trouvelot suggested, these strata would have to differ in altitude by thousands of miles. The intervening Jovian atmosphere would have to be almost perfectly transparent, a scenario Burton found implausible.

▼ French artist Étienne Trouvelot witnessed a spurious double shadow of Io while observing Jupiter on the evening of April 24, 1877.



DRAWING: ÉTIENNE TROUVELOT / *A HANDBOOK OF DESCRIPTIVE AND PRACTICAL ASTRONOMY*

Writing in a 1939 issue of the *Journal of the Royal Astronomical Society of Canada*, the Greco-French observer Eugène M. Antoniadi characterized the double shadows as a "deceitful phenomenon" and attributed them to the "irregular refraction of rippling air."

Three years later Bertrand Peek, Britain's top mid-20th century Jupiter observer, saw the shadow of Io, which was traversing the southern part of Jupiter's South Equatorial Belt, accompanied by a ghostly companion that was ". . . quite as sharply defined and only a little smaller . . ." This curious appearance persisted "for minutes together except for a few seconds now and again of normal vision."

In his 1958 book *The Planet Jupiter* Peek recounted:

> The observation was a perfectly good one of course — of the image formed in the focal plane of the telescope, not of what was happening on Jupiter — and can doubtless be explained on some such hypothesis as that a pocket or column of air of different temperature from its surroundings was tending to become stabilised over a portion of the 12¼-inch mirror. There can be little doubt that an electric fan, directed to the proper quarter, would have dispelled the illusion.

◀ These images by Alan Adler capture the deceptive distortions of a double star produced by a warm boundary layer of air located above the surface of the cooling primary mirror of his 8-inch Newtonian reflector.

Peek's mundane explanation hit the proverbial nail on the head. The freak appearance arose not from turbulence in the atmosphere above his telescope but from the air *inside* its tube.

Engineer Alan Adler has imaged stars distorted into ellipses, and even spurious companion stars, through his 8-inch f/6 Newtonian (*S&T:* Jan. 2002, p. 132). The phenomenon is caused by a boundary layer of warm air located just in front the surface of the telescope's primary mirror. These illusory appearances immediately disappeared when a fan was employed to sweep away the boundary layer.

These oddities can appear in any type of telescope. While imaging Jupiter one evening, NASA planetary geologist Tim Parker recorded a distorted satellite shadow that he traced to a gentle current of warm air flowing up the baffle tube of his 8-inch Schmidt-Cass. Refractors are also not immune to the issue due to the tendency of a pocket of warm air to gather just behind the objective lens along the upper side of its enclosed tube (*S&T:* Jan. 2004, p. 114).

In recent decades both ATMs and commercial manufacturers have taken increasing pains to optimize the thermal characteristics of their instruments. Reports of double satellite shadows may become increasingly rare as a result, but they remain a cautionary tale that is well worth remembering. Observers should watch for these anomalous appearances when witnessing shadow transits, because illusions can be just as interesting as reality.

■ Contributing Editor **TOM DOBBINS** has been enamored with the planets for more than 4 Jupiter years.

▲ **SPIRAL BEAUTY** Few galaxies match our conception of an "island universe" as well as M81, in Ursa Major. For backyard telescope users, M81's attractiveness is enhanced by its proximity to neighboring galaxy M82, located just 37′ north.

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

Big Bear Pair

Exploring M81 and M82 is double the fun in more ways than one.

It was New Year's Eve, 1774, and Johann Elert Bode certainly had reason to celebrate. That night, the German astronomer discovered an attractive pair of nebulous objects in Ursa Major, the Great Bear. Word of the discovery was slow to circulate — French astronomer Pierre Méchain chanced upon "Bode's Nebulae" independently in 1779, and comet hunter Charles Messier credited both observers when he added the objects to his list of "false comets" in 1781.

Today, we usually refer to Bode's Nebulae by their Messier numbers, **M81** and **M82**. And we know they're galaxies, not nebulae. M81 glows impressively at magnitude 6.9, and M82 weighs in at magnitude 8.4. Standing 37′ apart, these cosmic siblings comprise arguably the finest galaxy pairing in the heavens.

Beauty and the Beast

The Bode galaxies aren't remote — M81 is only 12.1 million light-years away and M82 a million light-years farther. Together they dominate the M81 Group, a neighbor of the Local Group in which our Milky Way resides.

Some 90,000 light-years across, M81 is similar in size to the Milky Way. We see the two-armed spiral nearly face-on, its opposing arms wound in graceful symmetry around a broad central bulge. The fertile arms contain vast populations of hot, blue-white stars. Scores of pink emission nebulae incubate yet more protosuns. Curving threads of interstellar dust lace a galactic system of sublime elegance.

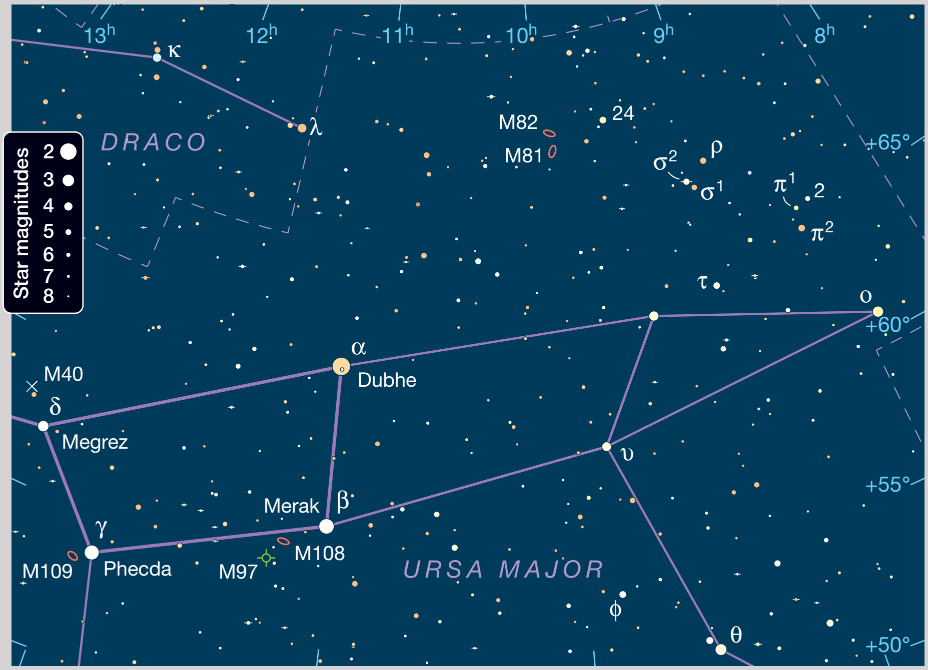
By contrast, M82 is an enfant terrible, throwing a temper tantrum. Its vestigial spiral arms are overwhelmed by a long, luminous bar scarred by jagged dust clouds. This strangely mutilated object is disgorging immense outflows of hydrogen gas from its central region. Inside the disrupted core are vast clumps of massive, ultra-hot stars — a sign of youth in a region where older suns are the norm. Astronomers think M82 suffered a close encounter with M81 perhaps 300 million years ago. Mighty M81 emerged from the sideswipe relatively unscathed, but M82 was battered and bruised. The result is a gorgeous spiral beside a disfigured wreck — a celestial Beauty and the Beast.

Locator Logic

For mid-northern skywatchers, the big bear pair are circumpolar and well placed for much of the year. That said, springtime is primetime.

We can star-hop to the galaxies via the Big Dipper. A line drawn diagonally across the Dipper's bowl, from 2.4-magnitude Gamma (γ) Ursa Majoris to 1.8-magnitude Alpha (α) UMa, then veering slightly to the north for a dozen degrees reaches 4.6-magnitude 24 UMa. Trouble is, I can't spot 24 UMa in my drab suburban sky. So, I guestimate its location. Eventually, my finderscope snares it, along with 5.7-magnitude HD 83489 one degree to the southeast. After centering HD 83489 in a low-power eyepiece, I head eastward another degree to the Bode lode.

I prefer the roundabout but surefire star-hop promoted by former *S&T* senior editor Joshua Roth. Following Josh's advice, I cast my gaze west of the Dipper to 3.4-magnitude Omicron (ο) UMa, which mark's the Great Bear's nose. From Omicron, I turn northeastward and make a series of four-degree hops — first to a shallow triangle of 5th-magnitude stars that includes Pi^1, Pi^2 (π^{1+2}) and 2 UMa; then to a similarly bright isosceles triangle consisting of Sigma^1, Sigma^2 (σ^{1+2}), and Rho (ρ) UMa; and finally to 24 Uma where a right-angle turn finds HD 83489 and the galaxies. Circuitous, yes, but safe.



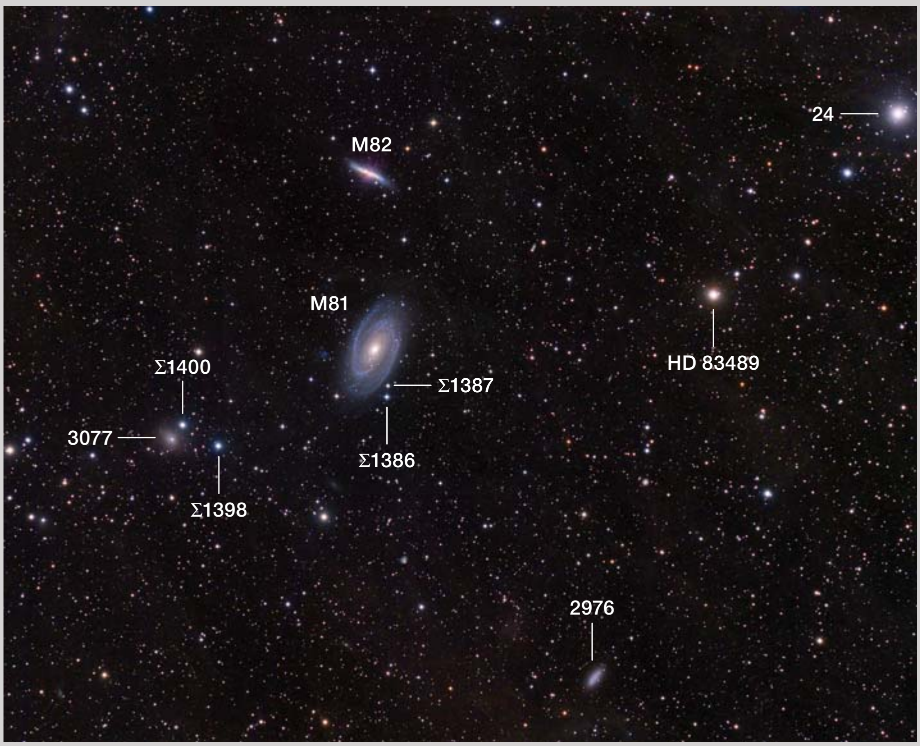
▲ **IN THE BEAR'S DEN** Two separate star-hops lead from the Big Dipper to the Big Bear pair. The most direct route involves a veering line from Phecda to Dubhe and on to the key 5th-magnitude star 24 Ursae Majoris. Longer, but easier to follow with optical finderscopes, is the multi-asterism star-hop from 3rd-magnitude Omicron Ursae Majoris, described in the text.

Attractive Opposites

In my 10-inch f/6 Dobsonian, a wide-angle 30-mm eyepiece producing 50× frames the galaxy pair with room to spare. The targets are delightfully unalike. M82, aptly named the Cigar Galaxy, is a strongly elongated, patchy nebulosity of modest central concentration. In contrast, M81 is a diffuse oval brightening smoothly toward its core.

Tripling the magnification and focusing on M81's center, I glimpse a teeny nucleus. Cupping my hands around the eyepiece and employing averted vision, I see that M81's elliptical halo is oriented north-northwest by south-southeast. On the latter side, the tenuous mist extends a few arcminutes to a couple of 11th-magnitude stars 85″ apart. Images show the spiral arms curling beyond those stars. Alas, the armless "nebula" in my 10-inch Dobsonian is reduced to a breadth of 8′ or 9′ — barely a third of its photographic size. Score one for the city lights.

Two more dots aligned north-south, 135″ apart, lie 10′ south-southwest of the galaxy. Each dot is a double star. The northern duo, **Σ1387**, comprises identical 10.7-magnitude components 9.0″ apart; **Σ1386** has 9.3-magnitude twins separated by 2.2″. The wider set is easy, and the tighter tandem splits cleanly in a 9-mm eyepiece yielding 169×. I've studied M81 for decades, not noticing



▶ **BODE'S NEBULAE** Discovered by Johann Bode in 1774, these dominant members of the M81 Group are separated by about one million light-years. During a sideswipe a few hundred million years ago, larger M81 severely distorted smaller M82. Lesser members NGC 3077 and NGC 2976 also participate in this slow but dangerous cosmic dance.

SEAN WALKER

▲ **THE BEAST** This HST portrait of M82 reveals vast outflows of dust and gas from the galaxy's central region. The disheveled specimen is seemingly bursting at the seams. Thanks to its relatively high contrast, M82 stands up reasonably well against city light pollution. Even a relatively modest telescope will reveal it (and beautiful neighbor M81) under such adverse sky conditions.

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

this double-double hiding in plain sight!

Here's another Ken mea culpa. From M81, the Cigar Galaxy is just a northward nudge away. The shift to M82 is simple when using an equatorially mounted scope. However, if you're scrutinizing M81 at high power with a Dobsonian, I can assure you the move isn't foolproof. I remember the times I'd casually aim kinda-sorta north to pick up the impossible-to-miss M82. Close, but no Cigar. Nowadays, I lower the magnification and carefully tip-toe directly north to claim my prize.

The spindly galaxy, canted northeast by southwest, divides into thirds. The southwest third (the end closest to M81) outshines the northeast third, which seems ghostly at low power. Thankfully, M82 magnifies well. At 169×, the disheveled galaxy fills out, spanning at least 8′. Its thickened middle third is splotchy, ragged, and lacks a conspicuous nucleus. Instead, there's a whitish area northeast of center, and a pale patch southwest. In place of the dynamic outflows captured in astro-images, with averted vision I see opposing indentations biting into the middle and almost cutting M82 in half. Somebody's been chomping on our Cigar!

Peripheral Players

Two lesser members of the M81 Group are within range of my trusty 10-inch. Both are pallid, dust-ridden, "peculiar" galaxies badly roughed up by M81. Aiming my scope some 40′ southeast of M81 snares two 8th-magnitude stars roughly 9′ apart, one northeast of the other. Together they guard **NGC 3077**, which lies a few arcminutes southeast of the northeastern marker. The 9.9-magnitude galaxy is only a wee oval haze. Its "guardian" stars, though, are challenging doubles. The northeastern guard, **Σ1400**, features a 9.8-magnitude companion 3.6″ southwest. The other binary, **Σ1398**, hides an 11.4-magnitude attendant 4.1″ east. These tough nuts crack at 169× in steady seeing.

From Σ1400, a 1.7° sweep southwestward, through Σ1398 and onward past 7.7-magnitude HD 85828, arrives at a lonely lump of light named **NGC 2976**. This bland, 10.2-magnitude galaxy seemed less appealing than NGC 3077 — until I examined it at 169×. Inclined approximately halfway between edge-on and face-on, NGC 2976 appears elongated roughly 2:1 on a northwest-southeast slant. An extremely dim star hugs its southwestern flank.

These peripheral players might not materialize in smaller backyard scopes, but the headliners — M81 and M82 — perform well in any optics. My 120-mm f/7.5 apochromatic refractor operating at 38× captures the Beauty and the Beast together perfectly.

One last thing: My views of the misty-smudgy M81 Group were slightly enhanced by a broadband light pollution filter. In the battle against city lights, we suburban stargazers need every break we can get.

Suburban Big Bear Bits

Object	Type	Mag(v)	Size/Sep	RA	Dec.
M81	Galaxy	6.9	25′ × 12′	$09^h\ 55.6^m$	+69° 04′
M82	Galaxy	8.4	11′ × 5′	$09^h\ 55.9^m$	+69° 41′
Σ1387	Double star	10.7, 10.7	9.0″	$09^h\ 55.1^m$	+68° 56′
Σ1386	Double star	9.3, 9.3	2.2″	$09^h\ 55.1^m$	+68° 54′
NGC 3077	Galaxy	9.9	5.2′ × 4.7′	$10^h\ 03.3^m$	+68° 44′
Σ1400	Double star	8.0, 9.8	3.6″	$10^h\ 02.9^m$	+68° 47′
Σ1398	Double star	8.0, 11.4	4.1″	$10^h\ 01.5^m$	+68° 43′
NGC 2976	Galaxy	10.2	6.2′ × 3.1′	$09^h\ 47.2^m$	+67° 55′

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.

■ Veteran deep-sky hunter **KEN HEWITT-WHITE** bears down on Ursa Major from his backyard whenever he can.

Exoplanet Watch

Have a hankering to contribute to a NASA project? With the right equipment you can, right from your own backyard.

Exoplanets are one of the hottest topics in professional astronomy today. Less than three decades after scientists discovered the first worlds around other stars, we know of more than 4,300 planets outside the solar system. Another couple thousand candidates await confirmation.

The Transiting Exoplanet Survey Satellite (TESS; a NASA-MIT collaboration) is actively adding to that tally. Astronomers predict that once they've finished digging through TESS's first two years of data, they'll identify about 10,000 new exoplanets via the *transit method*, which measures the minuscule change in the brightness of a star as a planet traverses its disk. Thus far, astronomers have used this method to find about three-quarters of all known exoplanets. Not only does it tell us something about the planet's size relative to its host star, it also provides a means for disentangling the chemical composition of the planet's atmosphere (see page 34).

The Hubble Space Telescope is already looking for — and finding — signatures of water in exoplanets' atmospheres. Several ventures in the planning, among them the James Webb Space Telescope (scheduled for launch in October) and the European Space Agency's Ariel mission (launch in 2029), will also be on the prowl, sniffing for exoplanets' chemical fingerprints. But to be able to do this, we need to catch the exact moment that a planet crosses its star's face.

That is challenging. Astronomers have to "keep the transit times 'fresh' to enable the efficient use of large telescope time," Robert Zellem (Jet Propulsion Laboratory) told participants during the virtual winter meeting of the AAS. "If your transit-timing uncertainty is on the order of 15 minutes, that's an extra 15 minutes you need to build into your observing scenario and your overhead. And that's effectively 15 minutes that's potentially wasted on just waiting for that transit to occur — or even completely missing the transit event."

Enter Exoplanet Watch. Led by Zellem, this NASA project aims to accurately identify the mid-transit times of exoplanets — with amateur help. Debuting this June, Exoplanet Watch (**https://is.gd/exo_watch**) is calling on amateurs to routinely observe carefully selected transiting exoplanets so as to keep their mid-transit times and orbital periods precise. Even telescopes as small as 6 inches in aperture are capable of detecting a 1–2% transit depth event in the light curve of an 11th-magnitude star.

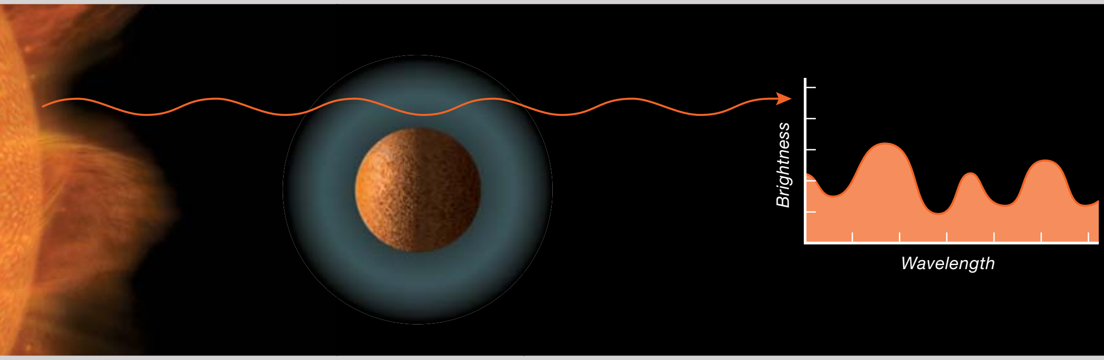
The project lists high-priority targets, but observers can point their telescopes at any known exoplanet. Once you've collected the data with your astronomical camera, you must reduce them. Exoplanet Watch's in-house data reduction software, EXOTIC, is a good place to start, as is the American Association of Variable Star Observers' package, AstroImageJ.

Once your data are spick-and-span, you'll upload them to the AAVSO's Exoplanet Database, established in 2018 to provide a long-term repository that professional astronomers can pull from to supplement their own data, explains Dennis Conti, chair of AAVSO's exoplanet section (**https://is.gd/exo_aavso**). "Since even these observations need a repository in order to discern long-term trends, AAVSO's Exoplanet Database was fortunately there to fill the need."

The project's data will be immediately made public. Exoplanet Watch staff will "scrape" the AAVSO database daily, process and fit all the data, and publish them also on their own website. And voilà — your data will be ripe for the picking. Zellem stresses that amateurs who contribute to published results will have coauthor status on all journal papers.

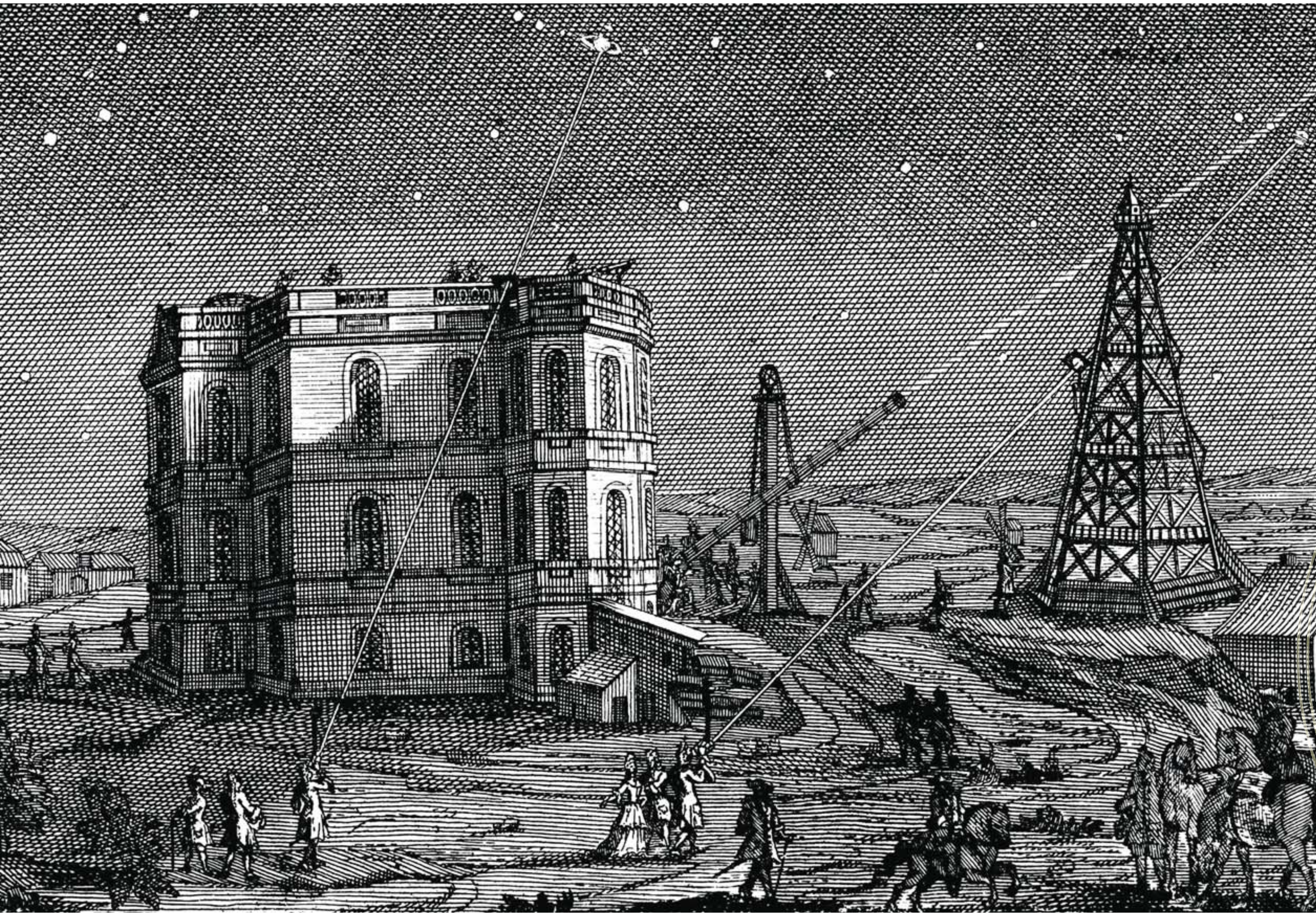
And who knows — maybe while gathering the all-important transit-timing data, you might even discover an exoplanet of your own. Zellem concludes, "Small telescopes really do have the opportunity to have a high impact on measuring these exoplanet transits." Go on, get your scope out, and start looking.

■ Observing Editor **DIANA HANNIKAINEN** can't get over how much we learn from watching worlds pass in front of stars.



When starlight passes through the atmosphere of a transiting exoplanet en route to us, astronomers can use it to decipher the chemical composition of the atmosphere. But to do this efficiently, we need to know exactly when the exoplanet transits in front of its host star.

S&T, SOURCE: NASA / ESA / Z. LEVY / STSCI



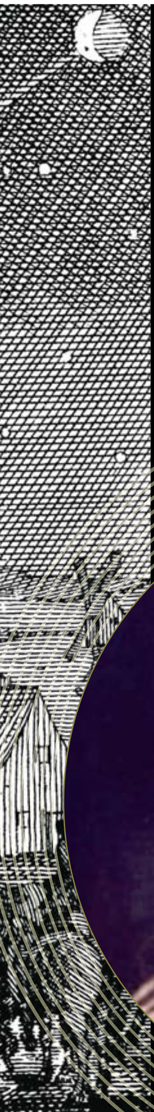
Giovanni Domenico Cassini and the Birth of Big Science

Innovations from an underappreciated 17th-century astronomer still reverberate today.

▲ **PARISIAN SKY AND TELESCOPES** This fanciful illustration appeared in Cassini's *Tables Astronomiques Du Soleil, De La Lune, Des Planètes, Des Étoiles Fixes* (Astronomical Tables of the Sun, the Moon, the Planets, the Fixed Stars) and depicts Paris Observatory. The structure at right is the Marly Tower, described in the text. Note the trio of "aerial telescopes," aimed at Saturn, Jupiter and its satellites, and the waning crescent Moon.

Ask any astronomer — professional or amateur — what comes to mind when they hear the name Cassini and they'll probably mention the Cassini-Huygens mission to Saturn, or perhaps Cassini's Division, the largest of the many gaps in Saturn's famous rings. But more likely than not, they'll know few details about the life and accomplishments of 17th-century astronomer Giovanni Domenico Cassini.

Co-naming one of the most complex and important space missions after Cassini is a clue that he must have played a highly significant role in the history of science. But why isn't he mentioned in the same breath as Galileo and Newton? When we consider Cassini's many important achievements, his relative obscurity seems all the more puzzling and unjust.



▶ **A RING DIVIDED** Amongst telescope enthusiasts, the great 17th-century astronomer is best remembered as the discoverer of the most conspicuous gap in Saturn's rings, known as Cassini's Division. The feature is visible even in small, modern instruments at medium magnification.

▼ **MAN WITH A MISSION** This portrait of a fashionable, middle-aged Giovanni Domenico Cassini belonged to Cardinal Filippo Maria Monti (elevated by Pope Benedict XIV in 1743), reflecting the astronomer's status as a "courtier scientist" in the service of the great and good of Italian and French society.

▲ **FAMOUS NAMESAKE** Giovanni Domenico Cassini is well known today thanks to the spacecraft mission that explored Saturn for 13 years. This illustration depicts the probe as it prepares to slip between the planet and its rings during its high-risk Grand Finale near the end of the spacecraft's mission in September 2017.

From Italy to France

Cassini's life was that of a "courtier scientist," spent conducting research at the behest of kings and noblemen. This was typical for prominent scientific figures of the time, and Cassini was especially successful.

He was born on June 8, 1625, in the northwestern Italian village of Perinaldo, near the border with France. As a young man, Cassini attended formal studies at the College of the Jesuits in Genoa, where he developed an interest in astronomy. When he was about 21 years old, he concluded his studies and dedicated himself to mathematics and astronomy under the guidance of Giovanni Battista Baliani — an important and influential politician with a passion for science. Baliani was a mathematician, physicist, astronomer, and author of scientific works on the motion of bodies under the influence of gravity. He introduced Cassini to various astronomical instruments — tools the young man would develop an aptitude for. At age 26, Cassini's great skills as an observer were noticed by Marquis Cornelio Malvasia, who helped the young man gain tenure in astronomy at the Archiginnasio, the prestigious university in Bologna.

During this period, Cassini worked on the meridian line of the Basilica of San Petronio and spent many years teaching and traveling. In 1657, at the Pope's recommendation, he was tasked with the important job of managing the waterways (crucial for commercial transport) and the stability of bridges for the towns of Ferrara, Ravenna, and Bologna. This position brought Cassini into contact with the highest ranks of Italian society, including important philosophers,

CASSINI PORTRAIT: THE HISTORY COLLECTION / ALAMY STOCK; SATURN: NASA / HST / THE OPAL TEAM; SPACECRAFT: NASA / JPL-CALTECH scientists, and members of the nobility who were particularly enthusiastic about the sciences.

However, Cassini's increasing fame was a mixed blessing and ultimately became a significant distraction from his real passion, astronomy. Little wonder that when King Louis XIV invited him to Paris to help complete a new astronomical observatory, Cassini jumped at the chance. In 1669, he settled in France, where he eventually became known as Jean-Dominique Cassini. Here at last he was able to fully devote himself to astronomy.

A Gifted Observer

Cassini's methods for practicing astronomy, both in Italy and France, were different in many ways from the standards of the time. In an era in which it was common for astronomers to build their own instruments, Cassini was principally an observer. He purchased his telescopes from the most skilled optical craftsmen of the day, including the Campani brothers and Eustachio Divini, as described on page 58 of the April 2020 issue.

Thanks to the high quality of his telescopes and his abilities as an observer, Cassini was able to distinguish planetary details others could not, leading to a series of remarkable discoveries. The best known of these is the gap in Saturn's rings, now called Cassini's Division, which he first observed in 1675. He also discovered four previously unknown satellites orbiting Saturn: Iapetus, Rhea, Tethys, and Dione. It's no surprise, then, that centuries later his name would be assigned to the robotic explorer that revealed so much about the ringed planet.

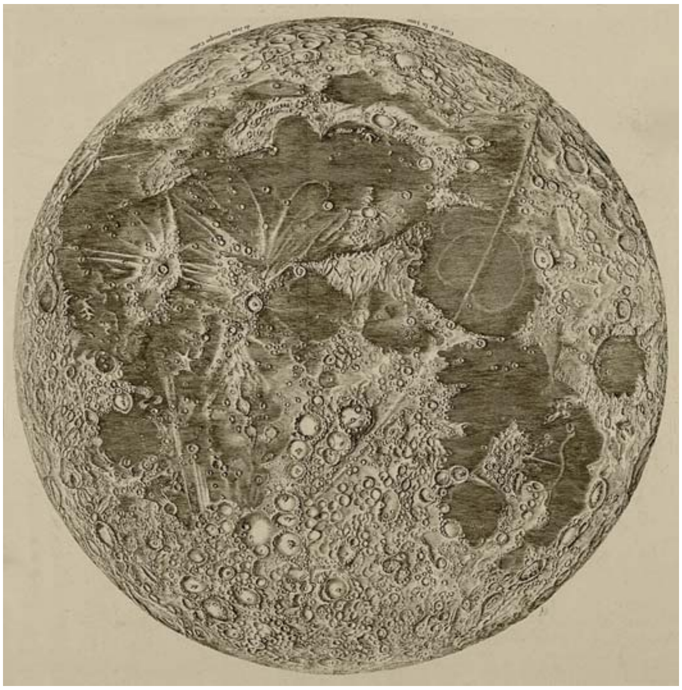
Perhaps even more impressive, Cassini was able to discern features on Mars and Jupiter clearly enough to determine the rotation rates of both planets. He was also a devoted cartographer and made observations that resulted in the most accurate Moon map available at the time.

Not only did Cassini possess a keen eye, he was also one of the few astronomers able to effectively tame the notoriously difficult beast known as the "aerial telescope." In the latter part of the 17th century, refractor telescopes were of Keplerian design, and performance was largely determined by focal length. This was to get around the aberrations inherent in the simple lenses available at the time — the longer the telescope, the better the view. Lenses for such telescopes could have focal lengths measured in hundreds of feet! This was the status quo until the invention of the Newtonian reflector telescope in 1668 and the arrival of the achromatic refractor lens in 1729.

The best aerial telescopes were so long that they couldn't be housed in an observatory building and instead had to be used in the open air, supported by enormous wooden towers. The one employed by Cassini, called the "Marly," was typical. Its name came from the support tower's previous role in Versailles, as part of the so-called Machine de Marly, which served to supply water for the palace's many fountains and gardens. The instrument at one time featured a Campani lens with a focal length of 136 inches.

Comets and Beyond

Cassini's astronomical interests were wide-ranging. For example, he studied the zodiacal light and correctly attributed the phenomenon to sunlight scattered by dust particles



◀ **MOON MAPPER** *(Top)* Cassini's dedication and skill as an observer are apparent in his detailed lunar map. At the time of its completion in 1679, it was the most detailed and accurate representation of the Moon's surface yet created.

◀ **LUNAR NAMESAKE** *(Bottom)* Two features on the Moon bear Cassini's name. One is the flooded, 57-km-diameter crater (Cassini) located on the northeast shore of Mare Imbrium. The other is "Cassini's Bright Spot" (circled in the photo) just north of Tycho. Although Cassini suspected the feature changed appearance over time, in reality it's simply an ordinary, 3-km-wide crater (Hell Q) with a tiny ray system.

CASSINI MOON MAP: OBSERVATOIRE DE PARIS; MOON CLOSE-UP: LRO around the Sun. Cassini also studied comets. In the 17th century, little was known about the true nature of these icy visitors, and their study lay at the forefront of astronomical research. Cassini observed a comet that appeared in 1652-53, and measures of its motion revealed that the object had no significant parallax, meaning it must be very far from Earth. This conclusion contradicted the commonly held hypothesis that comets were "emitted" by our planet, and it constituted an important contribution to the debate between Aristotelean and Galilean physics.

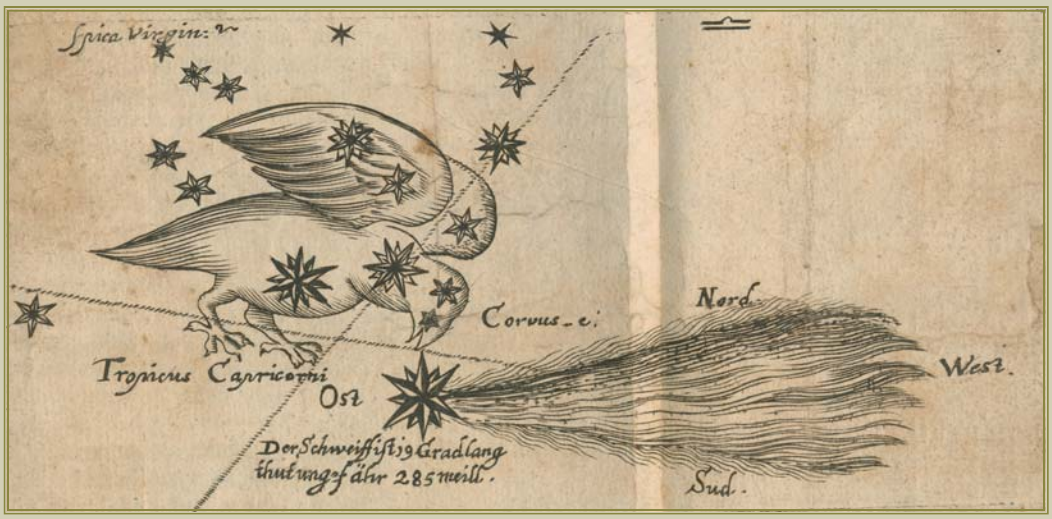
While in Rome in 1664, Cassini viewed a second comet from the Chigi Palace (home of the Pope's brother) and from the Riario Palace (residence of Queen Christina of Sweden). Cassini became the first astronomer to employ laws of planetary motion to predict a comet's path in the sky.

Cassini's instrumentation wasn't restricted to telescopes. As mentioned earlier, he designed the meridian line in the Basilica of San Petronio, in Bologna, Italy — one of the largest scientific instruments of the time. By measuring the passage of the solar disk on the meridian line, Cassini precisely determined the length of the year. Less well known is that he also used this instrument to demonstrate experimentally the validity of Kepler's Second Law, thus performing the first test of the laws of planetary motion that ultimately helped give rise to Isaac Newton's *Principia*.

Near San Petronio, Cassini exploited the 100-meter-high Asinelli Tower in Bologna to view an unobstructed horizon. This allowed him to produce a refined theory of atmospheric refraction that was much more accurate than the previous one proposed by Tycho Brahe.

These are just some of Cassini's scientific contributions. From the perspective of the 21st century, many of them may seem relatively minor; however, together they helped advance our understanding of the universe. But perhaps Cassini's greatest contribution isn't found in his numerous discoveries so much as in his methodology.

▲ **A TOWERING VIEW** This perspective of Bologna and its surroundings is from the top of the Asinelli Tower, where Cassini and other scientists made astronomical observations and performed experiments. In the distance is the blocky profile of the Basilica of San Petronio, where Cassini's meridian line is located.



◀ **COMET CATCHER** The comet of 1664 is shown near Corvus in this engraving from a German listing of comets from 1566 to 1664. Cassini observed the object and used Kepler's laws of planetary motion to predict its path across the sky.

COMET ILLUSTRATION: WIKIMEDIA COMMONS PD-US-ART; VIEW OF BOLOGNA: GABRIELLA BERNARDI

Medician Moons and Mars

One of the most important factors in Cassini's success was his systematic approach to observing. While this method of scientific inquiry is obvious today, it was far from common in the 17th century, when more erratic research habits were the norm. Consider Cassini's close contemporary, Christiaan Huygens. As the American science historian Albert van Helden noted in an article appearing in *The Seventeenth Century*, "A few years after Cassini's arrival in Paris, Huygens remarked to his brother Constantijn that Cassini was at the telescope every clear night and that he [Christiaan] would never want to do that."

Huygens was a solitary genius — exactly the opposite of Cassini, who was the first to pursue the notion that scientific work could be a collaborative effort among a large group of individual scientists. Cassini's talents and methods of research ultimately played a crucial role in his transfer to France.

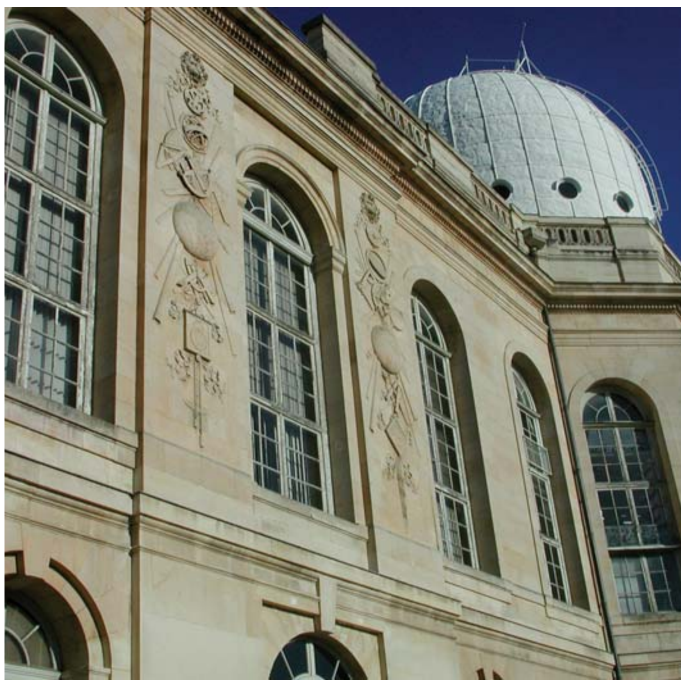
On July 28, 1668, the *Journal of the Scholars of Rome* announced the publication of Cassini's ephemerides of Jupiter's four brightest satellites. Entitled *Ephemerides Bononienses Mediceorum Syderum*, it was an astonishing result for the time, made possible by his indefatigable efforts as an observer. His work spread quickly throughout Europe, because accurate positions for Jupiter's moons were crucial for solving the most important scientific problem of the time: determining longitude on Earth.

At the beginning of the 17th century, Galileo understood that the timing of various Jovian satellite events depended on the observer's location, and that the difference between the observed and tabulated times could be used to determine the observer's longitude. With Cassini's tables, fixing the precise geographic coordinates of any point on Earth became possible, vastly improving the accuracy of maps. During the rule of Louis XIV, France was one of the most powerful nations in the world, and accurate maps were necessary to fulfill the ambitions of the Sun King. After several negotiations between representatives of the King and the Pope, Cassini moved to France in February 1669.

The establishment of the Astronomical Observatory of Paris was not only a matter of national prestige but was also instrumental for one of the most ambitious scientific projects of the time — making an accurate map of France. Such a project was perfect for Cassini, because it allowed him to pursue his astronomical interests. At the same time, Cassini

◀ **CASSINI AND THE SUN KING** This illustration depicts King Louis XIV and Cassini (gesturing) at the Royal Academy of Sciences. Out the window in the background, the new Paris Observatory is perched on a nearby hill.

▼ **PAST AND PRESENT** This photo by the author shows Paris Observatory in its present incarnation. The dome houses the Arago refractor telescope, which was installed in 1857 and features a 38-cm (15-inch) objective lens. One can only wonder what Cassini would have done with such a fine instrument.



CASSINI AND LOUIS XIV: METROPOLITAN MUSEUM OF ART; PARIS OBSERVATORY TODAY: GABRIELLA BERNARDI was perfect for the task because of his strong work ethic and affinity for collaboration.

These same traits were to bear remarkable fruit during the favorable Mars opposition of 1672. Cassini organized a group of astronomers to observe the event from several different locations. He remained in Paris while his colleague Jean Richer traveled to Cayenne in French Guiana, near the equator, and John Flamsteed, the first Astronomer Royal, observed from Derby, England. Flamsteed had predicted that Mars would occult the 4.4-magnitude star Psi^2 Aquarii, providing an ideal opportunity to use parallax to calculate the distances between Earth and Mars and between Earth and the Sun, thereby refining the value of the astronomical unit. The successful observations were a pivotal moment in the understanding of our place in the universe.

The Birth of Big Science

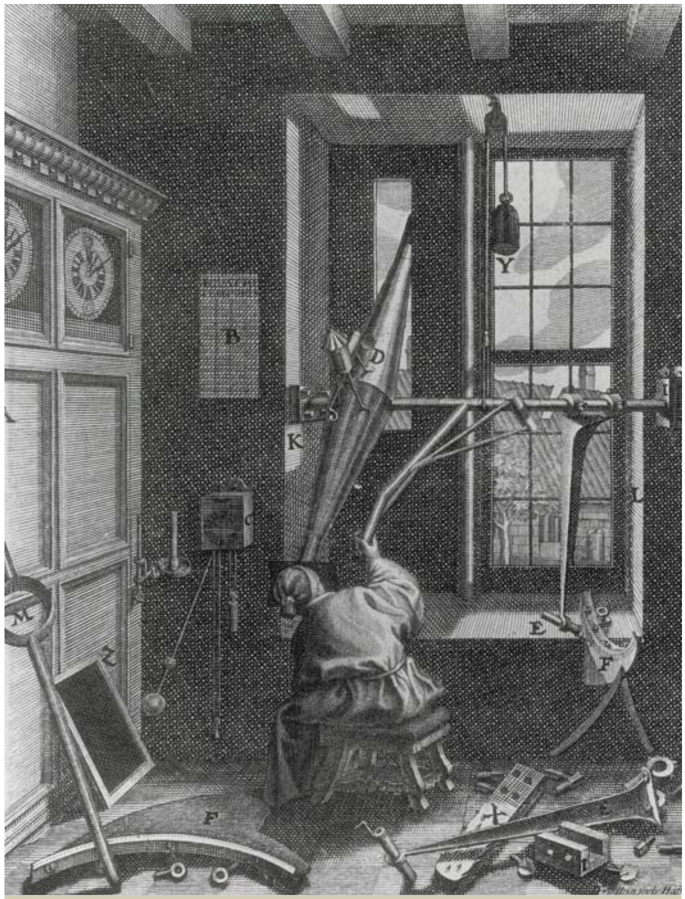
For all his many discoveries and impressive range of observations, perhaps Cassini's greatest contribution to science was introducing three elements of modernity: a distinction between astronomers and telescope-builders; a carefully organized observing method; and conceiving science as the collaboration among groups of scientists in order to achieve goals inaccessible to a single individual.

From our present perspective in the era of "big science," these developments might seem obvious and quite normal. However, that sense of normalcy arises only because scientists such as Cassini made it possible.

■ **GABRIELLA BERNARDI** is a freelance science journalist based in Turin, Italy. She is the author of six astronomy books, including *Giovanni Domenico Cassini: A Modern Astronomer in the 17th Century*.

▲ **CARVED IN STONE** Housed at the Paris Observatory is a statue of Cassini. Next to the left foot are scrolls listing some of the great astronomer's most notable discoveries. Cassini was the observatory's first director — a position he held until his death in 1712.

STATUE DETAIL: GABRIELLA BERNARDI; OLE RØMER: SCIENCE HISTORY IMAGES / ALAMY STOCK



Cassini and the Speed of Light

As notable as his list of discoveries is, Cassini also had a few near misses.

Most readers know that Danish astronomer Ole Rømer made the first estimation of the speed of light. He has earned a rightful place in history because of it, though he wasn't as devoted and prolific an astronomer as Cassini.

However, in the 1660s and '70s as he systematically observed the moons of Jupiter, Cassini noticed discrepancies between the timings of his observations and his predictions. This was obviously a problem since determining longitude required accurate tables. He set about calculating the corrections that would have to be applied to his tables in order to improve their accuracy. Interestingly, in a communiqué to the French Academy of Science of 1672, Cassini mentioned the possibility that the observed discrepancies could be ascribed to a finite speed of light. However, Cassini never quite carried the idea to its full conclusion as Rømer did.

▲ **MYSTERY MOONS** Puzzled by discrepancies between predictions and observations, Danish astronomer Ole Rømer discovered that the apparent errors were due to the finite speed of light — an idea that Cassini had also had but failed to pursue.

Some Thoughts About Today's Eyepieces

Eyepieces are just as important as telescopes when it comes to visual observing, but some of the conventional wisdom about them has changed over the years.

Bring up the topic of eyepieces with a group of seasoned observers and you better be prepared for a cascade of opinions. Comments about eyepiece designs, brands, and even costs are likely to surface along with opinions about such fundamentals as what range of magnifications is important for various types of observing. So, it's not surprising that eyepieces can be a confusing subject for someone new to the hobby of astronomical observing, especially given the huge variety of eyepieces available in today's marketplace. It's been awhile since we've run a general article on eyepieces, so what follows is a bit of an eyepiece primer mixed with some thoughts on how the conventional eyepiece wisdom I learned entering the hobby many decades ago has changed over the years.

Everyone knows that a telescope provides a magnified view of the world around us, be it terrestrial or celestial. And it's the eyepiece's job to create that magnified view of the image formed by a telescope's objective. An eyepiece's three fundamental attributes are its *focal length*, *angle of view*, and *eye relief*.

The focal length determines the magnification, and every beginning observer quickly learns that the simplest way to

calculate telescope magnification is to divide the scope's focal length by the eyepiece's focal length when both are expressed in the same units. For example, let's consider a refractor with a focal length of 500 mm used with an eyepiece having a focal length of 25 mm. The magnification will be 20× (500 ÷ 25 = 20).

There are two aspects of an eyepiece's angle of view. One is the true field, which is how much of the sky we are seeing through the eyepiece. The other is the apparent field, which is how big that circle of sky appears to our eye. Using an eyepiece with a small apparent field is a bit like looking through a paper tube, while one with a large apparent field is like stepping up to a porthole and viewing a scene so expansive that the edge of the field is almost out of our conscious view.

Up until the 1980s, most quality astronomical eyepieces had apparent fields no larger than about 50°. Since then, the field has been expanding (forgive the pun), and today there are excellent eyepieces with apparent fields of 100° and more. While observers don't usually think in these terms, the true and apparent fields are connected by magnification. Here's an example. To our unaided eye the Moon appears ½° in diameter. If we view the Moon at a magnification of 100×, it will appear to span an angle of 50° (½° × 100× = 50°). As such, an eyepiece yielding 100× on a telescope would have to have an apparent field of at least 50° to show us the whole Moon in a single view. If we switch to an eyepiece still yielding 100× but having an apparent field of 100°, the Moon will still appear the same size but now fill only half of the visible field. Flip that train of thought and you'll see that an eyepiece with a 100° apparent field will show the whole Moon at a magnification of 200× — an impressive increase in magnification from the eyepiece with a 50° apparent field. Note that it's just the apparent fields and magnifications that are important for these calculations, not any particular focal length for the telescope or eyepiece, only that the combination yields the desired magnification. I'll return to these thoughts in a bit since they are important.

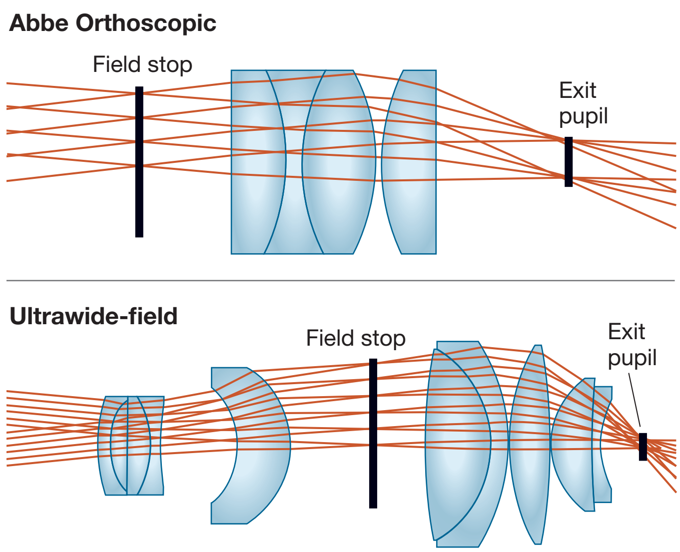
As the diagram at right shows, the bundles of light exiting an eyepiece cross at a point called the *exit pupil*. This is the point where you must place the pupil of your eye to see an eyepiece's full field, and its distance from the outer eyepiece lens is called the *eye relief*. Having sufficient eye relief is important when it comes to observing comfort. I could go on at length about the days of yore and the misery of having to cram an eyepiece almost into your eyeball to try to see the whole field of view. This was especially true of short-focal-length (high-magnification) eyepieces. Thankfully, most modern eyepiece designs have a generous amount of eye relief. Personal preferences vary, but most people who observe without wearing eyeglasses will be happy with an eye relief of at least 10 to 12 mm, and those with glasses will want between 20 and 25 mm. Having a long-eye-relief eyepiece is also beneficial for those of us who observe in cold temperatures since an eyepiece is less likely to fog up when our moist eyeball is kept farther from it.

Low Magnification

There are a variety of ways to approach assembling a set of eyepieces depending on the type of observing we want to do. For many newly minted observers, however, a modest eyepiece set that spans a range from low to high magnification is a good start. Let's begin with the low end of the range.

Back when I started observing and quality eyepieces had apparent fields of around 40°, the concepts of low power and wide field went hand in hand, and it was easy to fall into the mindset that a lower magnification always meant a wider field of view. But the real goal wasn't low magnification, but rather a wide field showing a big expanse of sky. And the fact is that it will always be better to have such a view with the highest possible magnification. Since most of us observe under some amount of sky glow, increasing the magnification darkens the apparent sky background and improves the contrast and the visibility of faint stars, which, at the magnifications were talking about, are not dimmed by increased magnification. Unlike stars, deep-sky objects, such as galaxies and nebulae, do not get a boost in contrast as the magnification increases, but they often become easier to see because they appear larger and we can resolve more details. I know it sounds weird, but having more "low-power" magnification is always a good thing.

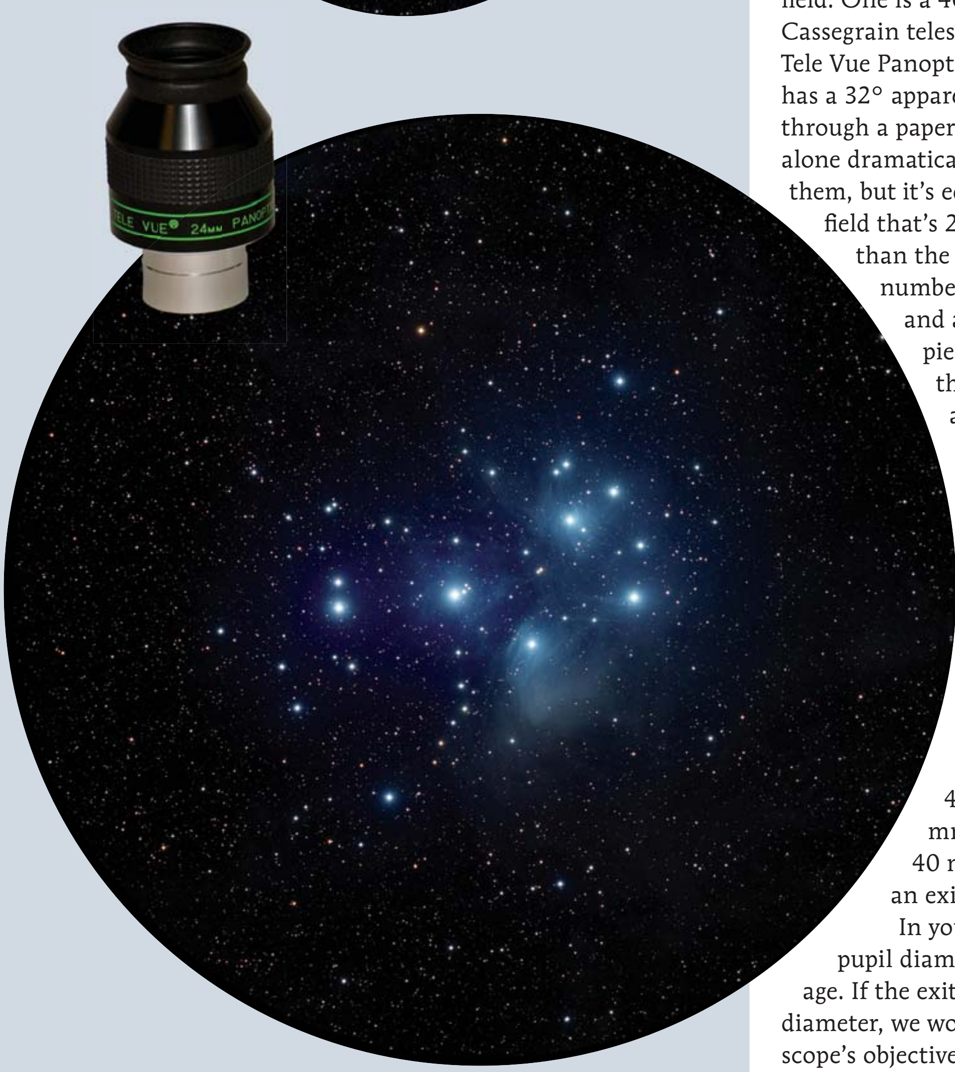
So what about that wide field? The amount of true sky we see in an eyepiece is set by the diameter of the eyepiece field stop, which can't exceed the diameter of the eyepiece barrel. The maximum field-stop diameter is about 27 mm for a 1¼-inch eyepiece and 46 mm for eyepieces with 2-inch barrels. An easy way to calculate the true angle of sky seen



▲ **EXPANDING FIELD** The Abbe Orthoscopic eyepiece with a roughly 45° apparent field of view is one of the most enduring astronomical eyepiece designs of the 20th century. But modern glass types and high-transmission coatings have helped usher in a new era of eyepiece designs that have apparent fields of 100° and more, and these designs have revised some of the conventional wisdom that surrounded older designs. The field stop and exit pupil are explained in the accompanying text.

ALL PHOTOS COURTESY OF AUTHOR UNLESS OTHERWISE NOTED; EYEPIECE BACKGROUND: GLITTERSTUDIO / SHUTTERSTOCK.COM; EYEPIECE DIAGRAM: LEAH TISCIONE / *S&T*

▼ **NOT SO SIMPLE** For a given telescope, lower magnification by itself does not mean a wider field of view. These simulated views are scaled to show the relative magnifications and true sky areas shown by two of the author's 1¼-inch eyepieces used with a telescope having a 500-mm focal length. The view below is with a 40-mm Kellner eyepiece from the early 1970s with a 32° apparent field, while that at the bottom is with a Tele Vue 24-mm Panoptic with a 68° field.



in a telescope is to multiply 57.3° by the eyepiece's field-stop diameter and divide the result by the telescope's focal length using the same units of measurement for both. For the telescope mentioned above with a focal length of 500 mm, the maximum possible field for a 1¼-inch eyepiece will be 3.1° (57.3° × 27 ÷ 500 = 3.1°) and 5.3° for a 2-inch eyepiece.

But the majority of eyepieces don't have field stops that are as large as the barrel diameters permit. They are usually smaller, and in many cases significantly so. Some manufacturers give the field-stop diameter in their eyepiece specifications, but others do not. Lacking the field-stop size, you can still get a reasonable approximation of the true field visible in an eyepiece by dividing its apparent field by the magnification of the set up. Recall the Moon discussion above in which an eyepiece with a 50° apparent field working at a magnification of 100× will just fit the Moon's ½° diameter into the field of view (50° ÷ 100× = ½°). In a perfect world this formula would be exact, but optical distortions, especially those in very wide-angle eyepieces, can alter the numbers a bit.

I have two 1¼-inch eyepieces in my collection that nicely illustrate the point above about magnification and true field. One is a 40-mm Kellner that came with a Schmidt-Cassegrain telescope in the early 1970s, while the other is a Tele Vue Panoptic 24 mm introduced in 2002. The former has a 32° apparent field (it really is like seeing the world through a paper tube), while the latter has a 68° field. This alone dramatically alters the perception of looking through them, but it's equally startling that the 24 mm shows a star field that's 28% wider with a magnification 66% greater than the 40 mm when used on the same telescope. The numbers for the 500-mm telescope above are 12.5× and a true field of about 2.6° for the 40-mm eyepiece and 20.8× and 3.1° for the 24-mm. Banish the thought that lower magnification by itself always means a wider field.

There are also practical considerations involving the exit pupil when it comes to picking a low-power eyepiece. For a given telescope, as magnification decreases the diameter of the exit pupil increases. Two easy ways to calculate exit-pupil diameter are to divide a telescope's aperture by the viewing magnification or divide the eyepiece's focal length by the telescope's f/ratio. Let's give our 500-mm telescope a 100-mm aperture, making it an f/5 instrument. The 40-mm eyepiece will then yield an exit pupil 8 mm in diameter (100 mm ÷ 12.5× = 8 mm, or 40 mm ÷ f/5 = 8 mm), and the 24-mm will yield an exit pupil of 4.2 mm.

In youth our dark-adapted eyes have a maximum pupil diameter of around 7 mm, and it decreases with age. If the exit pupil of an eyepiece exceeds our eye's pupil diameter, we won't have all the light collected by the telescope's objective enter our eye. In such cases the eye's pupil is

M45: SEAN WALKER / MDW SKY SURVEY (2)

effectively stopping down the usable aperture of the telescope and thus "wasting" light. But wasting isn't quite the right mindset, since we are actually using the maximum objective diameter possible for the given magnification. In the example above, the 8-mm exit pupil may be too big for our eye, but we're still seeing the brightest possible image for a 12.5× magnification. Regardless, the 4.2-mm exit pupil with the 24-mm eyepiece will pump all the light from the 100-mm aperture into even older eyes, thus showing fainter stars. Score more points for the higher-magnification eyepiece.

All of this makes a solid case for using the highest magnification we can that still gives us the true field we want to observe, and that points us toward eyepieces with large apparent fields. But what's a good true field? There are certainly spectacular celestial objects that can take advantage of fields of view at least 2° or 3° across — the Pleiades, the Andromeda Galaxy, the Orion Nebula, the Lagoon Nebula, and the Veil Nebula to name a few. But that list is still short compared to the countless open and globular star clusters, galaxies, and nebulae visible in backyard telescopes. Personally, I've found that a true field between ½° and ¾° in diameter is excellent for this type of "low-power" deep-sky observing. With eyepieces having a 50° apparent field, that means selecting eyepiece focal lengths that yield between 70× and 100× on a given telescope. With an 85° apparent field, the magnification becomes 120× to 170×, and with 100° eyepieces focal lengths that give 130× to 200×. And for me those higher magnifications possible with the 100° eyepieces really do offer big advantages in my suburban skies.

High Magnifications

If the discussion on low-power eyepieces seems long, you may want to avoid the details when it comes to picking high-magnification eyepieces. Part of the reason is that high magnifications are critical for planetary observing, in which there is a wealth of subtleties that go beyond just the eyepiece. But there is a shorter version of the story for those of us who fall into the category of casual high-magnification observers.

◀ **CIRCULAR MATTERS** Some eyepieces have field stops near the front of the eyepiece barrel and are easy to measure for the calculations mentioned in the text. Many modern designs, however, have internal field stops that aren't accessible, and their diameter must be obtained from manufacturer specifications or estimated by other means.

At first glance it would seem that wide-field eyepieces offer little advantage for most high-magnification observing. Even if magnified 400×, Jupiter has an apparent diameter barely approaching 5° in the eyepiece, and it would fit well within even the smallest apparent fields of view. But today's wide-field eyepieces often have long eye reliefs that make high-magnification observing very comfortable. And larger apparent fields mean larger true fields at a given magnification, and for anyone using a telescope without a tracking mount that means a longer viewing period before having to nudge the telescope to center the object again. So eyepieces with large apparent fields do offer some benefits.

Nevertheless, the central idea of high-magnification observing is to make visible the finest details that we can see with a given telescope. In the mid-19th century the English double star observer Reverend William R. Dawes determined that a telescope could just resolve a pair of equal-magnitude stars if their separation measured in arcseconds was equal to 4.56 divided by the telescope aperture in inches (or 116 divided by the aperture in millimeters). Telescope optics, however, are not the only issue since distortions introduced by Earth's turbulent atmosphere typically limit any telescope's

▶ **OCULAR PROGRESS** More than a half century of eyepiece evolution is represented by this collection of oculars that all have 9-mm focal lengths and thus yield exactly the same magnification when used on a given telescope. The eyepiece at far left, supplied with a 60-mm refractor in the early 1960s, has an apparent field of just 36°. Continuing clockwise around the arc the respective fields increase, expanding to 83° for the Tele Vue model at far right, and finally culminating with 100° for the Explore Scientific eyepiece in the foreground that shows nearly 9 times the area of sky in a single view than the eyepiece from the 1960s.

visual resolution to about 1 arcsecond on even good nights. But for the sake of argument, let's take a more-demanding resolution of ½ arcsecond, which the Dawes limit states can be resolved with a 10-inch telescope if the atmosphere cooperates. People with excellent eyesight can resolve about 1 arcminute with their unaided eyes, which means they could resolve that ½-arcsecond angle if it were magnified just 120×. But let's make it even easier on our eyes and double the magnification to 240×. Most of us don't think of that as extremely high magnification for a telescope, but it should be more than enough to show us all the detail that can be seen in a 10-inch or larger telescope, and certainly for smaller instruments and even the best "average" seeing conditions.

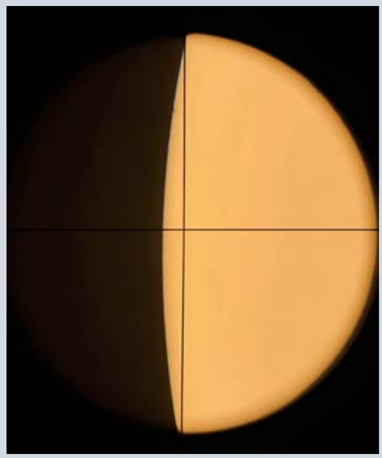
That 240× works out to a magnification of just 24× per inch of aperture for the 10-inch telescope or 40× per inch for a 6-inch instrument. These values fit well with the 25× to 50× per inch of aperture often suggested by experienced planetary observers. Furthermore, many of the great planetary observers in the late 19th and early 20th centuries rarely found an advantage to using maximum magnifications greater than 400× to 500× with even with the largest professional telescopes. Last October I was among the legions of observers viewing Mars. There was never a night when magnifications above 300× offered a better look at the planet with telescopes between 6-inch and 18-inch aperture, and most of the time my best views were at magnifications between 155× and 220× with a 6-inch refractor, which experienced acceptable seeing conditions far more often than the larger instruments.

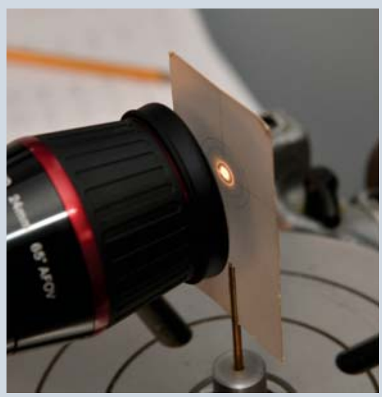
Final Thoughts

Armed with the above information, this is what I consider as a good set of eyepieces for a new telescope. At the "low-power" end of the spectrum I'd aim for an eyepiece giving the highest magnification and still providing the true field of view I want. And this would be the one that most warrants the investment necessary for one of today's eyepieces with a truly wide apparent field of view. My choice for a high-power eyepiece would be one delivering around 200×. And rounding out a basic set would be a third that delivers a magnification between these two. Rather than another eyepiece, my next addition would be a quality 2× or 3× Barlow that, when coupled with the three eyepieces, gives different magnifications than what's available with any of the eyepieces alone. The result would be a range of six magnifications that covers virtually everything I'd ever want for a typical night under the stars. Your mileage may vary.

■ **DENNIS DI CICCO** says old habits die hard, and he still occasionally catches himself reaching for a lower-power eyepiece rather than one that offers a wider field of view.

ON THE TEST BENCH Using equipment from his shop, the author set up a system for accurately measuring an eyepiece's apparent field of view. It works by using a paper target to position the exit pupil of an eyepiece attached to a refractor directly over the axis of a rotary table, and measuring the angle needed to sweep the crosshairs of a small finderscope (which provides a magnified look at the eyepiece's field of view) from one side of the field stop to the other. Of the dozens of eyepieces examined over the years, the measured fields rarely deviated by more than 1% or 2% from that specified by the manufacturer, and more often than not were exact.



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◀ WIDE-VIEW BINOS

Vixen announces a new pair of super-wide-field binoculars. The Vixen 2.1×42 Constellation Binocular ($299.99) allows you to see sprawling star fields in the Milky Way and entire constellations at once. The optics are based on a modified Galilean design that yields a 25° field of view and low magnification, permitting you to view stars about 1.2 magnitudes fainter than is possible with the naked eye. Under country skies, you can see many more stars and dark nebulae stand out with remarkable contrast. The interpupillary distance adjusts from 54 to 76 mm, and each eyepiece focuses individually. The binoculars include individual lens and eyepiece covers, and a soft case.

Vixen Optics
31878 Del Obispo St., Suite 118-338, San Juan, CA 92675
949-429-6363; vixenoptics.com

◀ STAR TRACKER

Vixen now provides an updated version of its popular star tracker. The Polarie U Star Tracker ($699) is an app-controlled camera mount that makes landscape astrophotography a snap. The device can carry loads of up to 2.5 kg (5.5 lb) as delivered, and more than twice that with optional mounting accessories. The drive is controlled by the *POLARIE U* app (available for both Apple and Android devices) and offers several tracking rates. These include settings for time-lapse imaging, a shoot-move-shoot feature, as well as rates for typical deep-sky photography with telephoto lenses and small refractors. The Polarie U also has an autoguider port to accept corrections in right ascension from ST-4-style autoguiders. The tracker comes with a mounting block with ⅜-inch threads to attach a ball mount, a detachable polar-alignment sight tube, and a mounting shoe with a ⅜ threaded socket and ¼-20 tripod adapter.

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◀ DEEP-SPACE IMAGER

Orion Telescopes & Binoculars adds a new full-frame model to its line of deep-sky cameras. The Orion StarShoot G24 Full Format Color Imaging Camera ($3,499.99) features a 35-mm format (24 x 36 mm), 24.5-megapixel Sony IMX410 CMOS detector with 5.94-micron-square pixels in a 6,064 x 4,040 array. This 14-bit camera has a full well capacity of 104,000e- and produces no amp glow. Its dual-stage, thermoelectric cooling system can achieve stable operating temperatures of 35°C below ambient, dramatically reducing thermal noise. The camera is ASCOM-compatible and connects to a computer through a single USB 3.0 interface. Each purchase includes an AC adapter, 2-inch nosepiece, additional spacer rings, a USB 3.0 cable, and a hard storage case.

Orion Telescopes & Binoculars
89 Hangar Way, Watsonville, CA 95076
831-763-7000; telescope.com

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The Trolley Dob

This mount is about as simple as it gets.

▶ David Newton's 10-inch scope awaits nightfall atop its minimalist Trolley Dob mount.

LAST SPRING, UK amateur astronomer and former physics teacher David Newton became the proud owner of a 10-inch Sky-Watcher OTA. The original owner kept the equatorial mount, leaving Dave with the scope still clamped in its tube rings. As he considered his options, Dave remembers thinking, "I wanted to do something slightly different than the typical boxy Dobsonian mount. In particular, I wanted to make use of those handy tube rings if possible. My aim was portability. I wanted to find out what the lightweight limit was for a small, effective, rigid Dob mount."

An old wooden bed frame became available at about the same time, which led to the obvious question: What could he build with a bunch of long, slender slats?

Dave says, "As the two tube rings were attached to the dovetail bar by two ¼-20 bolts, I made the assumption that the bolts would still take the weight of the tube if placed on either side and could therefore be used as the altitude bearings."

That led to a simple pair of triangles reaching up from the base. In considering that base, Dave realized that if he used the scope on a hard surface there was no real need for a ground board. So, he put three rollers underneath the platform, aimed so they would roll most easily in a circle. The rollers are called "trolley wheels," so of course Dave calls the mount his "Trolley Dob."

The upright arms started out relatively tall in order to put the eyepiece at a comfortable standing height, but the mount had quite a bit of flex, so Dave cut it down and added cross-bracing. That reduced the settling time to a respectable one second or less and puts the scope at a comfortable height to use while seated.

You might think that with its cross-braces way down at the bottom, those long arms would sway back and forth even in their shorter incarnation, but the tube isn't actually free-floating on top. It's pinned tightly to the frame with its tube ring and mounting bolts, together acting as a rigid cross brace in its own right.

Since the entire scope pivots in altitude on only those two ¼-inch bolts, Dave needed to add friction to that axis. He tried Teflon washers at first, but they were way too slippery. He then tested steel washers of various diameters before finally settling on 120-grit emery paper. That provided just the right amount of friction, which he can easily fine-tune by turning the knobs (custom made by Georgia Stamps) that tighten or loosen the bolts. He can remedy any imbalance in the scope by simply sliding the OTA up or down within its single tube ring.

The mount's base was initially rectangular, but Dave soon learned that he was catching the corners on things — especially his shins! — so he rounded the front end, which not only eliminated the shin-banging problem, but as

The parts are as simple as the finished product.

DAVID NEWTON (2)

▲ The three trolley wheels are angled to allow circular motion but resist sideways motion.

DAVID NEWTON

Dave says, "It helps to give the mount a proper front and back end shape, rather than looking like a hastily lashed together pallet."

Despite its small footprint, the mount doesn't tip over easily. And it's very easy to carry around. It weighs only 6 pounds, less than a quarter of the scope's 27-pound heft.

Dave reports that the mount works quite well on his backyard deck even though the deck has a grooved surface. The wheels are bigger than the grooves, so the irregularity presents no problem. On rougher ground he sets the scope on a small sheet of plastic or plywood or even a carpet square.

I think it would be pretty difficult to find a more minimalist altitude-azimuth mount for a 10-inch telescope. This is truly thinking outside the box.

Dave says, "Despite its somewhat rough-and-ready appearance, it's already become my go-to scope for short observing sessions. I can lift the whole assembly in one piece, set it down on the decking, and be ready to observe literally in a matter of seconds. Plus, my shins are now a little bit safer than they were last week."

For more information about constructing the Trolley Dob, contact Dave at **observatorydave@gmail.com**.

■ Contributing Editor **JERRY OLTION** appreciates the simple things in life.

CLOUDS OF ORION

David Wills

Billowing clouds of dust and gas separate M42 and M43, the Orion Nebula, from Sharpless 2-279, the Running Man Nebula, at top.

DETAILS: *Takahashi FSQ-85ED refractor with Starlight Xpress Trius Pro-694 CCD camera. Total exposure: 22 hours through Hα and RGB filters.*

◁ A WANING CRESCENT

Jim Thompson

This striking image of the crescent Moon features many eye-catching details, including Sinus Iridum (top), Copernicus (center), and Gassendi (lower center). Farther south, oblong craters Hainzel and Schiller (bottom) stand out in shadowed relief.

DETAILS: *MallinCam VRC-10 Ritchey–Chrétien telescope and ZWO ASI183MM Pro camera. Mosaic of 12 panels, each a stack of multiple video frames.*

▽ COMETARY VISITATION

Gregg Ruppel

Greenish Comet Atlas (C/2020 M3) glides past IC 410 in Auriga, which is commonly known as the Tadpole Nebula for the two backlit clouds of twisted gas left of center, pointing towards the open star cluster NGC 1893.

DETAILS: *10-inch f/3.7 ASA 10N Astrograph with SBIG STL-11000M CCD camera. Total exposure: 31¼ hours through Hα and LRGB filters.*

▷ MARS ON APPROACH

Enrico Enzmann and Damian Peach

Dusky Mare Cimmerium and the two protrusions known as Gomer Sinus stand out in this detailed image of Mars. The shrinking South Polar Cap (bottom) displays several rifts as it recedes.

DETAILS: *ASA EQ1000 Ritchey-Chrétien telescope with ZWO ASI290MM video camera. Stack of multiple frames recorded through RGB filters.*

▽ PERSEUS DOUBLE CLUSTER

Dave Doctor

NGC 884 (left) and NGC 869 (right) form a breathtaking pair of star clusters in Perseus. The ancient Greek astronomer Hipparchus was the first to catalog them in 130 BC as H and Chi (χ) Persei.

DETAILS: *Takahashi Epsilon-180ED astrograph with SBIG STXL-16200 CCD camera. Total exposure: 7½ hours through RGB filters.*

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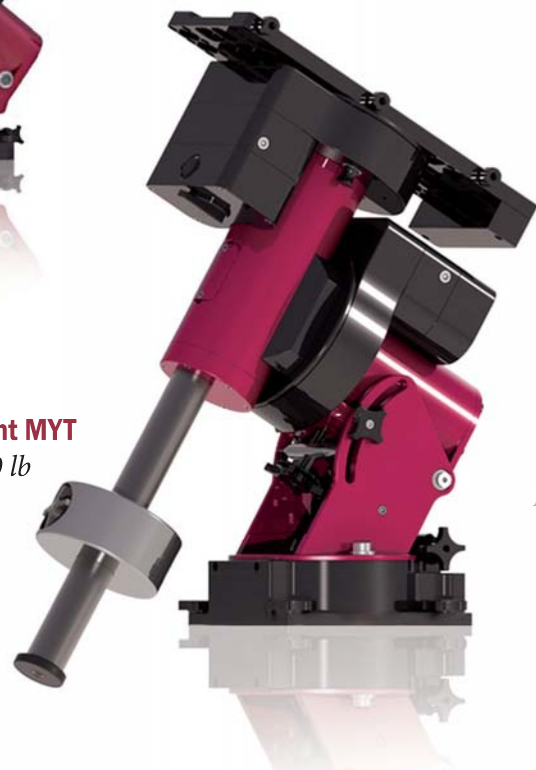

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LADY LIBERTY AND THE CONJUNCTION
Stan Honda
The Statue of Liberty appears to gaze at Jupiter (left) and Saturn just one day after the conjunction on December 21st, 2020, when they were 0.1 arc-minutes apart.
DETAILS: *Nikon D850 DSLR camera with 500-mm f/5.6 lens. Total exposure: ⅛ second at ISO 1600.*

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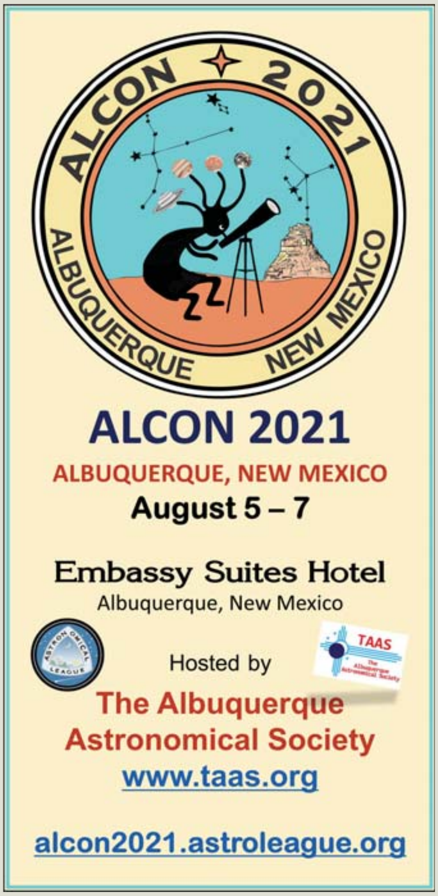

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Event Calendar

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/astronoborders

~~April~~ **CANCELED**
SOUTHERN STAR
Little Switzerland, NC
https://is.gd/southernstarcon

April 5-12
INTERNATIONAL DARK SKY WEEK
Everywhere!
idsw.darksky.org

April 7–10
MIDSOUTH STARGAZE
French Camp, MS
rainwaterobservatory.org/events

April 10
NORTHEAST ASTRONOMY FORUM
To be held virtually at:
rocklandastronomy.com/neaf1

May 2–9
TEXAS STAR PARTY
Fort Davis, TX
texasstarparty.org

May 15 (also October 9)
ASTRONOMY DAY
Everywhere!
https://is.gd/AstronomyDay

June 5–12
GRAND CANYON STAR PARTY
Grand Canyon, AZ
https://is.gd/GCSP_2021

June 9–12
BRYCE CANYON ASTRO FESTIVAL
Bryce Canyon National Park, UT
https://is.gd/brca_astrofest

June 9–13
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

June 10–13
CHERRY SPRINGS STAR PARTY
Cherry Springs State Park, PA
cherrysprings.org

June 10–13
WISCONSIN OBSERVERS WEEKEND
Hartman Creek State Park, WI
https://is.gd/WIObserversWeekend

June 10–13
BOOTLEG SPRING STAR PARTY
Harmon, IL
facebook.com/bootlegastronomy

June 11–13
MICHIANA STAR PARTY
Vandalia, MI
michiana-astro.org

June 25–27
RASC GENERAL ASSEMBLY
To be held virtually at:
rasc.ca/general-assembly

July 7–11
GOLDEN STATE STAR PARTY
Adin, CA
goldenstatestarparty.org

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

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The "Wow" Now

After four decades, a mysterious radio signal from space remains excessively elusive.

IN 1977, THE BIG EAR radio telescope at Ohio State University recorded the so-called Wow signal (*S&T:* Oct. 2012, p. 86). It was the best candidate for an interstellar radio signal found during the university's seven-year search for extraterrestrial intelligence (ETI). It's also one of the best ever reported and the most well known.

In the more than four decades since, I've searched for the Wow signal a half-dozen times, because detecting it a second time might mean the discovery of ETI. I'm not a professional astronomer, but I know enough about radio telescopes to use them in searches for ETI, and I usually collaborate with a trained astronomer.

Gerry Harp, some of his colleagues at the SETI Institute, and I recently had the longest listen ever for the Wow signal — 100 hours using the Allen Telescope Array in California. We've reached a conclusion about that enigmatic signal picked up so long ago. Before sharing that, though, I'd like to tell you about some of the possibilities that have been considered, to show what a thorough job has been done.

Perhaps, I thought early on, the signal just required patient observing to detect again. The Ohio State radio telescope could only "see" the spot on the sky from which the signal may have originated for a few minutes each day. I built a 12-foot radio telescope and looked at that spot for 15 minutes a day for several years. But I didn't see a repetition of the signal, possibly because the antenna was too small.

Perhaps the Wow was an occasional hailing signal intended to attract attention to a similar but weaker signal that's present all the time. With Kevin Marvel (American Astronomical Society), I looked for signals 100 times weaker using the Very Large Array with 27 antennas each 82 feet in diameter. But we found only feeble natural radio sources in one hour of observing.

Perhaps it was a lighthouse-like signal that illuminates us for a few minutes every few hours. Simon Ellingsen (University of Tasmania) and I observed for 14-hour stretches using the Hobart 26-meter radio telescope in Tasmania. But we found only the glow of hydrogen and some obvious interference.

Perhaps it was a transmission from the surface of a planet that pings us "daily" as the planet rotates. The 100-hour Allen search should have caught a signal repeating as rarely as once every terrestrial day or two. But we didn't find anything like the Ohio State signal in the expected area of sky.

Failing to find the Wow signal after so many attempts, we conclude that the signal was most likely humanmade, maybe due to an aircraft or satellite, although the 1420 MHz Wow frequency is protected worldwide. That's disappointing, but following up on good candidates is worthwhile. And it's just possible that some sort of signal is present that these searches missed, such as a very narrowband signal. Surprisingly, nobody has ever looked for a narrowband signal with a modern SETI system.

Although the Wow signal hasn't proved to be from ETI, there's still the chance that, if ETI exists, we may be able to detect its presence across the void by looking for technosignatures like radio signals and biosignatures in atmospheric gases (see page 34). Finding either one would be a historic discovery and tell us something about our place in the scheme of things.

■ **ROBERT GRAY**, a consultant based in Chicago, authored *The Elusive Wow: Searching for Extraterrestrial Intelligence*.

LEAH TISCIONE / *S&T*

Milky Way at Stellarvue Dark Sky Star Party. Image by Tony Hallas.