

Astronomy

The world's best-selling astronomy magazine

TOP 10 SPACE STORIES OF THE YEAR

p. 12

- THE MILKY WAY IN NEUTRINOS • LUNAR HITS AND MISSES
 - JWST SPOTS 'UNIVERSE-BREAKING' GALAXIES
 - THE COSMOS' BACKGROUND HUM • ANNULAR ECLIPSE DELIGHTS
 - AI AIDS THE SEARCH FOR PLANETS ... AND LIFE
- AND MORE!**

PLUS

Going after wide-angle sky targets
p. 42

Witnessing the Perseids from Turkey
p. 36

Vaonis telescope reviewed
p. 48

Build a novel eclipse viewer
p. 46

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ON THE COVER

This year's biggest astro stories include findings on neutrinos, mysterious galaxies, and magnetars. AUREORE SIMONNET FOR THE NANOGRAV COLLABORATION

FEATURES

12 COVER STORY
Top 10 space stories of 2023

We tuned in to a cosmic background hum, JWST upended our ideas about the early universe, and the new Moon race heated up. ALISON KLESMAN

22
China's deep-space ambitions

Buoyed by successes at the Moon and Mars, China is embarking on a science and exploration program of staggering scale. ANDREW JONES



28
Sky This Month
Mars and Venus meet. MARTIN RATCLIFFE AND ALISTER LING

30
Star Dome and Paths of the Planets
RICHARD TALCOTT; ILLUSTRATIONS BY ROEN KELLY

36
Exploring Turkey's dark-sky delights
A great night of meteors capped off a trip filled with adventures in caves, ancient cities, and hot-air balloons. DANIELA MATA

42
See these super-sized celestial gems
These objects look best through small scopes — or none at all. KEVIN RITSCHER

46
Eclipse viewing made simple
With some dollar-store reading lenses and a cardboard box, you can easily make your own solar viewer. PHIL HARRINGTON

48
Vaonis' new smart scope reviewed
The Vespera combines ease of use with complex technology in a lightweight package. RAYMOND SHUBINSKI



54
Ask Astro
Daytime astronomy.

COLUMNS

Strange Universe 10
BOB BERMAN

Secret Sky 50
STEPHEN JAMES O'MEARA

Observing Basics 51
MOLLY WAKELING

Binocular Universe 52
PHIL HARRINGTON

7
QUANTUM GRAVITY
Everything you need to know about the universe this month: the Lucy mission's double discovery, M87's spinning black hole, Euclid's first images, and more!

IN EVERY ISSUE

- From the Editor 4**
- Astro Letters 6**
- New Products 53**
- Advertiser Index 53**
- Reader Gallery 56**
- Breakthrough 58**

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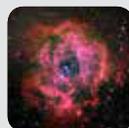


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A golden age of astronomy



Young stars like HL Tauri are giving radio astronomers new insights into the births of solar systems — just one of countless areas of research rocketing forward.

ALMA (ESO/NAOJ/NRAO)

One century ago Edwin Hubble discovered the nature of galaxies and unlocked the cosmic distance scale. We didn't really know of black holes until the 1990s, dark energy until 1998. We only discovered the structure of the Milky Way Galaxy in 2008. The examples go on and on.

The pace of astronomical discovery is now furious. I think it's reasonable to say that in the last generation, we've discovered as much as we had previously from the time of Galileo up to a generation ago.

This month's cover story (page 12) is penned by Senior Editor Alison Klesman, and offers details on the 10 most explosive discoveries or advances in research over the past year.

As the numbers of working astronomers have increased and the volume of research papers exploded, and building on previous discoveries, the sophistication of our knowledge has grown and become ever finer. We now report on viewing our galaxy in neutrinos, listening in on the universe's background hum, somewhat puzzling galaxies from the early days of the universe, a spectacular annular eclipse that washed over the Americas, and much more.

I hope you'll enjoy Alison's story and will also look forward to the countless exciting discoveries and areas of research that lie ahead.

Yours truly,

David J. Eicher
Editor

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In this often hectic life, we're never quite satisfied. We're always looking for improvements, stretching for more, wanting more, always seeking to expand our horizons. It's hardwired, just part of the human condition.

But have you taken a pause to reflect on how good we have it? As people interested in the cosmos, the origin, evolution, and fate of the universe, we are living in a truly golden age of astronomy.

Our species has been around for about 200,000 years. Modern astronomy, many have argued, began with Galileo training his telescope skyward just 414 years ago.

Astronomy

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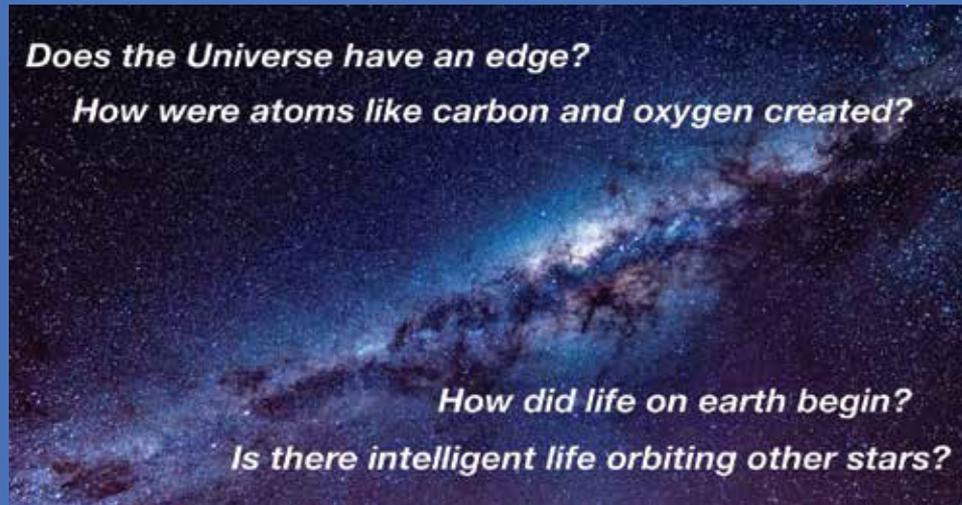
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The image of Mars featured in our September 1973 issue shows how far technology has come over 50 years of *Astronomy*.

STEVE REED



Photo highlight

I just received the 50th anniversary issue of *Astronomy* (August 2023) and was pleasantly surprised to see one of my photos from 50 years ago. I never realized that my Mars photo was the first amateur planetary photo to

appear in *Astronomy*. I've continuously subscribed since Vol. 1, Issue 1, and have enjoyed reading and watching your fine magazine grow over the years. May the next 50 years be even more successful for you! — **Steve Reed**, Montgomery, TX

→ We welcome your comments at *Astronomy Letters*, P.O. Box 1612, Waukesha, WI 53187; or email to letters@astronomy.com.

Please include your name, city, state, and country. Letters may be edited for space and clarity.

Complex beings

Your September 2023 cover article “Could Venus host primitive life?” prompted me to think that there is no

such thing as “primitive” life. Even lowly microbes on our planet depend on complex DNA structure and complicated energy-conversion processes (e.g., the Krebs cycle), as more evolved multicellular creatures do. The development and maintenance of living creatures on Earth likely originally resulted from the presence and availability of large amounts of organic compounds, and the formation of extravagant crystalline structures as precursors. So even the most humble of life (as we know it, at least) on Earth is not “primitive.”

— **Kenneth Lynn**, Glen Carbon, IL

Importance of art

Stephen O’Meara’s “Express Yourself” in the September 2023 issue immediately brings STEAM to mind. Most *Astronomy* readers know STEM education: science, technology, engineering, and mathematics. Perhaps fewer know of STEAM; that’s STEM with art included. Mr. O’Meara’s comments with the vivid visuals show how neatly these can all work together.

Come to think of it, would *Astronomy* magazine itself have lasted these 50 years without its inspiring graphics?

— **John Haley**, Huntsville, AL



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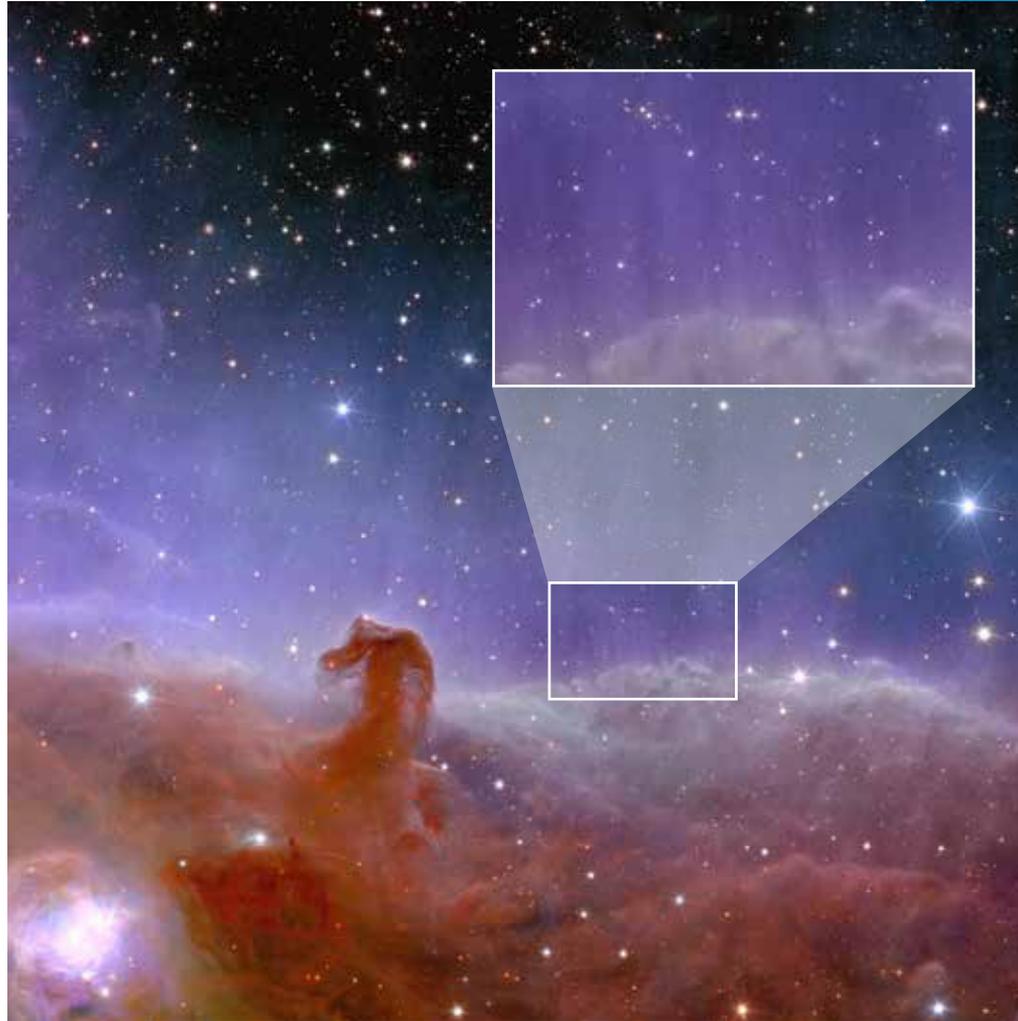
EUCLID'S FIRST VISTAS

In searching for the unknown, Euclid began with the familiar.

The Horsehead Nebula (Barnard 33) in Orion is an iconic target for backyard astrophotographers — and it was one of the first scientific targets for the European Space Agency's Euclid mission, which launched July 1, 2023, and released its first batch of images to the public Nov. 7.

"It's a familiar and beautiful nebula, but it's also a star-forming region," Euclid project scientist René Laureijs tells *Astronomy*. Euclid's ability to image large regions of space at high resolution — as demonstrated in the inset — is allowing scientists to search the Horsehead not just for stars, but also for rogue planets the size of Jupiter. These objects may have formed on their own or been ejected by their home stars. Finding them will tell us about how accreting objects fall into different mass ranges and form stars, brown dwarfs, and planets.

Euclid's overarching mission is to map the distribution of normal matter in the universe by peering back 10 billion years to some of the earliest galaxies. In doing so, scientists hope to uncover the fingerprints of dark matter and dark energy, which together account for 95 percent of the universe. — JOHN WENZ



HOT BYTES



SPINNING PROOF

M87 is the first galaxy whose central supermassive black hole has been confirmed to spin. Radio data show that the black hole's jet wobbles back and forth every 11 years, indicating the black hole is spinning like a precessing top.



ICY SMASH-UP

Astronomers reported a dramatic collision between two ice-giant planets 1,850 light-years away. A bright infrared glow spotted, by an amateur, in archival data was followed by a drop in visible light over three years later — thought to be the debris cloud slowly traveling across the host star.



BACK TO EARTH

After an extended stay on the International Space Station due to a coolant leak Dec. 14, 2022, NASA astronaut Frank Rubio and two Russian cosmonauts landed Sept. 27 near Kazakhstan. The trio spent 371 days in space, earning Rubio the record for the longest spaceflight by a U.S. astronaut.

NASA'S LUCY DISCOVERS SURPRISE ASTEROID ON 'DINKY' FLYBY

The craft zipped past Dinkinesh as a test run, but wound up discovering a new object.



THIS IS GETTING OUT OF HAND ...

During its flyby Nov. 1, Lucy discovered that its target, Dinkinesh, is not one, but two asteroids. Here, the smaller companion appears from behind the larger Dinkinesh. NASA/GODDARD/SWRI/JOHNS HOPKINS APL/NOIRLAB



Since its launch two years ago, NASA's Lucy mission has been traveling the inner solar system on its way to explore Jupiter's Trojan asteroids. Lucy is a flyby-only mission, meaning it won't stop to orbit any of its targets. Instead, it will take as much data as possible as it approaches, passes, and pulls away from each asteroid on its list.

But thanks to Lucy's Terminal Tracking System (TTS) — a pair of cameras that image its targets as Lucy approaches — the craft will get up-to-the-minute position information that allows the instruments to autonomously determine when it will be best to collect valuable data.

On Nov. 1, 2023, Lucy zipped past 152830 Dinkinesh, a tiny main-belt asteroid less than half a mile (0.8 kilometer) wide. The flyby, intended to test the TTS, saw Lucy pass within

just 300 miles (480 km) of Dinkinesh, and revealed not one, but two asteroids: the larger Dinkinesh and a smaller, 0.15-mile-wide (220 meters) companion. That brings Lucy's total number of targets up to 11; the mission was launched intending to visit nine asteroids, with Dinkinesh only added earlier this year.

And if that bonus wasn't enough, more detailed images delivered a few days later found that Dinkinesh's satellite is actually two bodies in permanent contact with one another, known as a contact binary. Initial images of the Dinkinesh system, which first saw the moon, did not catch the contact binary because one lobe sat directly behind the other from that point of view. Although such two-lobed asteroids are common in the solar system, researchers have had few opportunities to study them up close. This is the first known contact

Cosmological simulation milestone

THE DYNAMICAL DANCE of physics can entrance — especially when modeled in vast supercomputer simulations of the cosmos. A new project dubbed FLAMINGO is one of the most detailed simulations to date, taking place in a virtual volume of space over 9 billion light-years on a side filled with 300 billion particles, each the size of a small galaxy.

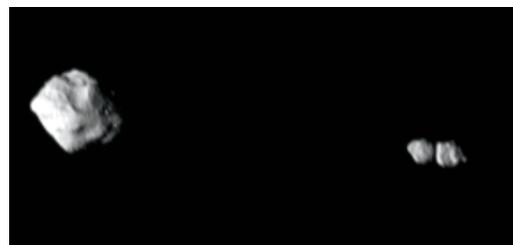
But what makes FLAMINGO truly stand out is that it incorporates the effects of both dark matter and normal matter. Such simulations often focus on dark matter, the invisible stuff that scientists think makes up around 85 percent of the matter in the universe. This is convenient, because according to theory, dark matter barely interacts (or collides) with normal matter, meaning it can be modeled purely through gravity.

But normal (or baryonic) matter — despite only making up 15 percent of the matter in the universe — can't be ignored. For instance, the supermassive black holes at the centers of galaxies feed on normal matter, which generates magnetic fields that fire matter back out into the void. These winds collide

binary that is a satellite of another asteroid.

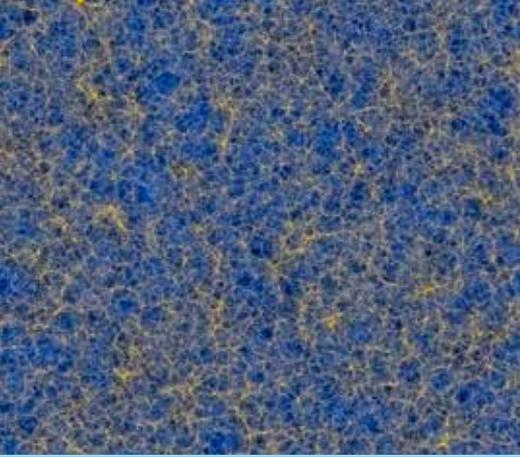
Lucy's next objective involves heading toward Earth for a gravity assist in December this year. The craft will then take images of another main-belt asteroid, 52246 DonaldJohanson, which is five times the size of Dinkinesh, on April 20, 2025. Lucy will begin its primary mission to study Jupiter's Trojan asteroids in 2027.

— ALISON KLESMAN, SAMANTHA HILL



... NOW THERE ARE TWO OF THEM! Six minutes after Lucy's closest approach to Dinkinesh, the craft snapped this image, revealing that the satellite is a contact binary.

NASA/GODDARD/SWRI/JOHNS HOPKINS APL



TANGLED WEB. The filaments of the cosmic web are apparent in this slice of a FLAMINGO simulation, 9.1 billion light-years wide. JOSH BORROW, THE FLAMINGO TEAM AND THE VIRGO CONSORTIUM

with intergalactic material, which, in turn, affects the growth of new galaxies. This means that cosmologists have to incorporate fluid dynamics into their simulations — a computationally intensive realm of physics — and FLAMINGO is the largest to do so. (FLAMINGO stands for Full-hydro Large-scale structure simulations with All-sky Mapping for the Interpretation of Next Generation Observations.)

FLAMINGO also includes the effects of dark energy, the unknown force causing the universe's expansion to accelerate. Cosmologists use simulations to test their theories, tuning parameters to find out which

values generate universes that resemble what astronomers see today.

Some of the most intriguing results in recent years have emerged when those values don't match the ones we observe. The most famous example is the so-called Hubble tension, a discrepancy between predictions and observations of the Hubble parameter, which describes how quickly the universe is expanding.

FLAMINGO is helping researchers investigate another issue, called the S_8 tension. In the standard model of cosmology, S_8 is a parameter that describes how unevenly distributed matter is in today's universe. Astronomers can measure this by studying how massive objects like galaxy clusters bend (or lens) light. It turns out that the universe is less clumpy than simulations predict, meaning those simulations are missing something that appears to prevent matter from clumping together over time.

The team wondered whether that missing something might be the effects of ordinary matter that FLAMINGO has introduced. But their initial analysis of FLAMINGO results suggests that those effects are not enough to account for the S_8 tension, leaving it an open mystery.

— MARK ZASTROW

QUICK TAKES

BRR, IT'S CO₂ IN HERE

JWST has detected carbon dioxide in geologically young regions of the surface of Jupiter's icy moon Europa. Scientists think the CO₂ may have originated from the moon's subsurface ocean, which suggests that the ocean could be friendly to life.

DINOSAURS' TRUE KILLER

Simulations based on dust recovered from a geological site in North Dakota suggest that the Chicxulub asteroid impact 66 million years ago kicked up more light-blocking dust than previously thought. This shut down photosynthesis for two years, sealing the dinosaurs' fate by eliminating major food sources.

TAKING UAPs SERIOUSLY

NASA announced on Sept. 14 that it would assign a team to help the U.S. government better understand unidentified anomalous phenomena (UAPs) — previously known as UFOs.

FAR, FAR AWAY....

NASA's Chandra X-ray Observatory and JWST have discovered a supermassive black hole growing in a galaxy just 470 million years after the Big Bang. It is the most distant black hole ever seen in X-rays and may offer clues to how the first such black holes formed.

FROM HOMAGE TO OUTRAGE

Virgin Galactic's Sept. 8 commercial spaceflight was criticized for carrying two ancient hominin fossils in an intended celebration of discovery. Researchers labeled the journey an unethical publicity stunt that put priceless cultural heritage at risk for no scientific return.

BLAST OFF!

NASA launched the Psyche spacecraft on Oct. 13 at 10:19 A.M. EDT from the Kennedy Space Center in Florida. The craft will study the strange, metal-rich asteroid 16 Psyche for 21 months to shed light on the formation of the solar system's planets. — DANIELA MATA

JWST CATCHES SUPERSONIC JET

A GASEOUS OUTFLOW

streams away from a young star just a few tens of thousands of years old and a mere 8 percent as massive as our Sun in this striking James Webb Space Telescope image of Herbig-Haro object HH 211. The object, which lies about 1,000 light-years away in Perseus, intrigues astronomers because it provides a look at a star system still in the stages of formation. In this image, jets of gas expelled at supersonic speeds by the young star are visible as they slam into the surrounding interstellar medium. A series of bow shocks at lower left and upper right appear pink-orange. Based on the way the jet is wobbling as it moves, astronomers think the protostar at the center may be an unresolved binary. Researchers also noted that the outflow of HH 211 primarily consists of molecules rather than separate atoms. Evidently, very young protostars like HH 211 are not yet able to generate outflows and shocks powerful enough to split the molecules apart when the jet hits the surrounding material. — ELIZABETH GAMILLO



ESA/WEBB, NASA, CSA, TOM RAY (DUBLIN)

Celestial fun

An astronomer's pleasure has several components.



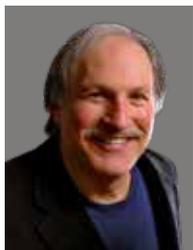
Countless people find astronomy fun, and for many good reasons. NPS/BRAD SUTTON



Our readers could probably recite a dozen reasons they put up with freezing air, fogged lenses, expensive accessories, and time-consuming mount collimation in order to experience hands-on astronomy.

Backyard astronomers often uncover new secrets like variable star anomalies and never-before-seen comets that advance our science. But while saluting those dedicated amateurs, let's admit most of us are mainly in it for fun. And if the frustrations sometimes mask the enjoyment, maybe we should occasionally remind ourselves of astronomy's unique highs, since our rewards can assume unusual forms found nowhere else. Sure, those who've earned an astrophysics Ph.D. have the satisfaction of being able to handle differential calculus to probe the orbital secrets of mysterious objects — like whatever it is that orbits Epsilon (ε) Aurigae every 27 years and weirdly cut its light in half. For the rest of us, though, our fun comes in various forms.

First, though, what exactly do we consider fun? Some of us find it fun to test ourselves, especially to lay our eyes on odd, wonderful sights. For instance: As claustrophobic and stuffy as the Giza pyramid's main passageway was, and as painful as it was to walk steeply bent over through its 4-foot-high (1.2 meters) passageway feeling suffocatingly entombed beneath a million tons of limestone and granite, I felt I should do it once in this lifetime. At the eyepiece, one never feels any comparable psychological terror — unless you count the horror as you watch your savings drain into the cost of your dream telescope.



BY BOB BERMAN
Bob's recent book, *Earth-Shattering* (Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.

So, what exactly makes astronomy fun? Let's dissect its little-explored aspects.

- **Challenge.** As in the case of my pyramid story, succeeding at tough tasks is enjoyable to many people. Astronomy offers great challenges, and sometimes they're not even terribly hard. I still feel elated 40 years after glimpsing Uranus and the asteroid Vesta with just the naked eye.

- **Weirdness.** Strangeness holds an undeniable attraction. People still sneak into Centralia, Pennsylvania, because an underground fire has been raging there for a half-century. Similarly, while the Cygnus star HDE 226868 (better known as Cygnus X-1) only looks like a pinpoint through a backyard instrument, you can take pleasure in its strangeness if you know you're looking at an invisible black hole hurtling around the massive star visible in your eyepiece. It offers unique satisfaction.

- **Beauty.** Many fight crowds to get a quick glimpse of the *Mona Lisa*. Sure, she's got a nice smile. But the thing is, beauty produces a singular kind of pleasure even if there's no rational explanation for it. So when our eyes land on a gorgeous celestial object, we recognize it on the spot. A bright comet. Saturn's rings. Vega through a spectroscope, its colors purer and more intense than any rainbow. We may be all alone at the eyepiece, but we're grinning like — well, like Ms. Lisa.

- **Philosophy.** What is the meaning of everything? Yeah, good luck with that. Nonetheless, there's something about a rich-field exploration of the Milky Way that conjures a sense of infinitude. What you make of that wonderful feeling may be a private excitement. But it's not nothing. And anyone who thinks part of observing's fun isn't being totally pulled away from the trivialities of the 6 o'clock news hasn't been looking through the right end of their instrument.

- **Sharing.** Rarely in life can you share something perfectly. You and a buddy could both look at a mountain, but your companion might focus on clouds sweeping its summit while you're into the late-day orange sun glinting off snowy outcrops. But a telescope's field of view is self-defining. If the Orion Nebula is centered, a friend's turn at the eyepiece will reveal pre-

cisely the same gassy, gull-wing curves that enchanted you a minute earlier.

No wonder an astro-session's soundtrack often includes giggles and applause, even if they're only heard by Orion and the occasional owl.

A note to my readers: Due to changes, this is the final Strange Universe, and I will miss you all. It's been an honor to explore this eccentric cosmos with you for the past quarter-century. ♪

What exactly makes astronomy fun?



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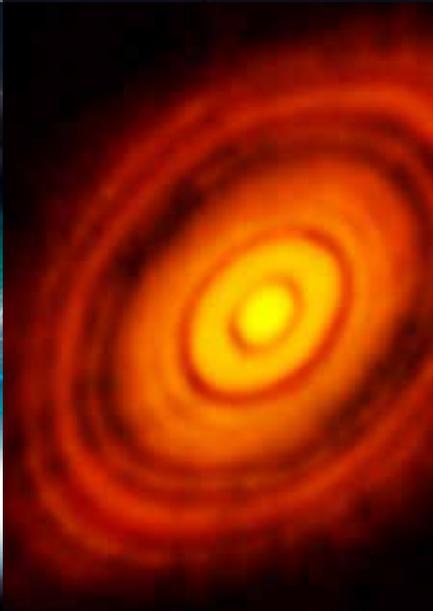
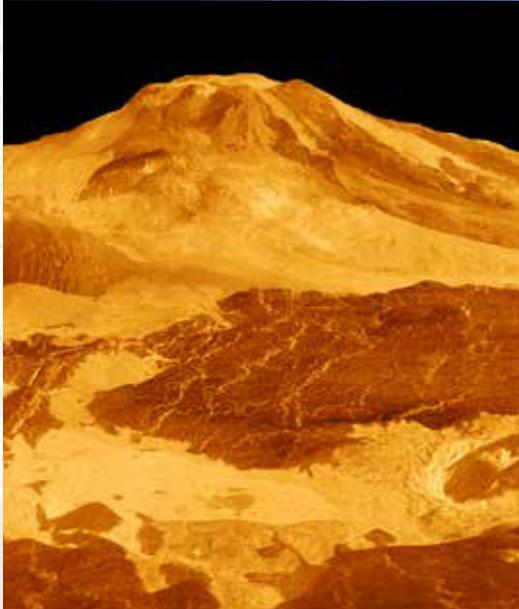
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TOP 10 SPACE STORIES OF 2023

We tuned in to a cosmic background hum, JWST upended our ideas about the early universe, and the new Moon race heated up. **BY ALISON KLESMAN**

NEW TOOLS AND TECHNIQUES can be transformative. Last year proved this time and again, as researchers took the first picture of the Milky Way Galaxy with particles instead of photons and an innovative team turned stellar corpses across the galaxy into one big gravitational-wave detector capable of tuning into the background “hum” of our cosmos. Among the many stunning results from the groundbreaking James Webb Space Telescope, new finds began to challenge astronomers’ picture of the early universe.

There was plenty of excitement closer to home, too. Numerous comets sent sky-watchers and astrophotographers rushing outside, while eager planetary scientists finally got their hands on the largest sample ever returned to Earth from a carbon-rich asteroid. And an annular eclipse across the Americas set the stage for totality in April 2024. Overall, 2023 was an exciting year of discovery that proved that patience, ingenuity, and vision can offer amazing payoffs.

10

OSIRIS-REX DELIVERED ITS PAYLOAD — AND THEN SOME

OUR FEBRUARY 2022 Top 10 list notes that on May 10, 2021, NASA's Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer (OSIRIS-REx) mission had turned toward home following its collection of material from the near-Earth asteroid Bennu.

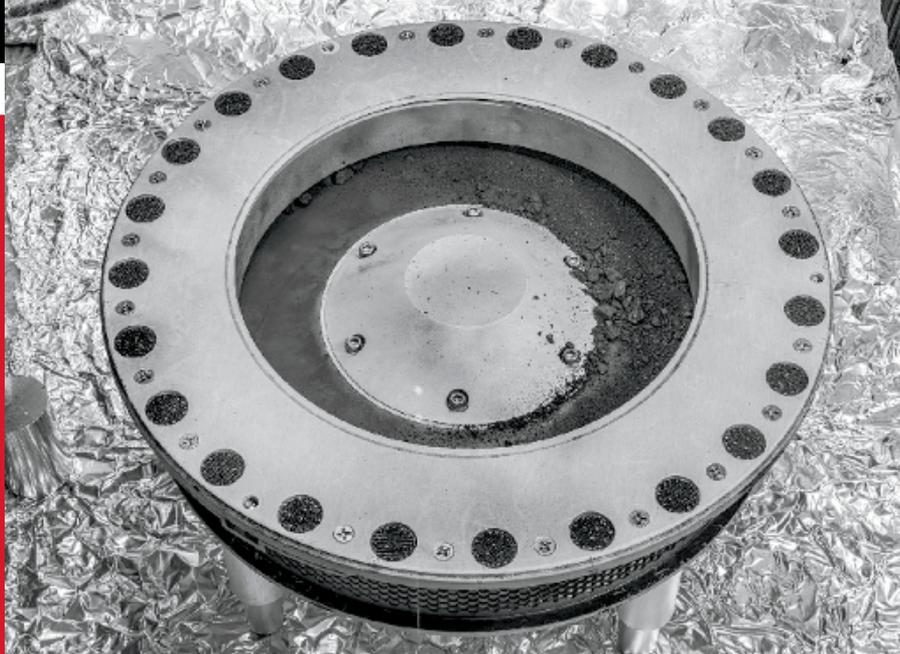
Last year, that effort came to fruition. Just before 9 A.M. MDT on Sept. 24, 2023, a beautiful sight appeared in the skies above Utah: the craft's sample-return capsule (SRC) safely falling to Earth beneath its broad, orange-and-white striped parachute. The capsule, which had been released just hours earlier when the spacecraft was 63,000 miles (102,000 kilometers) from Earth, landed on target at the U.S. Air Force's Utah Test and Training Range.

The next day, the SRC flew via cargo plane to NASA's Johnson Space Center in Houston, where a team waited to catalog and disassemble the canister and

its attached sampling mechanism, called the Touch-and-Go Sample Acquisition Mechanism (TAGSAM). These were first placed inside sealed "gloveboxes," preventing the samples from being exposed to Earth's atmosphere.

It was slow going: The TAGSAM and canister lid were coated in so much extra material that collecting and cataloging it before the canister itself could be accessed required exquisite care. It was "the very best 'problem' to have," said deputy OSIRIS-REx curation lead Christopher Snead in a statement. It's

Before researchers could open OSIRIS-REx's TAGSAM sample collector, they first had to gather and catalog the copious "bonus" material outside the canister, whose still-sealed lid is shown here. NASA/
ERIKA BLUMENFELD & JOSEPH AEBERSOLD



also a "problem" that researchers had anticipated, given the material seen overflowing from the TAGSAM head following the collection maneuver Oct. 20, 2020, when the TAGSAM sank some 20 inches (50 centimeters) into the asteroid.

By Oct. 11, 2023, NASA hadn't yet opened the canister. But the agency

9

A VOLCANO MAY HAVE ERUPTED ON VENUS IN 1991

PLANETARY SCIENTISTS are looking forward to the wealth of future data from Venus, with several missions preparing to visit the world in the coming years.

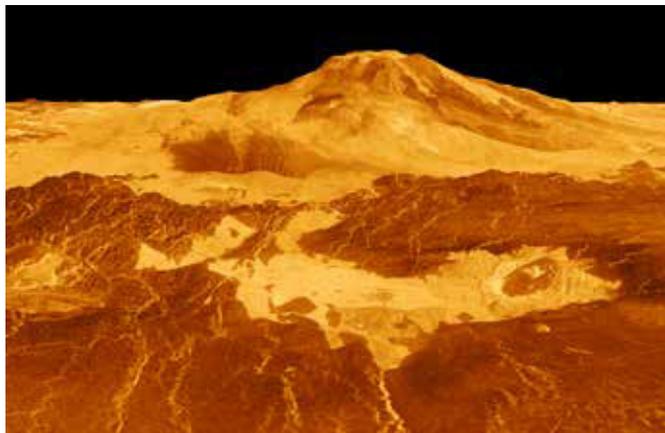
But new discoveries are still hiding within older, existing data, as a March 15 *Science* study proved.

In it, researchers examined some 200 hours of radar observations of Venus' surface taken by the Magellan spacecraft, which orbited the world from 1990 to 1994, mapping the entire surface. By looking for changes between different orbits, the team spotted direct evidence — the first ever seen — of recent volcanic activity on Venus.

"I saw two images of the same region taken eight months apart exhibiting telltale geological changes caused by an

eruption," explained Robert Herrick of the University of Alaska Fairbanks, who led the study, in a press release.

The images featured a region near Venus' equator that hosts some of the planet's largest volcanoes, including Maat Mons. Herrick spotted changes that occurred between



This 3D model of Maat Mons on Venus was generated using radar data from NASA's Magellan mission. Researchers carefully studying successive passes of the spacecraft noticed changes in a vent associated with the volcano that indicate ongoing modern-day activity. NASA/JPL

8

ASTRONOMERS IDENTIFY A POSSIBLE MAGNETAR PRECURSOR

revealed the results of an initial analysis of the excess material: Bennu is rich in carbon and hydrated clays, compounds that contain significant water. This means organic molecules — the building blocks of life — may also be present. Researchers also found sulfides, a necessary component of amino acids. These results bode well for scientists interested in the abundance and role of such materials in the early solar system and the development of life on Earth — and potentially elsewhere. Asteroids provide the perfect starting point for study, as they both contain pristine material that dates to the solar system's birth and are thought to be the main vehicle for delivering many elements, including water, to the young Earth.

NASA collected 2.48 ounces (70.3 grams) from the hardware alone, exceeding the mission's goal of retrieving 2.12 ounces (60 g) from Bennu before the sample proper was ever accessed. And with its precious cargo dropped off, the spacecraft is now headed to the near-Earth asteroid Apophis, which it will study up close starting in April 2029. Accordingly, the craft has a new name: OSIRIS-APEX, for APophis EXplorer.

MAGNETARS ARE objects with magnetic fields a thousand trillion times stronger than Earth's. They are a subclass of neutron stars, the remnants of massive stars. But while astronomers know how run-of-the-mill neutron stars are formed, they aren't sure yet of the specific conditions that create a magnetar, whose magnetic field is some 100 to 1,000 times stronger than a neutron star's.

At least part of the answer might lie in a star called HD 45166, the subject of a paper published Aug. 17 in *Science*. HD 45166 is a Wolf-Rayet star; these massive, helium-rich stars typically weigh 25 times the mass of the Sun and blast out powerful winds of charged particles. Because of their high mass, they rapidly fuse hydrogen into helium in their cores, living for a fraction of the Sun's lifetime before exploding as supernovae and leaving behind neutron stars or black holes.

But HD 45166 is an oddball among Wolf-Rayets at only 2 solar masses — a real lightweight. And its magnetic field has a strength of 43 kilogauss, or 100,000 times stronger than Earth's magnetic field. That makes it the most magnetic massive star ever found.

"We've never detected a magnetic field in a massive helium star that will

undergo core collapse [a type of supernova]," says study leader Tomer Shenar of the University of Amsterdam. "It's really a new type of star." Shenar and his colleagues think HD 45166 didn't evolve the way other Wolf-Rayets do (as part of some massive stars' life cycles), but perhaps as the product of a merger between two other more intermediate-mass helium-rich stars.

Despite the staggering strength of HD 45166's magnetic field, it is still 10 billion times below that of a magnetar. But in a few million years, when HD 45166 explodes as a supernova and leaves behind a neutron star, its magnetic field will be confined to a region just 12 miles (20 km) across — the size of a typical neutron star. Because magnetic flux is conserved, compressing the field will boost its strength by about 10 billion times, creating a magnetar.

"We thought that the most likely magnetar candidates would come from the most massive of stars," said study co-author André-Nicolas Chené of the National Science Foundation's National Optical-Infrared Astronomy Research Laboratory in Hilo, Hawaii, in a statement. "What this research shows us is that stars that are much less massive can still become a magnetar, if the conditions are just right."



This three-panel illustration shows the HD 45166 system, which contains a massive Wolf-Rayet star with a powerful magnetic field (right) in a binary with a companion star (left). The top panel shows the system as it is today, while the middle shows the Wolf-Rayet star's death in a supernova explosion. The blast will leave behind a highly magnetic neutron star (bottom) called a magnetar.

NOIRLAB/AURA/NSF/P. MARENFIELD/M. ZAMANI

February and October 1991 in a vent on the volcano's lower slopes. When compared with the earlier images, the October data showed that the previously circular vent had roughly doubled in size and become distorted in shape. It also seemed to have filled with lava, with some even flowing downhill, away from the vent.

This analysis was no simple task. The data resolution was low and the images had been taken from different angles. Comparing them required modeling the vent to explore all possible explanations, including passive landslides. But ultimately, "only a couple of the simulations matched the imagery, and the most likely scenario is that volcanic activity occurred on Venus' surface during Magellan's mission," said study co-author Scott Hensley of NASA's Jet Propulsion Laboratory, an expert in analyzing radar data. Provided their interpretation is correct, then, "it confirms there is modern geological activity" on Venus, he said.

The idea has far-reaching implications. Venus has more volcanoes than any other planet, but scientists previously believed none were active over the past billion years. If one volcano is still active, why not more? The more we study Earth's twin, the more we find there is still much to learn about how rocky planets form and evolve.



Several comets dazzled skywatchers and astrophotographers alike in 2023. Comet Nishimura, photographed here on Sept. 8 from Martinsberg, Lower Austria, took the crown. GERALD RHEMANN

7

COMETARY SURPRISES DELIGHT

COMETS ARE notoriously unpredictable. In 2023, that worked in our favor, with three particularly notable comets stealing attention.

The year opened with what we expected to be its best comet: C/2022 E3 (ZTF), which reached perihelion — the closest point to the Sun in its orbit — on Jan. 12. On Feb. 1, ZTF passed closest to Earth, coming within about 0.3 astronomical unit of our planet. (One astronomical unit, or AU, is the average Earth-Sun distance.) During its visit, ZTF ultimately reached magnitude 4.5 and developed a well-defined anti-tail seen in many photographs.

Magnitude 4.5 is also the brightness our next visitor, 12P/Pons-Brooks, is expected to reach in April this year, weeks before perihelion. That's when, as first noted by amateur astronomer Dave Weixelman, it will appear some 24.5° from the Sun during the total solar eclipse April 8.

But Pons-Brooks wasn't willing to wait for fame. On July 20, 2023, observer Elek Tamás went looking for the then-magnitude 16.6 comet — and discovered an outburst had catapulted it to magnitude 11.6. By early October, the comet had faded only slightly — and underwent a

second outburst Oct. 5, reaching roughly the same magnitude as in July. Both times, the comet displayed a unique “horned” or horse-shoe shape, earning it the nickname “devil comet.” According to comet researcher Richard Miles (who spotted the second outburst), Pons-Brooks has had similar flare-ups during past visits to the inner solar system. Perhaps it's had yet another since this issue went to press!

Avid skywatchers already know we've saved the best for last: Comet ZTF was not 2023's best. That title goes to C/2023 P1 (Nishimura), which burst onto the scene Aug. 12 when Japanese amateur astronomer Hideo Nishimura of Kakegawa, Japan, spotted it in Gemini, already at magnitude 10.4 and 1 AU from the Sun. Nishimura passed closest to Earth a month later, before rounding the Sun at a perihelion distance of just 0.23 AU on Sept. 17, peaking at an impressive magnitude 2.5. After perihelion, it disappeared from Northern Hemisphere skies and could only be picked up below the equator as it faded quickly on its way back to the outer solar system.

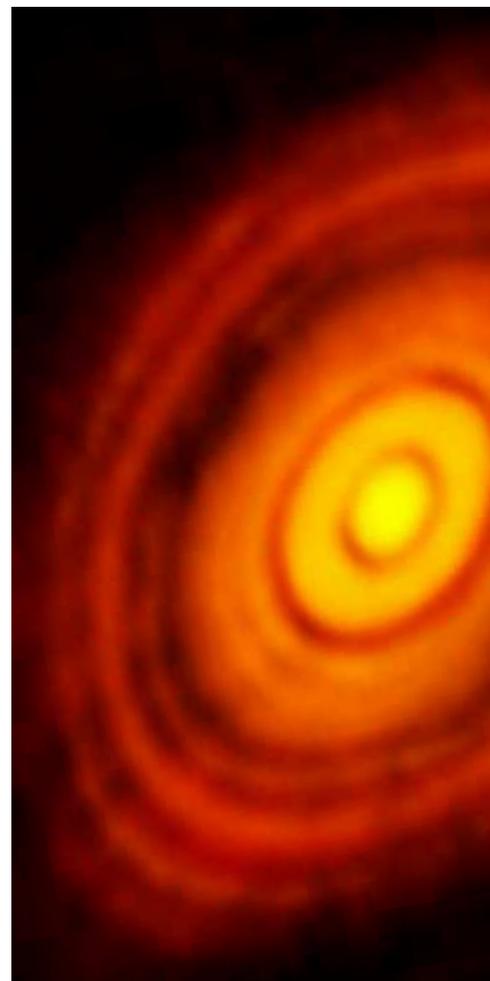
Its appearance was brief and it was never an easy naked-eye object due to its low elevation. Nonetheless, Nishimura was the definitive winner of 2023's cometary crown.

6

AN ANNULAR ECLIPSE CROSSES THE AMERICAS

ON OCT. 14, an annular solar eclipse crossed parts of North, Central, and South America. Although many considered the event a “preview” of 2024's total eclipse, October's annular eclipse was more than just a prelude. It was stunning in its own right, a once-in-a-lifetime event for millions of people that offered its own unique reward.

While a total solar eclipse lets earthbound observers glimpse the Sun's outer atmosphere, called the corona, an annular solar eclipse occurs when the Moon is too far from Earth to cover the Sun's disk completely. A thin sliver of the solar disk is left around the Moon, often called the ring of fire.



October's ring of fire began in the Pacific Ocean before moving from Oregon through Texas as the first U.S. annular eclipse in more than a decade. The next will not occur until 2041. Some 6.6 million Americans lived in the path of annularity, with roughly half that number in Texas alone. Millions more lived within just a few hundred miles of the center line. Observers beneath the shadow experienced some four-plus minutes of annularity, with parts of Texas seeing nearly five minutes.

After leaving Texas, the eclipse passed through parts of Mexico, Central America, Colombia, and Brazil, finally ending over the Atlantic Ocean.

Eclipses offer unique opportunities for science, both on the ground and above it. For instance, NASA launched three sounding rockets from New



The Oct. 14, 2023, annular solar eclipse brought a ring of fire to those in the path. This image was taken from the X Bar Ranch in Eldorado, Texas, just 4 miles (6.4 km) from the center line. ALLEN MITCHELL

Mexico — one before, one during, and one after the eclipse — as part of the Atmospheric Perturbations around the Eclipse Path mission to study how eclipses affect Earth's upper atmosphere, particularly the ionosphere. This region is affected by variations in sunlight when the Sun naturally sets or rises, changing the amount of incoming ultraviolet radiation that can alter the properties of the atoms there.

If October's annular eclipse whetted your appetite, you're in luck — a total solar eclipse will soon cross North America, bringing the Moon's shadow back to Earth along a path that includes the homes and businesses of 31.6 million Americans. With millions more again within driving distance, April 8 is sure to be one of 2024's most noteworthy dates.

5

AI AIDS THE SEARCH FOR PLANETS ... AND LIFE

HEADLINES IN 2023 were often dominated by the way AI is changing our world. And although the use of machine-learning tools in astronomy isn't new, the practice began to see more attention in 2023 (including a feature in our July issue).

A Jan. 30, 2023, paper in *Nature Astronomy* showed how scientists searching for alien civilizations used AI to sift through nearly 500 hours of radio signals from over 800 stars. They were looking for patterns that couldn't be natural, while throwing out interference from human technology. The algorithm pared down nearly 3 million events to just 20,515, which were examined by eye to ultimately identify eight possible technosignatures — signs of a technologically advanced civilization — from five stars. The signals were not seen when these stars were re-observed — so we haven't found aliens yet. But the researchers noted the technique had fulfilled its purpose by identifying specific signals for follow-up.

Radio observations of the young star HL Tauri reveal a massive protoplanetary disk of dust and gas surrounding the star (at the center). Nascent planets can affect the material orbiting in the disk, causing instabilities and carving out gaps. Researchers are now using AI to help identify subtle signs of planet formation within such disks. ALMA (ESO/NAOJ/NRAO)

An April 21 paper in *The Astrophysical Journal* showed that machine-learning tools can identify planets forming in the disk of dust and gas around a star. A team led by Jason Terry of the University of Georgia in Athens developed an algorithm to search images for the subtle signs of fledgling planets, which affect the orbit of nearby material and eventually carve out gaps in the disk. Not only did their model “rediscover” known planets, it also flagged a planet around the star HD 142666 that researchers *hadn't* spotted. Terry's team followed up and confirmed a likely forming planet there, demonstrating the model's potential. “We think there will be an important place for these types of techniques as our datasets get even larger,” Terry said in a press release.

On Sept. 25, a paper in *Proceedings of the National Academy of Sciences* presented a machine-learning algorithm that could determine whether a sample of material was produced by life or through natural (abiotic) processes. And it could do so with 90 percent accuracy. The technique can be applied with existing technology and used on future space missions — or trace the history of ancient life on Earth.

These are just highlights from a year filled with AI-assisted discoveries. There will doubtless be many more in the years to come.

4

LUNAR HITS AND MISSES

IN LATE 2022, NASA's uncrewed Artemis I successfully completed its trip around the Moon, splashing down Dec. 11 that year. Spending about a month in flight, the mission largely served as a test of the new Space Launch System rocket and Orion crew spacecraft. Now, NASA is gearing up for Artemis II, scheduled to launch in November 2024



for a 10-day round-the-Moon flight. On April 3, 2023, the agency announced the mission's crew: NASA astronauts Reid Wiseman, Victor Glover, and Christina Koch, and Canadian Space Agency astronaut Jeremy Hansen.

But the U.S. isn't the only one with eyes on the lunar prize. On Aug. 23, 2023, India became the fourth country to successfully land on the Moon when its Chandrayaan-3 mission touched down some 370 miles (600 km) from the lunar south pole, the closest landing to the pole to date. NASA is targeting this coveted region for its crewed Artemis III landing, as the terrain there may contain water ice useful for fuel and other needs.

One day after landing, India's 3-foot-long (90 centimeters), 60-pound (27 kilograms), solar-powered Pragyan rover rolled out of the Vikram lander. For two weeks, the pair studied the lunar surface, even detecting a possible moonquake Aug. 26. Both went into sleep mode for the coming lunar night, also two weeks long. Neither craft had been designed to withstand the frigid temperatures of nighttime on the Moon; nonetheless, the mission team hoped they would reawaken when day broke over

The Pragyan rover took this image of the Vikram lander on the lunar surface Aug. 30, a week after landing. The rover was about 49 feet (15 m) from the lander at the time; it ultimately traversed a total of 330 feet (100 m). ISRO

3

ASTRONOMERS LISTEN IN ON THE COSMOS' BACKGROUND HUM

GRAVITATIONAL WAVES are ripples in space-time that arise from extremely energetic events, such as the collisions of neutron stars or black holes. Since their first detection in 2016 by the Laser Interferometer Gravitational-wave Observatory (LIGO), gravitational waves have given us a new way to study the universe — and 2023 brought a fresh twist.

Scientists are limited to studying a narrow range of gravitational waves. That's because their wavelength, or the distance between successive crests of each wave, is proportional to the masses of and the distance between the objects creating them. This means a pair of stars orbiting in a tight binary create shorter-wavelength gravitational waves than do merging supermassive black holes with millions or billions of times the mass of the Sun. In fact, supermassive black hole mergers can create gravitational waves with crests tens of light-years apart.

Detecting such long-wavelength

gravitational waves is beyond current observatories like LIGO and Virgo, which only catch the high-pitched "chirps" of binary objects a few to about 100 times the Sun's mass. These signals represent the last minutes or seconds of a merger, as the objects circle ever closer before slamming together, all the while releasing angular momentum as gravitational waves.

For supermassive black holes, this process plays out over a much greater span of time. When galaxies merge, their individual supermassive black holes sink to the center and eventually merge over some 100 million to 200 million years. During that time, other galaxies elsewhere in the universe will merge as well, and their black holes will begin their own hundred-million-year inward spiral.

"If there's a lot of these [long-wavelength] gravitational-wave signals, they can add together and give you a gravitational-wave background," said Yale University Assistant Professor of Physics Chiara Mingarelli in a video release. Mingarelli is part of the North American

Nanohertz Observatory for Gravitational Waves (NANOGrav) collaboration, which announced the first-ever detection of this background June 29 in several papers in *The Astrophysical Journal Letters*.

Without instruments tuned to long wavelengths, the NANOGrav collaboration looked to fast-rotating neutron stars called pulsars. As a pulsar spins, it shoots beams of radiation from its poles; every revolution, these beams sweep over Earth like light from a lighthouse. The beams' arrival is incredibly regular, down to a fraction of a second, turning each pulsar into its own highly accurate cosmic clock.

NANOGrav monitored a network of 67 pulsars throughout the Milky Way for 15 years, looking for tiny shifts in the timing of the arrival of their beams. These occur when a gravitational wave passes by, subtly squeezing or stretching the space-time between the pulsar and Earth, causing the signals to arrive slightly sooner or later than expected, respectively. "Like a huge ocean swell, the stars in our galaxy are all moving in concert to waves in

INDIA'S SECOND SUCCESS STORY

Shortly after Chandrayaan-3's landing, India successfully launched its Aditya-L1 mission to study the Sun on Sept. 2. Originally conceived in 2008 as a small Earth-orbiting satellite, the craft evolved into a five-year-long mission that will orbit the Sun at Lagrange point 1 (also called L1), about 900,000 miles (1.5 million km) from Earth. There, it will continuously monitor

our star with a payload of seven instruments, providing unique views not available on other solar missions, such as multi-wavelength observations near the solar limb and images in previously unobserved ultraviolet wavelengths. Overall, Aditya-L1 aims to answer questions about the



Sun's super-hot outer atmosphere, the corona, as well as how the star's magnetic field generates space weather and affects our atmosphere here on Earth.

Both Aditya-L1 and Chandrayaan-3 are testaments to the country's efforts in recent years to ramp up its space program and become a major player capable of interplanetary missions for new discoveries.

the landing site Sept. 22. But by Oct. 6, the team had received no communications, and back-burnered further attempts at contact. Nonetheless, the mission was a rousing success for the Indian Space Research Organisation (ISRO).

Not all lunar stories last year were successes. Russia's Luna 25 lander, also targeting the lunar pole, crashed into the Moon Aug. 19. A few days later, Roscosmos cited an engine malfunction that caused the engines to burn too long while orienting the craft for landing. The lander was Russia's first lunar mission in nearly five decades. The agency said it planned to accelerate its next two lunar missions, Luna 26 and 27, in

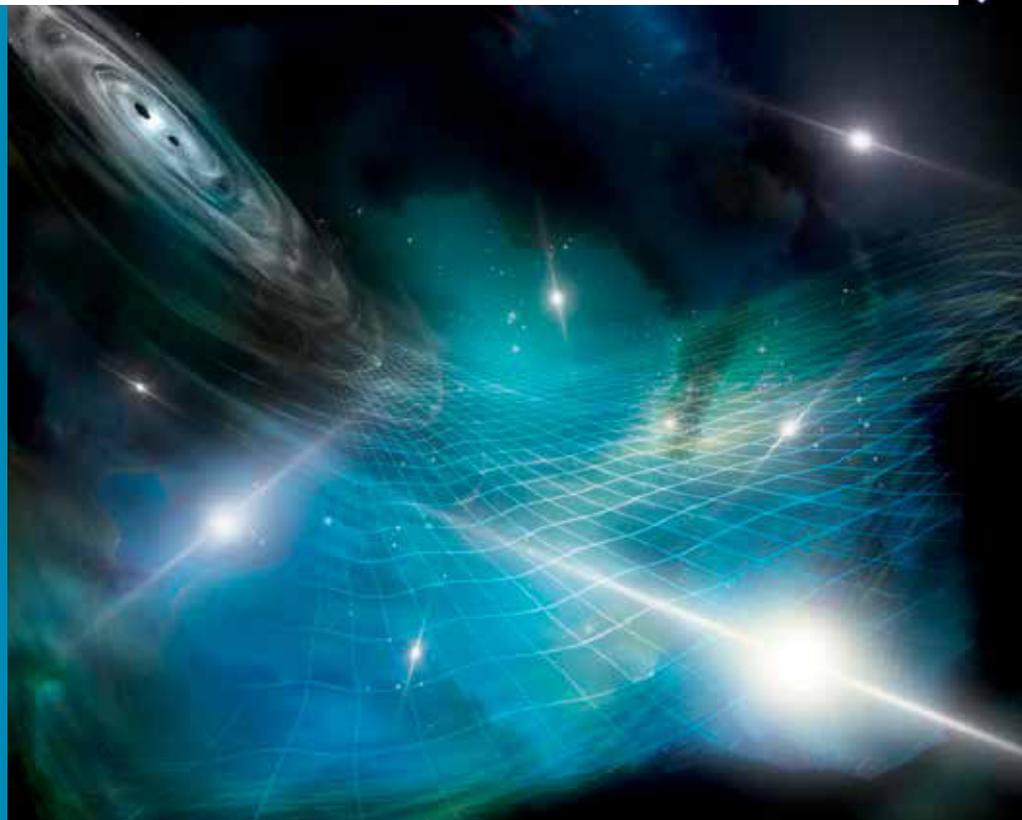
response to the failure. Both are set to launch later this decade. And earlier in the year, Japanese startup ispace attempted the first commercial lunar soft landing, targeting Mare Frigoris' Atlas Crater with the HAKUTO-R Mission 1 Lunar Lander. Although the craft was in good shape on approach, it did not send confirmation of touchdown after the scheduled landing time on April 25. Shortly after, mission engineers determined its propellant likely ran out, causing the lander to crash.

All this goes to show that landing even uncrewed craft on the Moon is far from easy or routine, and many challenges still await both robotic and human explorers.

space-time that take more than a decade just to complete one cycle of the wave," says Kelly Holley-Bockelmann of Vanderbilt University, a gravitational-wave researcher who is not part of NANOGrav.

That's why NANOGrav had to monitor the pulsars for so long. And it was worth it. The resulting pattern of timing disruptions matches exactly what is expected if there is a background of gravitational waves humming throughout the cosmos. "After years of work, NANOGrav is opening an entirely new window on the gravitational-wave universe," said NANOGrav collaborator Stephen Taylor, also of Vanderbilt, in a statement.

The detection has now clinched the case that supermassive black holes do merge — previously a long-standing question in astrophysics. It has also revealed surprises: The gravitational-wave background is twice as loud as expected. Perhaps supermassive black holes are larger or more numerous than current estimates. But perhaps something previously unimagined is contributing to the volume as well. "We'll need to keep observing to reveal the true nature of these gravitational waves," says Holley-Bockelmann.



Supermassive black holes merging throughout the universe (upper left) create a gravitational-wave background, represented by ripples in the grid in this illustration. Researchers have picked up this signal by looking for slight shifts in the timing of received pulses from pulsars (bright points) across the galaxy as gravitational waves pass by. AURORE SIMONNET FOR THE NANOGrAV COLLABORATION

2

JWST SPOTS POTENTIALLY 'UNIVERSE-BREAKING' GALAXIES

IT SHOULD BE NO SURPRISE that the James Webb Space Telescope (JWST), last year's top story, has yet again made our list. With more than a full year of science under its belt, JWST has truly begun revolutionizing astronomy.

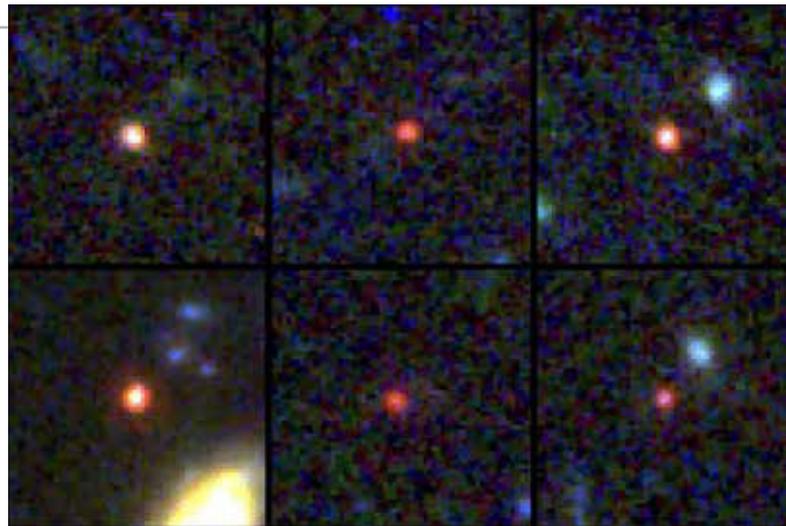
And it didn't start small. Scientists analyzing JWST's early images announced Feb. 22 in *Nature* that they'd identified some of the youngest galaxies now known: six of them, shining roughly 540 million to 770 million years after the Big Bang.

But these young galaxies didn't look like they should. They were massive. *Too* massive, housing some 10 billion to 100 billion solar masses' worth of stars. "These galaxies should not have had time to form," based on our current understanding of how quickly matter in the early universe could conglomerate and form new suns, said study co-author Erica Nelson of the University of Colorado Boulder in a press release. "You just don't expect the early universe to be able to organize itself that quickly."

"The revelation that massive galaxy formation began extremely early in the history of the universe upends what many of us had thought was settled science," added co-author Joel Leja of Penn State. "We've been informally calling these objects 'universe breakers.'"

Is that it, then? Did JWST break the universe? Various groups have presented alternative explanations that rescue our current understanding of the cosmos. One, led by researchers at Saint Mary's University in Halifax, Nova Scotia, argued that the galaxies' redshifts, or distances, may not be as high as originally thought. That's because the initial team didn't look at the objects' spectral features across all wavelengths, but instead took images in various filters at discrete wavelengths — a common alternate technique, but one prone to bias. The technique may also have picked out only the very biggest and brightest galaxies, which are not representative of the general population. And the Saint Mary's University study warned against making broad statements about the early universe as a whole based on just a handful of examples. The work had been submitted to *Monthly Notices of the Royal Astronomical Society* but not yet peer-reviewed at the time of this writing.

Another study, published Oct. 3 in *The Astrophysical Journal Letters*, used simulations to show that brief, irregular bursts of furious star formation can temporarily make galaxies appear brighter. In other words, JWST may have imaged these galaxies during a short period when they were birthing lots of stars



Astronomers combing through early JWST images discovered six galaxy candidates — each appearing as a small red point of light in the cutouts tiled here — that appear to be too massive and bright for their age, less than a billion years after the Big Bang. NASA, ESA, CSA, I. LABBE (SWINBURNE UNIVERSITY OF TECHNOLOGY). IMAGE PROCESSING: G. BRAMMER (NIELS BOHR INSTITUTE'S COSMIC DAWN CENTER AT THE UNIVERSITY OF COPENHAGEN)

before calming down again. If this were the case, astronomers assuming a steady rate of star formation would overestimate the amount of stars these galaxies had created over time

based on their artificially enhanced brightness. But such an effect has not yet been observed in real galaxies, so further investigation is still needed.

1

WE VIEW THE MILKY WAY IN NEUTRINOS

THE MOTTLED MILKY WAY is a familiar sight in the night sky. And whether viewed in visible light, with a radio telescope, or even with high-energy gamma rays, the image comes to us via photons of light. But last year, astronomers finally saw our galaxy in an entirely different way: not with light, but with neutrinos. Their accomplishment was published June 29 in *Science*.

Sometimes called "ghost particles" because they rarely interact with other matter, neutrinos reveal where high-energy events are taking place. One region astronomers expected them to come from is the plane of the Milky Way. There, cosmic rays (themselves hallmarks of high-energy events) slamming into gas and dust produce gamma rays that have been previously spotted. Researchers believed these interactions should also produce neutrinos.

But spotting neutrinos takes a special setup. For that, there's the IceCube Neutrino Observatory at the South Pole, with 5,000-plus sensors buried beneath the ultra-pure Antarctic ice. Arrayed over roughly 0.24 cubic mile (1 cubic kilometer), these detectors don't see neutrinos directly, but instead key into the reaction that occurs when a neutrino does occasionally slam into an atom in the ice. The collision produces a slew of charged particles that cascade through the ice, generating a glow called Cherenkov radiation. Based on where and when

Astronomy Senior Editor **Alison Klesman** always looks forward to the new science and discoveries each year brings.

As for the original team, Leja noted that not all the objects — officially labeled galaxy “candidates” in the paper — might truly be galaxies after all. Instead, he proposed some may be accreting supermassive black holes called quasars, which can shine more brightly than the galaxy around them and confuse astronomers’ estimates for brightness, size, and mass. And initial follow-up studies did discover one of the six candidates is indeed a young quasar. Only additional work to characterize the remaining candidates will tell whether they are truly young, massive galaxies forming lots of stars when they shouldn’t be, or something else masquerading as such.

Still, said Nelson, “if even one of these galaxies is real, it will push against the limits of our understanding of cosmology.”

STORIES TO WATCH FOR IN 2024

■ JAXA’s Martian Moon eXploration (MMX) mission is scheduled to launch in September 2024 (top). The craft will retrieve a sample of Mars’ moon Phobos and return it to Earth later this decade.

■ The launch window for NASA’s Europa Clipper, a mission seeking out habitable regions beneath that icy jovian moon’s surface, opens Oct. 10, 2024.

■ ESA’s Hera spacecraft will launch in October 2024 to study the binary asteroids Didymos and Dimorphos, the latter of which was impacted by NASA’s Double Asteroid Redirection Test (DART) in September 2022 (middle).

■ ESA’s BepiColombo mission will fly by Mercury twice in 2024, on Sept. 5 and Dec. 2.

■ A total solar eclipse will cross parts of Mexico, the U.S., and Canada on April 8, 2024, with tens of millions of people living in the path of totality (bottom).



TOP TO BOTTOM: JAXA; ESA; NASA/ARMSTRONG’S GULFSTREAM III

each detector registers this glow, researchers can work backward to determine where on the sky the neutrino came from.

Although IceCube had previously detected neutrinos from outside our galaxy, finding those originating within the Milky Way has been difficult. That’s because neutrinos from far-off galaxies leave straight, easy-to-trace showers of light when they smack into the ice. To detect neutrinos produced inside the Milky Way, the team instead focused on tracks that were more like spherical blobs; these are harder to trace back to their origin and had typically gone ignored. That is, until a team developed a machine-learning algorithm to comb through a decade of readings, analyzing more than 60,000 detections for details such as position and energy. This helped differentiate between neutrinos produced in

galactic dust and gas, and those commonly created when cosmic rays hit Earth’s atmosphere.

The result was a map of the Milky Way in neutrinos — our first glimpse of our galaxy in anything other than light.

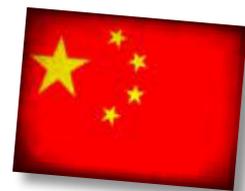
That map matches well those produced using gamma rays, as astronomers hoped. And within that map, there are hints of not only neutrinos from gas and dust, but possibly smaller sources — such as black holes and neutron stars — as well. Teasing out those sources is one of the team’s future goals.

“Observing our own galaxy for the first time using particles instead of light is a huge step,” said Naoko Kurahashi Neilson, an IceCube team member at Drexel University in Philadelphia, in a release. “As neutrino astronomy evolves, we will get a new lens with which to observe the universe.”

This artist’s concept shows the Milky Way as imaged using neutrinos. The blue glow shows where neutrinos are being created via interactions between cosmic rays and intergalactic gas, with some contributions from individual sources like black holes. ICECUBE COLLABORATION/U.S. NATIONAL SCIENCE FOUNDATION (LILY LE & SHAWN JOHNSON)/ESO (S. BRUNIER)



CHINA'S DEEP-SPACE



WHEN CHINA'S FIRST LUNAR LANDER, Chang'e 3, touched down in Mare Imbrium on the Moon in 2013, it was the pinnacle of the country's space endeavors. The robotic lander and its small Yutu rover companion were the first spacecraft to operate on the Moon since the 1970s, and provided new insights into our planet's natural satellite.

RIGHT: China's Yutu (or Jade Rabbit) rover touched down on the Moon Dec. 14, 2013, as part of the Chang'e 3 mission. It was the first soft lunar landing by any nation since 1976.
INSTITUTE OF HIGH ENERGY PHYSICS, CHINESE ACADEMY OF SCIENCES/WIKIMEDIA COMMONS/CC BY 4.0



FAR RIGHT: The space station Tiangong has been constructed over the course of multiple launches. It consists of a central core module named Tianhe and two lab modules named Wentian and Mengtian. In this rendering, a Tianzhou cargo craft is docked in the foreground, with a Shenzhou crew capsule docked in the background.
GREMLIN/E+ COLLECTION/GETTY IMAGES. FLAG: LACHRIS777 DREAMSTIME.COM

But for China, the Moon landing was just one piece of a broader effort to lay the groundwork for much bigger things. In fact, China carried out 14 successful launches that year (plus one failure). Most of these were technology tests or reconnaissance and Earth observation satellites, as China looked to establish basic space infrastructure.

Since then, China's space activities have exploded in range, frequency, and ambition. The country now rivals the U.S. for the most launches per year, with around 80 missions having been planned for 2023. The nation has its own modular space station, named Tiangong, which is expected to be continuously occupied by a rotating crew of three astronauts for at least a decade.

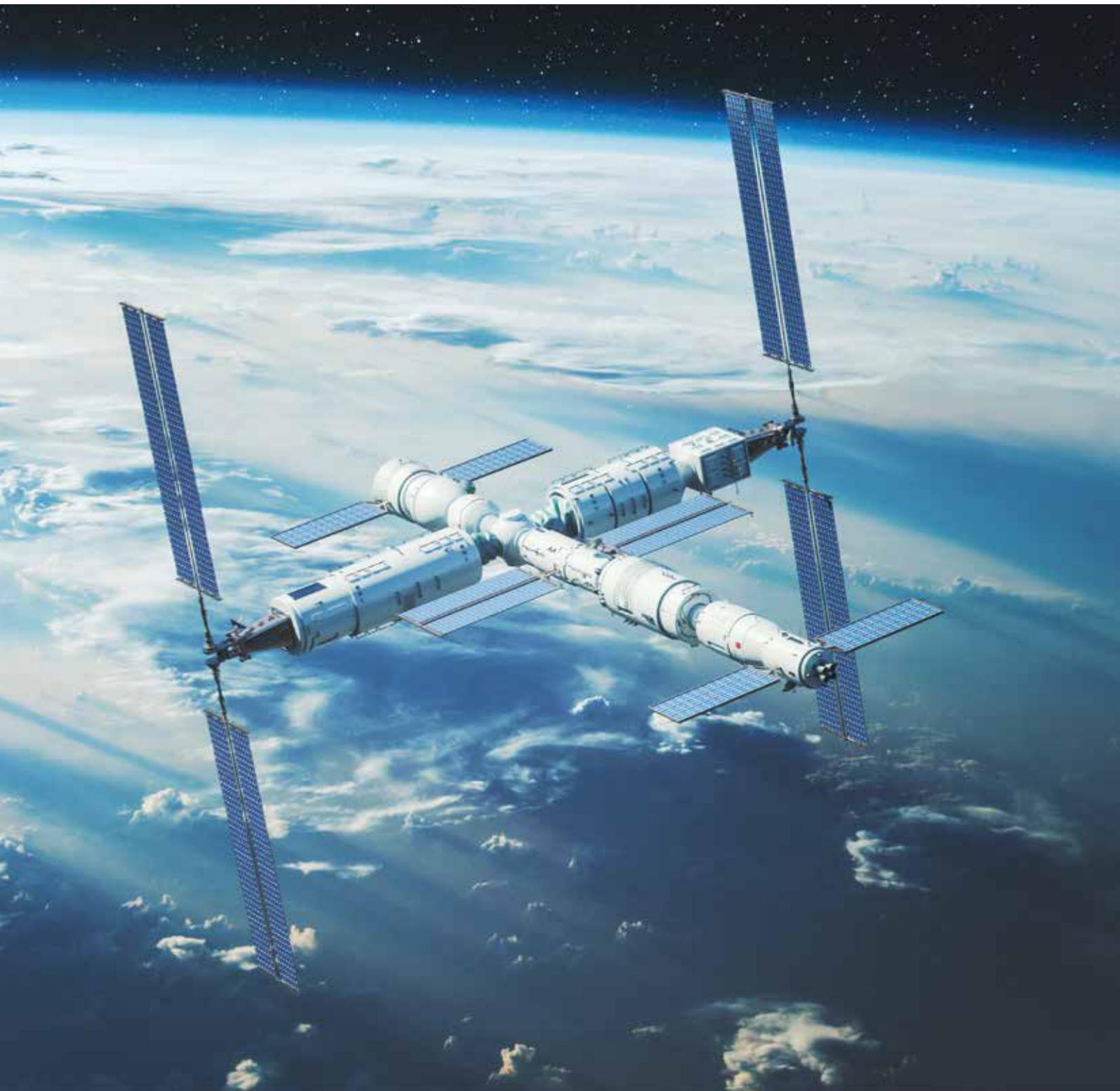
China also has launched a full constellation of satellites for its own version of GPS, known as BeiDou, which provides civilian location, navigation, and messaging services, as well as encrypted signals for use by the People's Liberation Army. In an effort to keep pace with the U.S., the country is fostering a commercial space sector to bring competition and innovation to launch vehicles, remote sensing, and even asteroid mining. And it aims to build its own, 13,000-satellite-strong answer to SpaceX's Starlink internet-providing satellite megaconstellation.

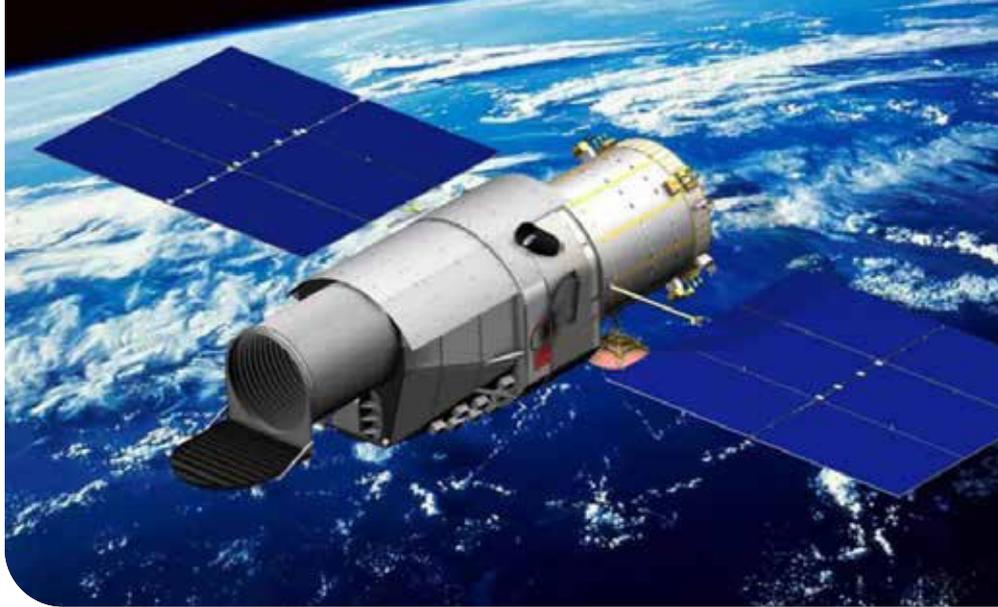
But China has also been working hard in solar-system exploration, space science, and even planetary defense. It has already registered



Buoyed by successes at the Moon and Mars, China is embarking on a science and exploration program of staggering scale. **BY ANDREW JONES**

AMBITIONS





ABOVE: The Xuntian space telescope, shown here in an artist's concept, is scheduled for launch in 2025. It will have a 2-meter mirror — similar in size to Hubble, but with a much larger field of view. It will occupy a similar orbit to the Tiangong space station and is designed to be able to periodically dock with it so a crew can perform maintenance and upgrades. CNSA

RIGHT: Zhurong poses for a selfie with its Tianwen-1 lander on the surface of Mars. CNSA



some major feats, which have provided big boosts to the scientific community. It is now building on these accomplishments with a series of major missions across the next decade.

Over the Moon

Change 4, launched in late 2018, provided the country with a true spaceflight first: an unprecedented landing on the Moon's farside.

Change 5 marked yet another leap, collecting fresh samples from Oceanus Procellarum and delivering them to Earth for analysis after a complex and daring three-week mission. Change 5's samples were carried from the Moon by an ascent vehicle, which rendezvoused and docked with a return craft in lunar orbit — a process similar to how NASA's Apollo astronauts landed on the Moon and made it back to Earth. The prize was 3.82 pounds (1,731 grams) of precious lunar material, which has yielded new insights

into the volcanic history of the Moon and the unexpectedly high water content of its regolith.

"The successful launch of the Change 5 mission has inaugurated a new epoch in lunar science for Chinese scientists," says Yi Xu, an associate professor at the Space Science Institute at Macau University of Science and Technology. Chinese researchers "can now delve into the dating, mineralogy, chemical composition, microscopic features, and more, of lunar samples."

Another major milestone, one previously achieved only by NASA, was the May 2021 landing of the Zhurong rover on the martian surface as part of the Tianwen 1 mission, which also featured an orbiter. Zhurong successfully completed 347 martian days of exploration before going into hibernation in May 2022. Although the rover never woke up, it exceeded its 90-day intended lifespan several times over.

Zhurong has greatly encouraged researchers in the field of martian science and wider planetary sciences in China, according to Xu. One of its major discoveries is that water may have existed on the surface of its landing site in the recent past — evidence that could not have been detected by remote sensing from orbit.

These missions are not just technology demonstrations. The scientific data they have returned are also providing new opportunities and helping to build interest and expertise. "They're developing a community, and the community is really excited," says James Head III, a planetary scientist at Brown University in Providence, Rhode Island. "The China National Space Administration is also doing a really good job and building the community towards engineering interactions that are only going to strengthen the program further."

Aiming higher

These flights also served as a test run for more complex missions — including two of the most challenging endeavors for any major space power.

First, China aims to put astronauts on the Moon before the end of this decade. The nation's human spaceflight agency formally announced this goal on May 29, 2023, just one day before it inaugurated its Tiangong space station with the launch of its first crew.

It is a timeline that China has a good chance of achieving, based on its progress in rocketry, crewed spaceflight, and robotic lunar missions. The country's main space contractor, China Aerospace Science and Technology Corporation (or CASC), is developing a new rocket, the Long March 10, capable of putting 27 tons into lunar orbit. A pair of these rockets will send a crewed spacecraft (which has already flown in a high-orbit test) and a lander stack to the Moon; these will rendezvous



INVESTING IN SCIENCE

THE TIANWEN DEEP-SPACE and Chang'e lunar projects are China's national-level, flagship missions. These will require — and demonstrate — serious ambition and resources. But there is another player in China with its own plans to further knowledge of the solar system and the universe: the Chinese Academy of Sciences (CAS), a sprawling network of national institutes researching topics that include astronomy, planetary sciences, physics, and more.

CAS kickstarted China's engagement in space science with a cluster of missions attuned to target key science questions. These included Wukong, also known as the Dark Matter Particle Explorer (DAMPE), which looked for signs of weakly interacting particles theorized to be dark matter. China also launched its first X-ray observatory, the Hard X-ray Modulation Telescope. And the Quantum Experiments at Space Scale (QUESS) spacecraft conducted pioneering experiments in quantum encryption and teleportation. QUESS was the first craft to generate entangled photons in space, which could be used to produce virtually unbreakable encryption keys for secure communications. All three launched across 2015–2017 as part of what China calls a Strategic Priority Program (SPP) on space science.

The second round of SPP missions are now launching. The Gravitational Wave High-energy Electromagnetic Counterpart All-sky Monitor (GECAM) launched in 2020 as a pair of microsatellites, seeking X-ray and gamma-ray counterparts to gravitational-wave events; however, only one of the two GECAM craft is currently operational. And the Advanced space-based Solar Observatory (ASO-S) went up in 2022 to investigate the relationship between the Sun's magnetic field, solar flares, and coronal mass ejections.

Next, the Einstein Probe, which aims to launch in early 2024, will scan the sky for X-rays emitted from the most violent events in the universe, like stars being torn apart by supermassive black holes. The Solar wind

Magnetosphere Ionosphere Link Explorer (SMILE), a space weather collaboration with the European Space Agency, will follow around 2025.

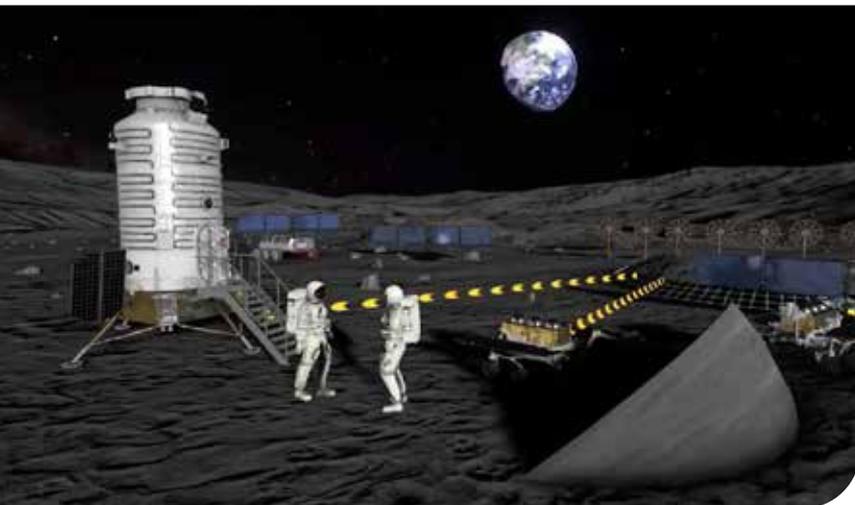
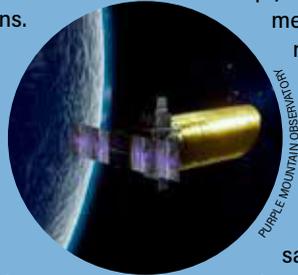
The third SPP round, currently undergoing a selection process, has been broadened to include potential deep-space exploration and exoplanet-hunting missions. One of two exoplanet proposals — the Closeby Habitable Exoplanet Survey (CHES) and Earth 2.0 (ET) missions — is likely to be selected. CHES (shown at left in an artist's concept) aims to search for exoplanets with the astrometric

method, making precise measurements of the positions and movements of 100 Sun-like stars within 33 light-years of Earth to see if any unseen planets are tugging on them.

ET will use the transit method to search for Earth-size exoplanets with similar orbits around Sun-like stars. These would supplement a flagship mission named Miyin, which envisions a system of five formation-flying telescopes out at the Earth-Sun Lagrange 2 point, the same locale as the James Webb Space Telescope, to use the principle of interferometry to directly image exoplanets.

Other SPP III mission concepts include a low-cost sample-return mission to the near-Earth asteroid 1989 ML, which would help fill a gap in our understanding of the asteroid population by delivering the first samples of an E-type, iron-poor asteroid. And the Venus Volcano Imaging and Climate Explorer (VOICE) would potentially join a burgeoning international fleet of craft inspired by the resurgence of interest in our twin inferior planet. In total, around six or seven missions from 13 proposals under the SPP III program will be selected to fly.

Future concepts include a follow-on to DAMPE to detect signals of dark matter and a mission to Ceres to investigate the dwarf planet's origins, underground ocean, and geological activity. Again, budgetary constraints and economic conditions, as well as continued progress and economic stability, will determine what can be achieved in these arenas. — A.J.



super-heavy-lift rocket named Long March 9. Later, crews will be sent to inhabit the lunar outpost. The country is currently seeking international partners for the megaproject, which will happen alongside NASA's Artemis program to return astronauts to the Moon. Depending on funding, technical hurdles, and other variables, this could develop into a geopolitically tense race to see who gets boots back on the Moon first.

The other related project is the current holy grail of Mars science: a Mars sample-return mission. Bringing pieces of the Red Planet back to Earth for analysis in laboratories will reveal much more about the planet's history — and potential ancient life — than can be gleaned from robotic rovers. The Tianwen 3 mission will be

in lunar orbit. A lunar lander, a rover (possibly commercially developed), and a lunar space suit are all in the works.

The landing wouldn't be a mere flags-and-footprints

mission, but fit into a wider plan known as the International Lunar Research Station. For this, China envisions constructing a permanent, initially robotic base on the Moon using five launches of a

LEFT: The International Lunar Research Station is China's plan for a permanent Moon base with international partners. CNSA



ABOVE: A Long March 5B rocket lifts off from the Wenchang Spacecraft Launch Site on the island of Hainan Oct. 31, 2022, carrying the Mengtian laboratory to orbit — the final module of China's Tiangong space station. The Long March 5B has prompted sharp criticism from other nations for its design, in which it falls back to Earth in an uncontrolled reentry. CHINA NEWS SERVICE

China's effort to collect and retrieve martian samples, currently scheduled to lift off around 2030 with the help of two Long March 5 rockets.

Collecting samples from Mars will be more challenging than from the Moon. The much greater distance and time delay require greater automation, and adjustments will need to be made for Mars' gravity. Launching a two-stage rocket from inside the martian atmosphere is a different proposition than a single-stage launch from the airless Moon. But if China meets these challenges, it could beat NASA's efforts. NASA has a head start — its Perseverance rover has already cached dozens of samples and left them on the ground. However, the mission to retrieve them is facing budgetary headwinds.

On the science side, the plans and objectives are beginning to take shape. Head attended a conference in Hefei, Anhui province, in 2023, held as part of China's annual national space day — April 24, the anniversary of the country's first orbital launch in 1970. The Tianwen 3 sessions drilled down into the engineering constraints and geological criteria for landing, he says. According to Head, researchers have compiled a preliminary list of 86 sites with

potential astrobiological and geological value. The meeting also discussed the main science objectives — including searching for signs of life — and issues such as handling the samples once on Earth.

Technologically, the mission builds on accomplishments demonstrated by Chang'e 5: robotic

Launching a two-stage rocket from inside the martian atmosphere is a different proposition than a single-stage launch from the airless Moon.

sampling, deep-space rendezvous and docking, and launching a return vehicle from the surface of another world. Tianwen 1 also provides valuable reference information for the future martian sample-return mission; the Zhurong rover tested China's ability to perform entry, descent, and landing onto the martian surface.

Worlds beyond Mars

China will also lean on its sample-return prowess in the much nearer future for two intriguing missions. China plans to launch the Queqiao 2 lunar relay satellite into a unique orbit around the Moon in early

2024. The orbit is elliptical and inclined, chosen for its stability. Queqiao 2 will spend much of its 24-hour orbital period visible to both the lunar farside and ground stations on Earth. This communications link will allow the Chang'e 6 spacecraft, launching later in 2024, to attempt to land in the South Pole-Aitken basin on the Moon's farside. The samples it aims to collect from Apollo Crater could contain material from the lunar mantle and provide insight in the history of the Moon and, in turn, the solar system.

China will follow that with another sample-return mission, Tianwen 2, this time to a near-Earth asteroid. The spacecraft is scheduled to launch in 2025 and will swing by Earth to drop off material collected from asteroid 469219 Kamo'oalewa. It will then get a gravity assist from Earth and continue on a second mission to rendezvous with the main-belt comet 311P/PanSTARRS, arriving in the 2030s.

The negligible gravity of the asteroid Kamo'oalewa will mean new challenges for Chinese mission teams, including achieving and maintaining orbit and approaching the surface for sampling. For the latter, Tianwen 2 will use multiple sample techniques. One is the well-established touch-and-go approach used by Japan's Hayabusa 2 and NASA's OSIRIS-REx. In this method, the spacecraft approaches the surface while holding out its sampling arm, plunges it into the surface, and backs away seconds later. But Tianwen 2 will also attempt an anchor-and-attach process, in which it actually lands on the

asteroid with four drilled-tipped robotic arms. Combining approaches is more complex, but increases the chances of obtaining samples — and gathers more experience and technical know-how for future missions.

China's first voyage to the outer planets is scheduled for 2030 with Tianwen 4, which will set out for Jupiter. After a period where it will roam the jovian system, conducting flybys of Jupiter and its moons, the mission will settle in around Callisto, the outermost of the four Galilean moons. It lies outside Jupiter's fierce radiation belts and also has — unlike Ganymede, Io, and Europa — an ancient surface, which could harbor clues to the history of the jovian system. Honing in on Callisto will also complement ESA's JUICE mission, which focuses on Ganymede, and NASA's Europa Clipper.

But Tianwen 4 will have another major component: An additional probe will continue on for Uranus, performing a rare flyby of the ice giant in the 2040s.

And it may not be the only Chinese foray into the outer reaches of the solar system. The China National Space Administration (CNSA) also stated in April 2023 that it will build and launch a pair of probes to the fringes of the solar system, in opposite directions. They are separately destined for the head

and tail of the heliosphere — the bubble of the Sun's magnetic influence, which is deflected back as it moves through the interstellar medium.

The two craft will not be the first to explore the heliosphere — both Voyager missions have reached its boundary and crossed over into interstellar space. But the Voyagers were planetary missions, first and foremost, focused on the flybys enabled by a rare alignment of planets; only later were they adapted for improvised heliosphere measurements. China's probes will be optimized for heliosphere research, while also taking advantage of planetary flybys. Possible visits to minor planets have also been slated, but much depends on the as-yet-unknown time frame for launch.

Global leadership?

From a technological standpoint, China is already one of the world's top space powers and is rapidly gaining expertise and

racking up accomplishments. And while previous missions have focused on providing data to Chinese researchers, the nation is increasingly looking to forge international collaborations. Data and samples from these missions will be available to international researchers after a period of 12 months. Xuntian, a space telescope similar to Hubble but with 300 times the field of view, could launch as soon as 2024. This could provide a huge opportunity for scientists to collaborate.

However, cooperation with the U.S. at a governmental level looks as though it will be severely restricted by geopolitical tensions. Some argue that scientific collaboration can help defuse tensions between rival superpowers, as was sometimes the case with the U.S. and Soviet Union. But there are also legal obstacles to collaboration, including the so-called Wolf Amendment, a 2011 law that puts up high barriers to NASA engaging with Chinese entities.

What is clear is that China continues to grow its capabilities and has set out a road map to comprehensively explore the solar system across lunar, planetary, and deep-space missions. These in turn are strengthening and inspiring China's scientific community, and will bring new value, science, and impetus to astronomy and space exploration. ☪



ABOVE: The Chang'e 5 mission collected samples from the vast lunar mare Oceanus Procellarum and returned them to Earth — the first lunar sample-return mission since 1976.

CNSA LUNAR EXPLORATION AND SPACE ENGINEERING CENTER

BOTTOM LEFT: China's first full-fledged X-ray observatory was the Hard X-ray Modulation Telescope (HXMT), launched in 2017.

INSTITUTE OF HIGH ENERGY PHYSICS, CHINESE ACADEMY OF SCIENCES

Andrew Jones

is based in Finland and reports on China's space industry for SpaceNews. He writes about space science, exploration, and more for outlets including Space.com and National Geographic.



SKY THIS MONTH

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.
BY MARTIN RATCLIFFE AND ALISTER LING

FEBRUARY 2024 Mars and Venus meet

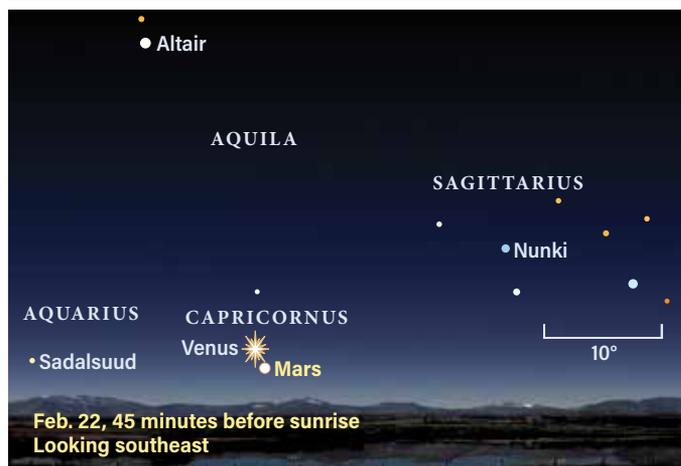
» Jupiter is the highlight of evening observation for anyone with a telescope. Its moons dance around the planet and intriguing transits and occultations occur. Meanwhile, Saturn is very low in twilight — you can catch it early in the month. The binocular giants, Uranus and Neptune, are visible all evening. The morning sky carries a bright Venus and the return of Mars; the two undergo a close conjunction later in February. And spy Mercury early in the month before it goes behind the Sun.

Catch **Saturn** 45 minutes after sunset on Feb. 1, when it stands 12° high in the west. The planet is lost in twilight after the second week of the month. Your last view may be Feb. 10, when a 1.1-day-old Moon stands just over 2° south of Saturn. The pair is 6° high 30 minutes after sunset and drops below the horizon about half an hour later. Saturn shines at magnitude 0.9 and can be spotted easily with binoculars.

Saturn reaches superior conjunction Feb. 28 and will reappear in the morning sky in late March.

Neptune sets around 8:30 P.M. local time in the first week of

Morning meetup   



This month's conjunction of Venus and Mars will appear similar to this 2017 image, with ruddy Mars to Venus' lower right (south). ALAN DYER

Venus and Mars meet as morning stars in late February. Catch them low on the horizon less than an hour before sunrise. ALL ILLUSTRATIONS: ASTRONOMY; ROEN KELLY

RISING MOON | Out of round

OBSERVING HIGHLIGHT

MARS passes 36' due south of VENUS the morning of Feb. 22.



February, so it's best viewed before 7:30 P.M., when it drops below 10° altitude. It's located in Pisces the Fish, just south of the Cirlet asterism. Neptune shines at magnitude 7.8.

A line of three 5th- to 6th-magnitude stars spans nearly 3°, running southeast to northwest due east of Neptune's location and some 5° south-southeast of magnitude 4.5 Lambda (λ) Piscium. Binoculars will easily find the trio, with Neptune standing 40' west of the northwesternmost star, 20 Psc. There's a 7th-magnitude star just slightly brighter than the planet in the same field of view, southwest of Neptune. The gap between Neptune and 20 Psc narrows to 15' by Feb. 15 as the giant planet moves east.

That easterly trek continues but Neptune is setting earlier each night, becoming more difficult to follow at low altitude. Neptune passes 8' due north of 20 Psc on the 23rd, but the two are only 8° high in the western sky an hour after sunset, and set by 7:30 P.M. local time.

Jupiter is a stunning object high in the southern sky as February opens. It's located in Aries the Ram and shines at magnitude -2.3 on Feb. 1, dimming to magnitude -2.2 by the 29th. Begin your observing as twilight falls — the lower contrast of the jovian disk is a sight to behold. You'll easily catch the four bright Galilean moons

— *Continued on page 34*

STANDING OUT IN THE DEEP SOUTHWEST

of a waxing gibbous Moon lies the striking shoe-print form of Schiller. Only half of it is visible on the 19th, a few days before Full, sporting rim shadows reaching toothily into the darkness.

Lit up on Feb. 20th, Schiller's mostly flat floor and overly elliptical shape catch the eye. Of course, all circular craters close to the Moon's limb appear oval through foreshortening, but Schiller seems squashed twice as much as any other in the area. The following night, the shadows in Schiller are much shorter.

Earlier lunar observers were left scratching their heads trying to explain its form. Research into high-velocity impacts a few decades ago showed that a single projectile at a grazing angle could produce unusual craters, including ones like Schiller. Well after the initial impact, lava welled up through fractures in the crust to make a smooth floor. Messier A in the Moon's southeast is the poster child for low-angle impacts.

To the northeast, you can't miss the complex elliptical crater Hainzel. Look closely and you can figure out that this feature was created over time by separate impacts. On the northwest side is a roughly circular form with a classic central peak. The southeast region seems to have come later because the floor of the overlapping area is a better match for texture and albedo. The southern component was first not only because

Schiller and Hainzel



The view shown here will match best what you see through your scope just after midnight Feb. 20. CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

the other two overlay it, but also because its rim is softer, a result of wear and tear from long-term bombardment.

When you're done, take a close look at the staggeringly bright Aristarchus in the northern third of the Moon. When Earth's atmosphere is very turbulent or the Moon is very low to the horizon, refraction effects can sometimes give the appearance of outgassing and colored vapors.

METEOR WATCH | View the false dusk

Striking upward



METEORS ARE RARE in February, with no major showers. The background rate of half a dozen or so meteors per hour is best seen in the evening sky for the first half of the month, when the Moon is out of the way. Earth's orbital path crosses many ancient streams that have long since dispersed to create this sporadic background.

The plane of the ecliptic is also littered with fine meteoritic debris and in early February, the combined glow of this material reflecting sunlight can be seen as a faint cone of light

above the western horizon once evening twilight has all but disappeared.

This is the zodiacal light and it is visible only from locations far from city glow. Getting to a high altitude helps as well, as this reduces the scattered light from our own atmosphere. Shimmering almost as bright as the Milky Way when viewed from very dark locations, the zodiacal light passes through the constellations Aquarius, Pisces, and Aries. See if your location is dark enough to spot it extending to near the Pleiades in Taurus.

From very dark locations, the zodiacal light may appear to extend up through the Pleiades in Taurus. NASA/JPL-CALTECH

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. February 1
9 P.M. February 15
8 P.M. February 29

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- ⊕ Globular cluster
- Diffuse nebula
- ⊕ Planetary nebula
- Galaxy

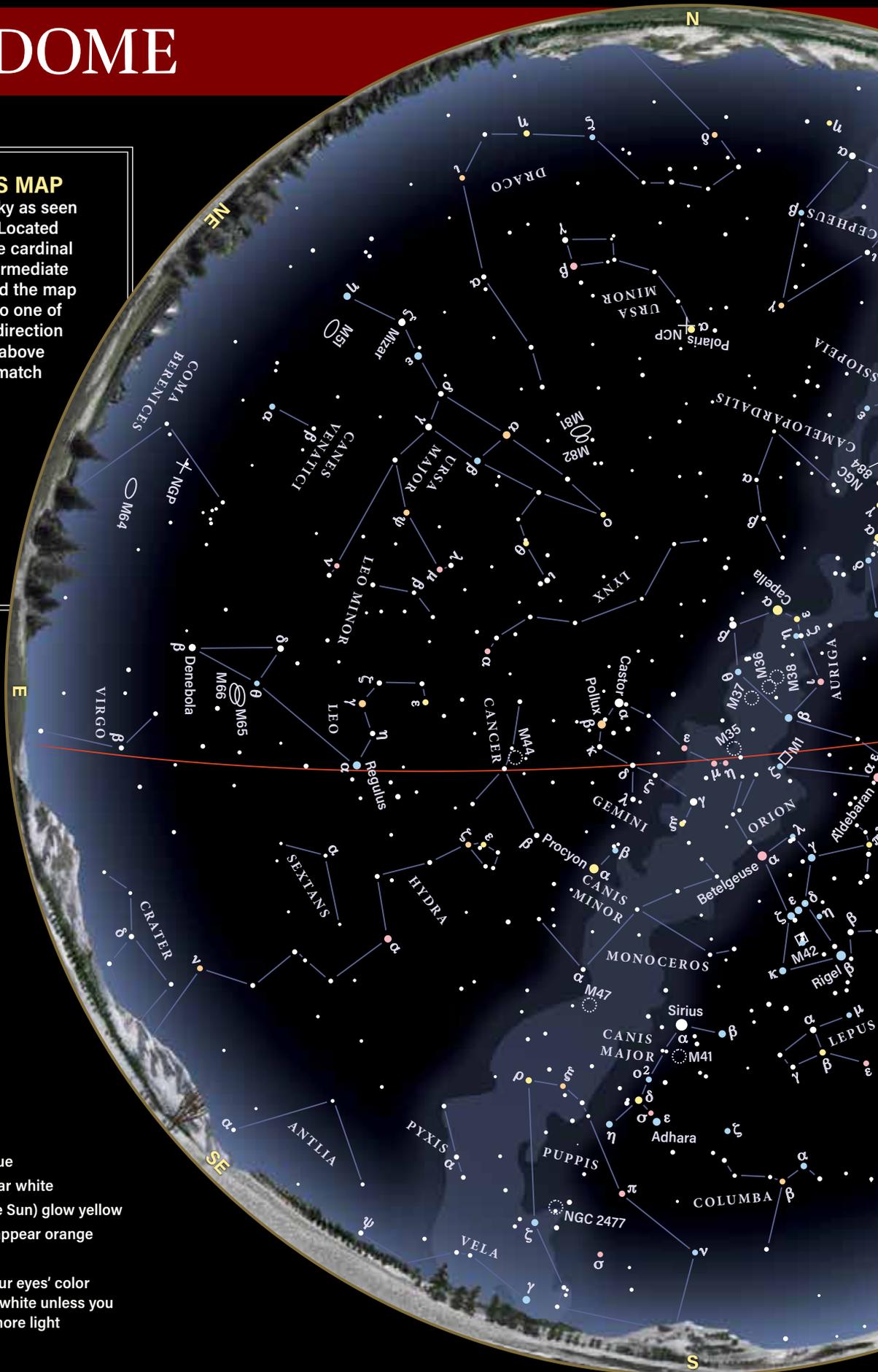
STAR MAGNITUDES

- Sirius
- 0.0 ● 3.0
- 1.0 ● 4.0
- 2.0 ● 5.0

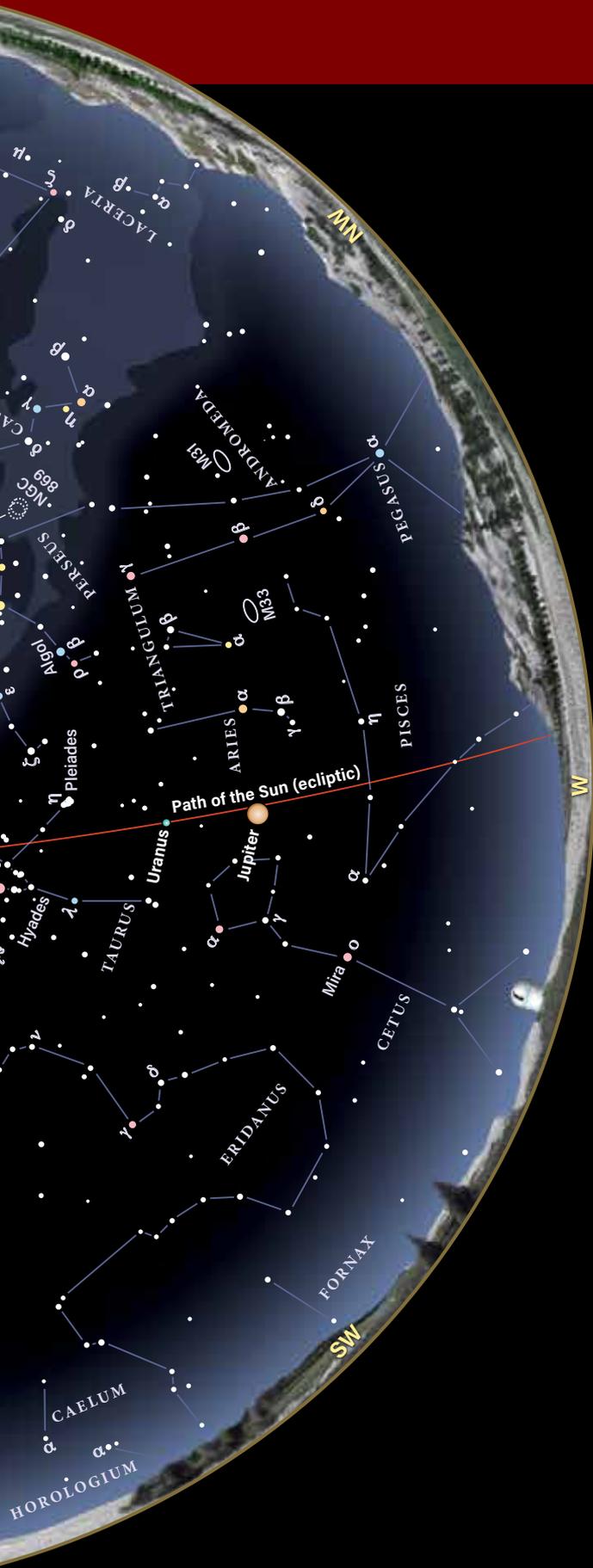
STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light



BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT www.Astronomy.com/starchart.



FEBRUARY 2024

SUN.	MON.	TUES.	WED.	THURS.	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		

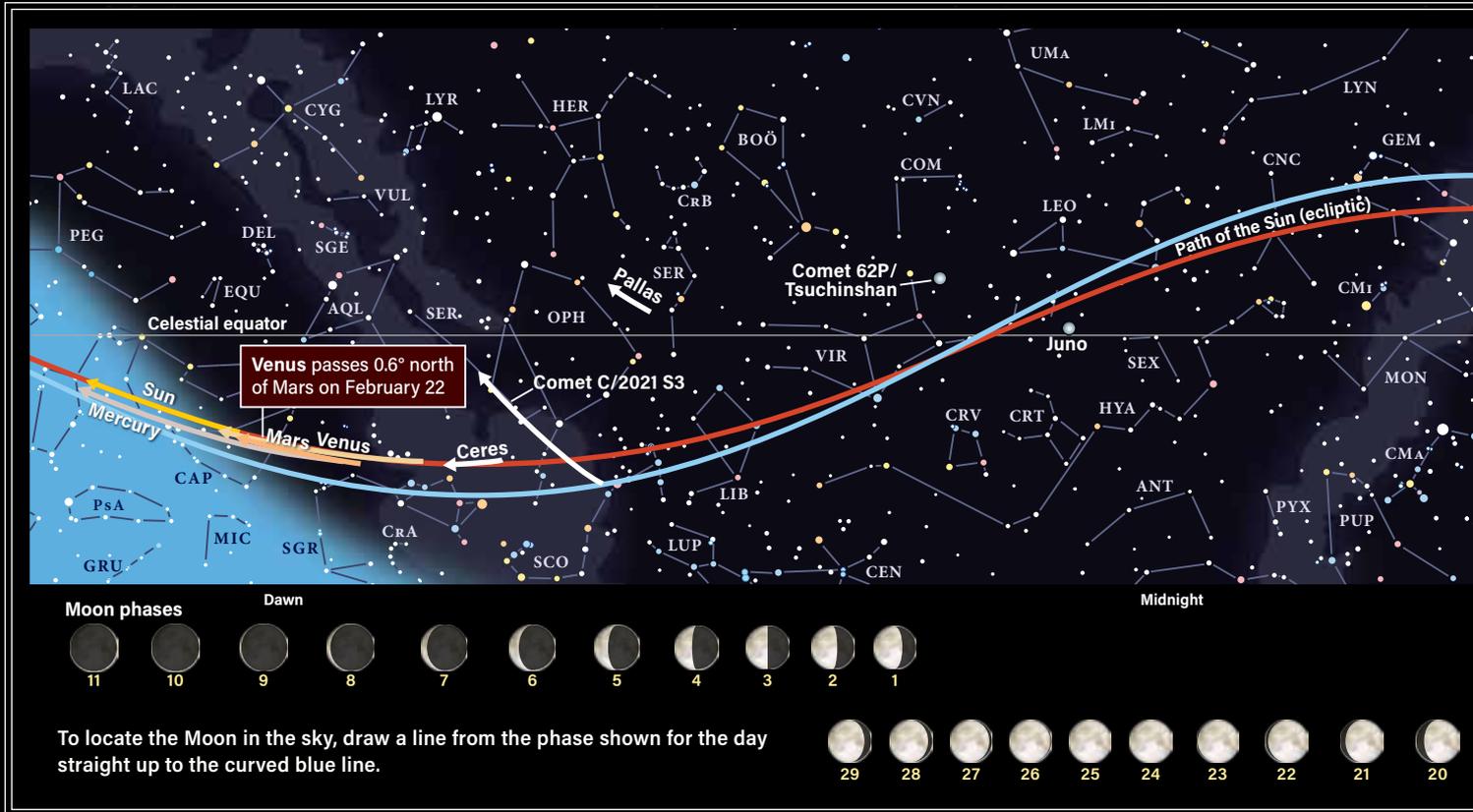
ILLUSTRATIONS BY ASTRONOMY/ROEIN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

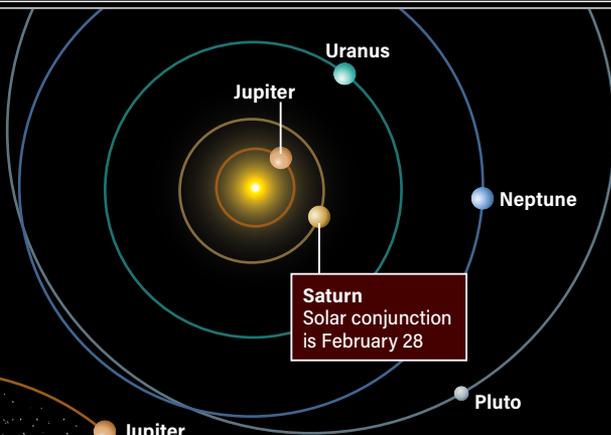
- 2 Last Quarter Moon occurs at 6:18 P.M. EST
- 4 The Moon passes 0.6° north of Antares, 8 P.M. EST
- 7 The Moon passes 5° south of Venus, 2 P.M. EST
- 8 The Moon passes 4° south of Mars, 2 A.M. EST
Asteroid Vesta is stationary, 1 P.M. EST
- 9 New Moon occurs at 5:59 P.M. EST
- 10 The Moon is at perigee (222,506 miles from Earth), 1:53 P.M. EST
The Moon passes 1.8° south of Saturn, 8 P.M. EST
- 12 The Moon passes 0.7° south of Neptune, 2 A.M. EST
- 15 The Moon passes 3° north of Jupiter, 3 A.M. EST
The Moon passes 3° north of Uranus, 9 P.M. EST
- 16 First Quarter Moon occurs at 10:01 A.M. EST
- 22 Venus passes 0.6° north of Mars, 11 A.M. EST
- 24 Full Moon occurs at 7:30 A.M. EST
- 25 The Moon is at apogee (252,470 miles from Earth), 9:59 A.M. EST
- 28 Mercury is in superior conjunction, 4 A.M. EST
Saturn is in conjunction with the Sun, 4 P.M. EST

PATHS OF THE PLANETS



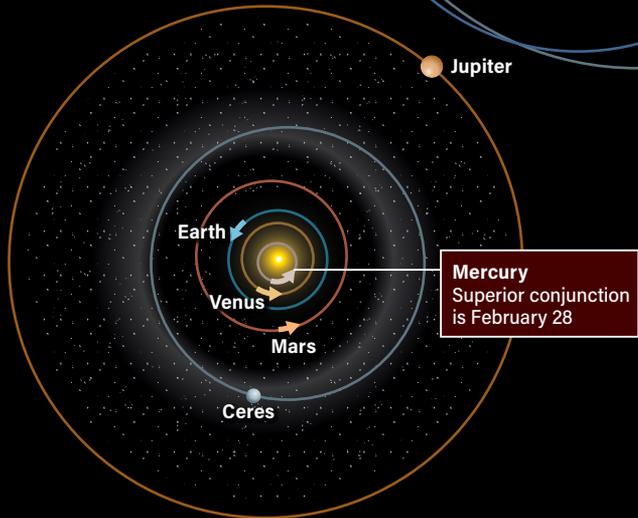
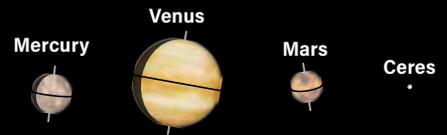
THE PLANETS IN THEIR ORBITS

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.



THE PLANETS IN THE SKY

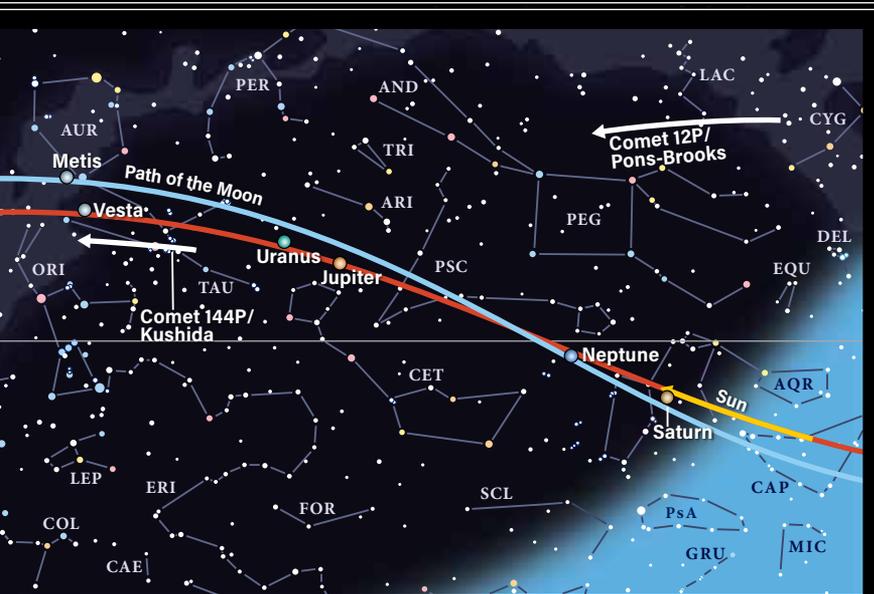
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



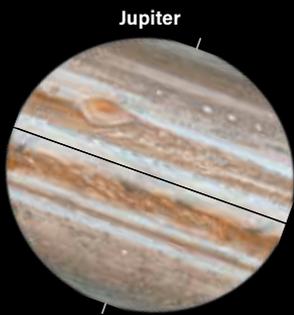
PLANETS	MERCURY	VENUS
Date	Feb. 1	Feb. 15
Magnitude	-0.3	-3.9
Angular size	5.2"	11.6"
Illumination	88%	89%
Distance (AU) from Earth	1.291	1.434
Distance (AU) from Sun	0.466	0.726
Right ascension (2000.0)	19h41.4m	19h58.8m
Declination (2000.0)	-22°27'	-20°41'

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

FEBRUARY 2024



Early evening



Jupiter



Saturn



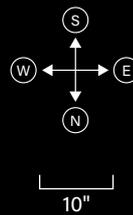
Uranus



Neptune



Pluto



10"



Callisto



Europa



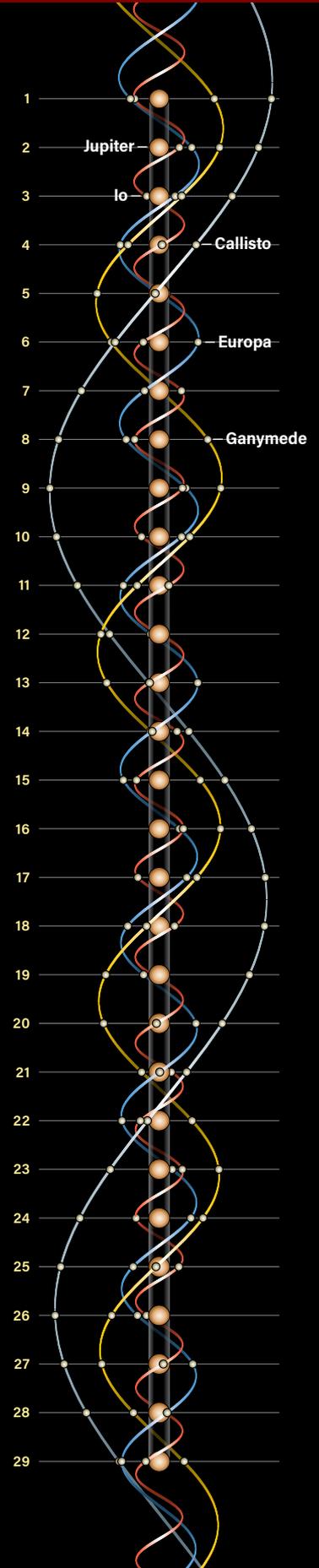
Io



Ganymede

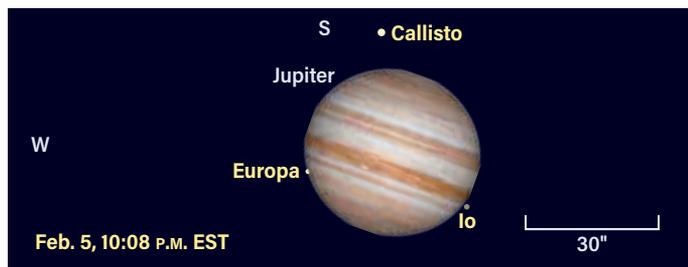
JUPITER'S MOONS

Dots display positions of Galilean satellites at 11 P.M. EST on the date shown. South is at the top to match the view through a telescope.



MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Feb. 15	Feb. 15	Feb. 15	Feb. 1	Feb. 15	Feb. 15	Feb. 15
1.3	9.1	-2.3	0.9	5.8	7.8	15.2
4.1"	0.4"	38.0"	15.7"	3.6"	2.2"	0.1"
98%	98%	99%	100%	100%	100%	100%
2.267	3.276	5.189	10.614	19.694	30.750	35.845
1.428	2.797	4.994	9.729	19.606	29.903	34.953
20h13.8m	18h10.2m	2h26.3m	22h34.0m	3h06.1m	23h46.8m	20h13.3m
-20°52'	-22°44'	13°28'	-10°46'	17°10'	-2°45'	-22°49'

Hide-and-seek 🔭



Catch Jupiter at the right time on Feb. 5 to see Io slipping out from behind the disk, still in shadow, moments before Europa disappears completely. Ganymede lies farther west.

in any telescope, and even through binoculars.

As the night proceeds, Jupiter's altitude drops. On Feb. 1 it stands 60° high at 7 P.M. local time; three hours later it is half that. Jupiter sets by 12:30 A.M. local time on Feb. 1 and nearly two hours earlier by the 29th. The apparent diameter of planet's disk shrinks from $39''$ to $36''$ during the same period. That disk offers prominent weather systems that change hourly, including the dark North and South equatorial belts that straddle the equator. Be on the lookout for the Great Red Spot, which is carried around the planet once every 10 hours and makes an appearance every other day or so.

The Galilean moons — Io, Europa, Ganymede, and Callisto — undergo transits and occultations. What follows is not an exhaustive list but focuses on some highlights.

The combination of one moon's disappearance with another's reappearance occurs Feb. 5. Look before 10 P.M. EST and you'll see Europa approaching the western limb. But watch the eastern limb at the same latitude and at about 10:05 P.M. EST, Io reappears from behind Jupiter — though the small moon is traveling through the planet's long shadow. Within four minutes, Europa

disappears behind Jupiter's disk. Io finally emerges into the sunlight just after 11:20 P.M. EST. During the event, Callisto stands southwest of Jupiter and Ganymede lies far to the west.

Uranus is now nearly 20 AU from Earth, while Neptune is almost 31 AU distant.

Ganymede, Jupiter's largest moon, reappears from behind the planet's northeastern limb soon after 10:40 P.M. CST on Feb. 7. (Note the planet is very low in the Eastern time zone and difficult to observe.) It takes a few minutes to fully emerge. When do you first notice it?

Feb. 13 finds Io and its shadow tracing a path across the face of Jupiter. Io's trek is best seen from the eastern half of the U.S. this time, as the moon exits the disk around 9:19 P.M. EST, just as full darkness arrives in the Mountain time zone. The shadow exits shortly before 9:40 P.M. CST,

WHEN TO VIEW THE PLANETS

EVENING SKY

Jupiter (southwest)
Saturn (west)
Uranus (southwest)
Neptune (west)

MIDNIGHT

Jupiter (west)
Uranus (west)

MORNING SKY

Mercury (southeast)
Venus (southeast)
Mars (east)

again as the planet is very low for East Coast observers.

Europa follows suit the next evening, Feb. 14, when the moon ends its transit around 9:43 P.M. EST. Within 15 minutes, its shadow appears on the opposite (eastern) limb and leaves around 11:11 P.M. CST.

COMET SEARCH | All night long!

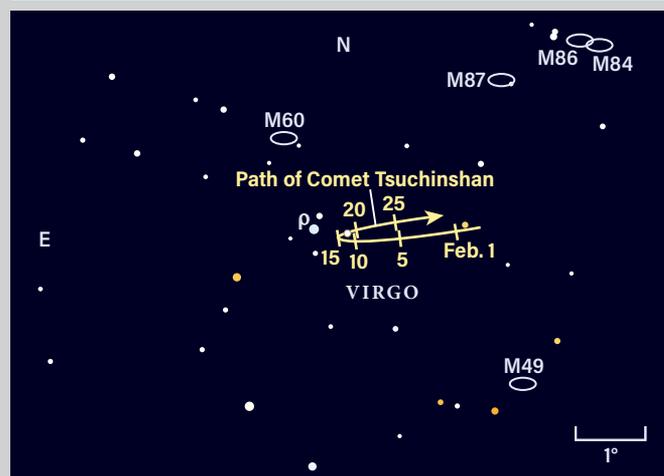
THE CORNUCOPIA OPENS at nightfall with 8th-magnitude 12P/Pons-Brooks. Bring a detailed finder chart to a dark site for this rarely visited zone north of Pegasus. Visually you won't see the green glow that imagers are posting, but you can detect color in the Blue Snowball (NGC 7662) just to the north late in the month. Even if Pons-Brooks does not repeat its earlier outbursts, next month it brightens past 6th magnitude.

Comet 144P/Kushida might just be visible in an 8-inch scope when it passes through the Hyades during February's first week, then hides in Aldebaran's ruddy glare on the 9th. All other comets noted here should be easy in a 4-inch from well outside the city.

Outshining the galaxies of the Virgo Cluster, Comet 62P/Tsuchinshan flaunts its 8th-magnitude glow in the gap between M87 and smaller M49 just 2° farther south. Hugging 5th-magnitude Rho (ρ) Virginis, by midnight Tsuchinshan is more than 15° high in the east.

Brighter (only this month) at 7th magnitude, C/2021 S3 (PanSTARRS) bookends the night before dawn breaks, climbing away from Antares low in the southeast. Better views are from the Gulf States, with peak geometry south of the equator. On the morning of the 11th, you can readily compare PanSTARRS to the globular star clusters just to its northeast. Is it brighter than M9? Two days later they share the same field, a great photo op with contrasting green and white snowballs.

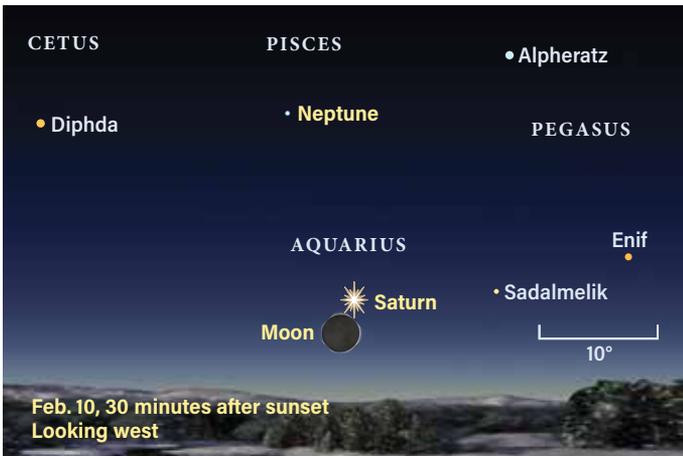
Comet 62P/Tsuchinshan 🔭



Eighth-magnitude Tsuchinshan carves a path near the Virgo galaxy cluster this month. Epsilon (ϵ) Virginis lies just east of this field; only galaxies with magnitudes brighter than 9 are shown, though many fainter ones are present.

LOCATING ASTEROIDS | Five-minute binocular watch

A young moon shines near Saturn   



Catch Saturn early in the month near the delicate sliver of a 1-day-old Moon. Neptune's position is also shown, but you'll need optical aid (and perhaps a bit more darkness) to easily spot it.

Ganymede's shadow is always a treat to observe as it's the largest shadow and, due to the tilt of the moon's orbit relative to our line of sight, it crosses the extreme southern portion of Jupiter, displaying a very elongated shape. Such a shadow transit begins around 9:30 P.M. EST on Feb. 18. The shadow begins its long exit shortly after 10 P.M. CST. Observers can view Ganymede itself making a transit across the south polar region on Feb. 25 between about 8:30 P.M. and 10:30 P.M. EST.

Uranus, also in Aries, starts the month 12° farther east along the ecliptic than Jupiter. The distance between the planets shrinks to 8° by the end of the month. Uranus dims to magnitude 5.8 and is best seen through binoculars or a telescope. It's located some 12° southwest of the Pleiades (M45), a short hop with binoculars. On the last day of February, you'll find the dim bluish planet 37' due south of 53 Arietis. The planet spends the whole month in this 6th-magnitude star's

vicinity, a region some 2° south and slightly west of Botein, the 4th-magnitude star also known as Delta (δ) Arietis.

You'll find **Uranus** 3° south of a nearly First Quarter Moon Feb. 15. The planet stands almost 20 astronomical units (1.86 billion miles; 1 astronomical unit, or AU, is the average Earth-Sun distance) from Earth by the end of the month. Through a telescope, it shows off a tiny 4"-wide disk.

Early on Feb. 1, **Mercury**, **Mars**, and **Venus** are spread out over 13° along the ecliptic in morning twilight. Mercury and Mars stand 3.5° apart.

Mercury shines at magnitude -0.3 and stands only 3° high in the southeast 30 minutes before sunrise. Mars is more difficult at magnitude 1.3, but rises 10 minutes before Mercury. With a very clear eastern horizon and some luck, you might spot the Red Planet 10° to the lower left of Venus 45 minutes before sunrise.

Mercury is lost in the first few days of February as it heads for solar conjunction. As the

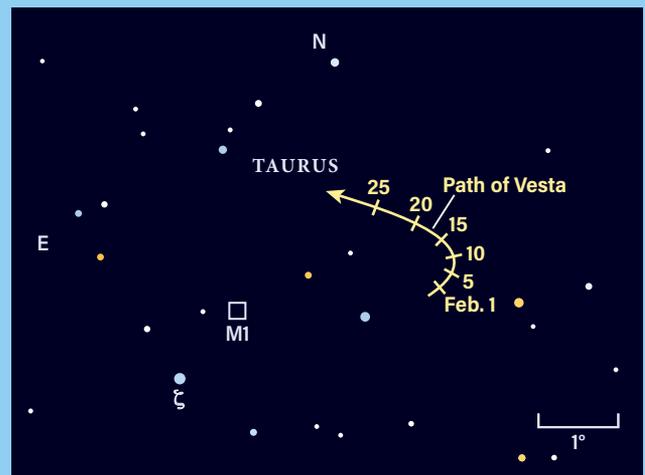
EVEN IF YOU DON'T HAVE TIME — or it's too cold — for a "proper" observing session, you can still snag an asteroid in the time it takes to play a typical song.

Binoculars or a grab-n-go mini-scope will readily reach 8th magnitude from most suburbs. Main-belt asteroid 4 Vesta fades through magnitude 7.5 this month, sitting one binocular field of view north of Zeta (ζ) Tauri, the star at the east end of the Bull's southern horn. In a dark sky, you'll pass by M1, the Crab Nebula. Thanks to all the dust in this part of the Milky Way, there is nothing to confuse you in this sparse backdrop. Avoid the 16th through the 19th, when the Moon is nearby, casting its glare all over.

Normally you can spot an asteroid shift against the background over the course of at least one evening each month, but not this time. Vesta is finishing its westward travel and backtracking to the east very slowly. This apparent retrograde loop is caused by the faster Earth overtaking Vesta on the inside track of our not-quite-circular orbits around the Sun. You might need four nights to notice a displacement.

Vesta spans some 300 miles, the second-largest object in the main belt. The Dawn spacecraft studied it closely back in 2011.

Crawling past the Crab  



Vesta should be easy to spot this month, passing near Zeta Tauri and the famous supernova remnant M1.

month progresses, Venus drops in altitude while Mars gains it. They meet on Feb. 22, with Mars 36' due south of Venus. The latter is an easy target at magnitude -3.9 . The pair stands 3° high in the southeast 45 minutes before sunrise (about 6 A.M. local time for U.S. observers). If you can swing a telescope this low, you'll find Venus spanning 11" and revealing a 90-percent-lit disk, while Mars is about one-third that apparent size at 4" wide, with close to a fully illuminated disk.

By the end of February, the planets stand more than 3° apart, with Venus getting lower and heading for solar conjunction, while Mars is on a long and slow increase in altitude. It will still be a few months before it becomes an easy object. ☾

Martin Ratcliffe is a planetarium professional with *Evans & Sutherland* and enjoys observing from Salt Lake City. **Alister Ling**, who lives in *Edmonton, Alberta*, is a longtime watcher of the skies.



GET DAILY UPDATES ON YOUR NIGHT SKY AT
www.Astronomy.com/skythisweek.

EXPLORING

TURKEY'S DARK-SKY DELIGHTS

A great night of meteors capped off a trip filled with adventures in caves, ancient cities, and hot-air balloons. **BY DANIELA MATA**

Merhaba! That's Turkish for "hello." After a week of encountering so many warm-hearted Turkish people, I was saying this word in my sleep.

My adventure began with 12 hours of travel from Milwaukee. When my feet touched Turkish soil in Kayseri, it finally felt official: I was going to observe the Perseids at Turkey's annual meteor-observation festival on the slopes of the inactive volcano Mount Erciyes, amongst a myriad of locals and foreigners.

This extraordinary opportunity arose through *Astronomy's* travel partner, Eclipse Traveler (ET). Traveling to Turkey for the Perseid meteor shower and learning about the region's rich history and culture is something I recommend everyone to do at least once in their life.

I was picked up by ET's experienced guide Mesut Pehlivan and our kind personal driver, Refik. When they asked if I was hungry for Turkish food, I had to admit that I'd been waiting to be asked that question since they first told me about the trip. We ate at the restaurant Taş Mekan and ordered nearly

everything on the menu — not for the last time on this trip.

After completely filling up on food, we headed to Kayseri Erciyes A.Ş. Ski Resort. There, I was generously welcomed by Deputy of Kayseri Murat Cahit Cingi and General Manager Zafer Akşehirlioğlu, who gave me and Mesut a grand tour, explaining their exciting plans for sports and social activities throughout the year. We had a delicious break with five Turkish desserts at the restaurant H2650 (named after the altitude in meters), next to the gondolas on Hacılar Kapı (one of the slope

trails). That's also where night-sky enthusiasts would gather the next day to view the Perseids — known to locals as a "starfall."

Afterwards we traveled to the exquisite boutique hotel Gesi Efkeriye Estates, owned by archaeologist and ET President Cengiz Aras. Throughout my stay in Kayseri, this historic establishment quickly felt like home, with family-like company from the guides and staff, and some of the best authentic homemade Turkish meals and desserts. I had to persuade my stomach to grow a stomach to take full advantage.

Long-exposure images capture the stunning streaks created by Perseid meteors. Their tails can vary in color depending on their speed and chemical composition. KAYSERI ERCIYES A.Ş. SKI RESORT





ABOVE: After touring the ski resort, I was taken to the scenic Perseid meteors observing spot on Mount Erciyes — 8,694 feet (2,650 m) above sea level. PHOTOS BY DANIELA MATA UNLESS OTHERWISE STATED

Perseids Day!

The next day, Cengiz hosted a lavish lunch at his hotel for me, Murat, a city mayor, and another Kayseri area official. The mayor kindly gifted me souvenir models of two famous Kayseri landmarks: Döner Kümbett (the Rotating Tomb) and Bürüngüz Camii (the mosque at the heart of the city).

Afterwards, Mesut and I visited the ancient site Kültepe-Kanesh, located at the foot of Mount Erciyes. It was the center of Assyrian trade in the third and second millennium B.C.E. Then we went to the city center to see a more modern way of living and have an early dinner before heading up the mountain for the starfall event.

My heart was pounding with excitement as we rode the gondola lift up to the observing spot. The previous year, Mesut explained, the crowds were so big that arriving at the start time was too late

to get in. So we got there about two hours in advance — and thank goodness we did! Once at the observing site, I quickly saw that many others had the same idea.

Before long, I was taking pictures of the sunset as its pastel hues became increasingly vibrant. I also met the event's organizers from the Kayseri Science and Technology Center (STC). The crowd continued to swell; each time I looked around, there were 50 more people. About a hundred pictures later, I was surrounded by roughly 1,000 fellow observers. Like a mosaic, they came together beautifully to create a harmonious community, a crowd with one goal: to bask in the wonder and magic our cosmos have to offer.

Astronomical twilight passed and to kick off the night, the STC presenters called children forward to participate in a trivia game. They were asked questions like “How many planets are in our solar system?” or “Which galaxy is closest to us?” I could hear their little excited voices and see their silhouettes against the projection screen, jumping up and down with their arms waving around. If they



answered correctly, they won a red light-up meteor toy. (I was gifted one, too.)

With not a single cloud in the sky, the night was chilly but perfect for observing. The Perseid meteors are debris left behind by Comet Swift-Tuttle (named after the discoverers) — which takes about 132 years to orbit the Sun. We see them every year because Earth passes the debris every year, and thus, they annually peak around the same time: The second week of August, you can find them in the constellation Perseus.

Astronomers estimate that against velvet-black skies, over 60 meteors per hour can be seen traveling at around 41 miles per second (66 kilometers per second). I easily saw dozens of Perseid meteors of all sizes! My eyes were a little too slow to notice a true distinction between meteor colors — but that just gives me even more of a reason to appreciate long-exposure photographs. There was one monstrous meteor I can still see clearly in my mind that spanned more than 10° in the sky. Without warning, I involuntarily pointed and yelled out, “Ah,

LEFT TO RIGHT:

The night of the starfall event, children raise their hand in excitement to answer astronomy trivia questions and win a cool toy. ERCIYES A.Ş. SKI RESORT

Before sunset, friends and families gather to capture the momentous night. ERCIYES A.Ş. SKI RESORT

One of the many mouthwatering breakfasts we had: My favorite dish was created with egg, tomato, chile — and magic.

The extremely generous ET helpers and Cengiz (with sunglasses) took time for a photo with me.

One night in Gesi, I helped with some of the cooking on the patio, which is surrounded by a verdant garden and ancient artifacts. REFIK

A soul-feeding Turkish welcome



there!” And I wasn’t the only one to do that throughout the night.

Although the words spoken around me were purely Turkish, the language of exhilaration was universal. With each passing meteor, I first heard excitement, immediately followed by exclamations either matching the energy because they had also seen it, or disappointment because they missed it. These heartfelt human moments made me smile ear to ear — and I had to laugh at the more dramatic reactions. This was easily one of my favorite moments of the trip.

As the night came to an end, I was interviewed by two different Turkish public broadcasters, one from Kayseri Metropolitan Municipality Erciyes A.Ş. and one from TRT World (an English-language Turkish channel). As we finally descended the mountain, I was shocked to pass hundreds of cars lined bumper to bumper. About 2,000 people were sitting outside their cars, looking up and enjoying the visual feast.

Friendly Turkish delights

Before Mesut left to return home, the two of us and one of Cengiz’s assistants, Ibrahim, took a light trek through Koramaz Vadisi, a rocky but lush 9-mile-long (15 km) valley. I snacked on chemical-free plums and walnuts (probably for the first time ever), plus natural spring water from Mount Erciyes. The incredibly cold water and towering poplar trees provided some welcome relief from the Sun.

After the hike, we took a brief detour to the home of Cengiz’s friend Mehmet Uzunok, who gave us a tour of the indoor/outdoor restaurant he’s building, and shared some of his home-grown



The view from the largest balcony at the Gesi boutique hotel was serene. When Cengiz hosted a lunch for friends, we came up here to enjoy multiple desserts and Turkish tea.

blackberries. They were so incredibly sweet and juicy. His wife and children greeted us with Turkish coffee, which is some of the best coffee out there, if you ask me — it’s amazingly easy to drink black without tasting exceptionally bitter.

Around sunset, we returned to the hotel for dinner. This time it was my turn to cook! Fortunately for me, all I had to do was put pre-seasoned lamp chops on the grill and not dry them out. Beginners’ luck (or maybe natural talent!) made the meat come out nice and juicy. We paired it with grilled tomatoes, peppers, and bread, and everybody dug in until there was nothing left.

The following day, Cengiz showed me one location near the hotel with dozens of structures called pigeon lofts; they can also be found throughout the city. In the first

millennium B.C.E., these little houses were used to collect pigeon droppings to then sell. It was one of the largest sources of income for the residents at the time.

I then had the best kebab at Hasiralti Kebab House, an established restaurant also owned by Mehmet. Afterwards, Cengiz, Refik, and I visited the Kayseri Archaeological Museum, where Cengiz gave an excellent and interesting explanation of the artifacts. The marble Hercules Sarcophagus left me speechless — it’s an excellent example of the human capability to create something extremely fluid and intricate out of something sharp and straight. This artifact depicts the 12 labors of Hercules through intense carving depth and great anatomical detail.

To wrap up the day, one of Cengiz’s long-time neighbors and friends hosted us for dinner with his family. This turned out to be the best meal I had on



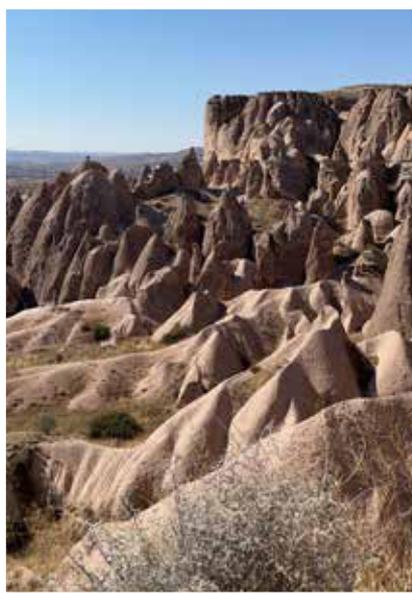


constantly repeated to myself, “Did I die and enter utopia unknowingly?” The panoramic vistas seemed straight out of a fairytale; I could have stared at them for hours and not fully taken in all the details.

Around 60 million years ago, volcanic eruptions covered hectares of Turkish lands with lava. Cappadocia now boasts colorful rugged mountains, valleys, extinct volcanoes, and fairy chimneys — tall rock pillars with mushroomlike caps formed by the ancient lava, ash, and basalt, which is then eroded by weathering — showcasing nature’s superb engineering.

The same soft rock from which fairy chimneys form also served as a sanctuary for past civilizations escaping religious persecution. About 2,000 years ago, refugees carved seemingly infinite labyrinths of houses, churches, and barns inside cone-shaped caves. At rock-cut complexes at the Dragon Church in Soğnali and the Open-Air Museum in Göreme, I could see beautiful frescoes, despite people of conflicting faiths destroying the faces. And a visit to the Kaymakli Underground City left me speechless at the ingenuity of these civilizations. We could access four out of the eight stories of this preserved city, which made it much easier to understand how these places could hold animals and thousands of people — every room led to two to five other rooms.

Apart from the more educational activities, we visited Kocabağ Winery and tasted award-winning wines, and saw a carpet-making demonstration at Yüksel



ABOVE: My unforgettable bird’s-eye view from Cappadocia Voyager Balloons: I could see the colorful fairy chimneys, hills, and valleys with the most stunning, vibrant backdrop.

LEFT: Countless cones and valleys consist of cooled ash that has solidified and hardened to form soft volcanic rock, giving off the illusion of being in a giant sandbox.

women, even though only the granddaughter knew English. All three of the women taught me Turkish formal and informal greetings. I absolutely loved it.

Cappadocian fairyland

After four days in Kayseri, we moved on to continue our adventures in the next region: Cappadocia, Turkey. If you want to go somewhere otherworldly and magical, Cappadocia is the answer. Throughout my three days there, we stayed at the Grand Cave Hotel — modern lodgings seamlessly merged with ancient structures — and wandered through spectacular landscapes. I

the entire trip: manti, a Turkish ravioli with a garlicky yogurt sauce and a spicy butter sauce topped with sumac. Thinking about it now still makes my mouth water. The family graciously welcomed me, and I especially connected with the three generations of wonderful

Cappadocia adventures



Dozens of pigeons wait to be fed — or scared into flight — at Pigeon Valley. At the Göreme Onyx jewelry store located across the street, I bought a ring to commemorate this year's Perseids.

Carpet and a pottery demonstration at Bei Kaya, a lovely pottery shop owned by two sisters.

Everlasting memories

Returning to the theme of the trip, I had a second opportunity to see the Perseids. Cengiz's friend Ziah kindly invited us and some others to stargaze at an isolated spot in the valleys, away from light pollution. We ate savory Turkish sausage and paired it with tomatoes and homemade cheese.

At one point in the night, two of the friends started singing and playing Turkish music with an oud and daf (a type of guitar and drum). As the music was playing and I looked up at the Milky Way and the star-filled sky, I teared up, overwhelmed with gratitude and happiness. Good thing it was so dark!

This happened again the next night when Ziah hosted us and others for a dinner. Both nights were filled with soul-feeding moments. For our last night in Cappadocia, Cengiz, Refik, and I went to a spectacular Turkish cultural show at the nightclub cave Yasar Baba.

High-flying finale

And what better way to start my last day than to ride a hot-air balloon over the scenic landscape? I was picked up from our cave hotel at 4 A.M. by Voyager Balloons. The company offered a quick



breakfast, then took us to our balloon.

As our pilot, Jim, took us over the caves, valleys, and fairy chimneys, a feeling of enchantment washed over me. I was already dazed by the ethereal landscape when viewing it from the ground, but now at a higher altitude? I was hypnotized. As the balloon gently rose and fell, we witnessed sunrise more than once, accompanied by the iridescent colors of the sky and landscape. It was the fastest 90 minutes of my life — though it pushed the limits of my phone's storage.

Once we touched land again, we honored a tradition dating to the 18th-century French balloonists: celebrating with a glass of champagne. We also received official passenger certificates as mementos, but I don't think it's possible to ever forget any of it.

I loved absolutely every little detail of this trip. Each time I had to say goodbye to somebody, I ended our conversation by saying, "Don't worry, I'll be back. This won't be the last time you'll be seeing me." And I meant every word.

Turkey took me by beautiful surprise, filled with unexpected delights. How could I not go back and try to persuade others to experience what I was so fortunate to experience? 🍷



Scan the QR code to watch a short video of hot-air balloons and the breathtaking panorama.

Daniela Mata is steadily crossing off adventures on her astro-events bucket list.



LEFT TO RIGHT:

Thanks to Cappadocia Voyager Balloons, I could take one of my favorite images of the fairy chimneys and the sunrise.

At Bei Kaya, I sat down at a kickwheel and attempted to throw a tall bowl — though it turned out more like a slanted cup.

Ziah hosted several of us at his home for a dinner of tarek — a fish found only in Turkey's Lake Van. REFIK

As I stood on Ziah's balcony, I found one of nature's silly faces. When I showed him, he excited my inner child by saying there were 10 more faces out there in the landscape.

Back on the ground after our hot-air balloon flight, we followed French tradition and toasted with champagne.



Carinae Nebula (NGC 3372)

See
these **SUPER-S**
CELESTIAL GEMS

The Milky Way contains some really, really big stuff: supergiant stars, unimaginably huge emission complexes, molecular clouds, star clusters, dark nebulae, and more. Beyond lie more galaxies and clusters of galaxies. The true cosmic scale of these objects has only become known during the last century or so. Peering at them through a telescope is an exhilarating experience.

Because of the scale of the universe, the components of even the closest galaxies are tough to see without big telescopes. But we can explore our own Milky Way's astonishing objects. Some are not only visible, but also appear really large in the nighttime sky.

SELECTION PARAMETERS

I started by creating a list of my personal top 50 large and spectacular celestial wonders, considering only deep-sky objects that are at least twice as large as the Full Moon in visible light. In other words, nominees to my list must span at least a degree on the sky.

Also, the objects had to be bright enough that it is possible to detect them visually under excellent conditions. That said, several of these are challenging to see through a telescope — but they're great targets for piggyback imaging if you have a mount that can track the sky.

Thirty-two of the 50 objects are visible to the naked eye; 45 are visible or best seen through binoculars; eight are faint and are a challenge to see visually; and seven are so far south that unless you live south of Mexico City or in Hawaii, you won't see them at all.

With one exception, the Spaghetti Nebula (Simeis 147), you should be able to see all of these through binoculars or a 6-inch telescope.

If you find tackling a list of 50 objects a bit daunting, no worries — here's a Top 12 list with three objects per season to get you started. Please note they aren't all the brightest, but parts of the objects will be visible through binoculars. And, of course, a small scope will add to your enjoyment.

WINTER

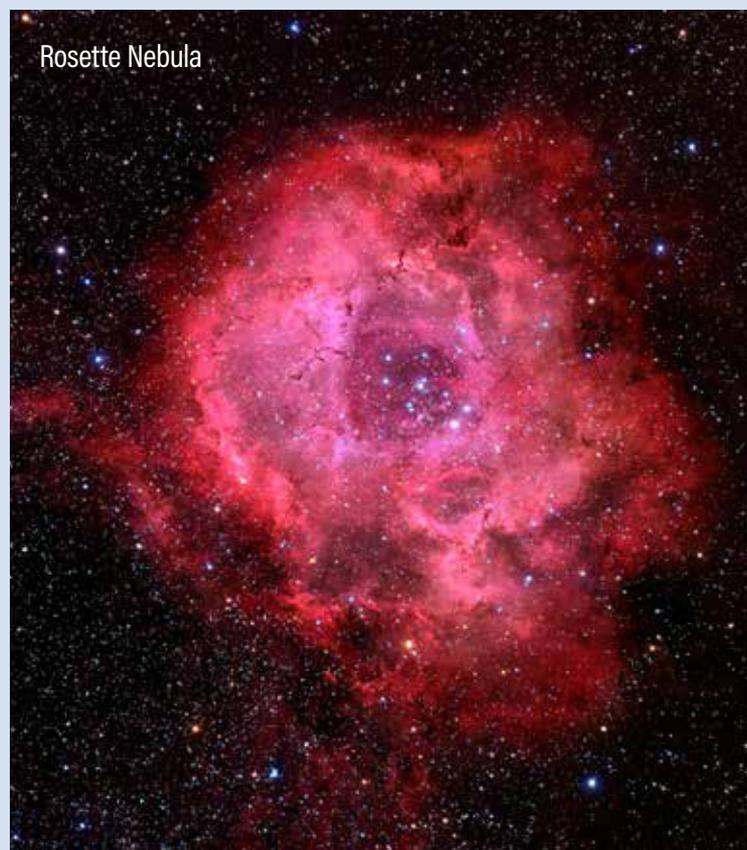
Despite being some 10° long, **Barnard's Loop** is one of my list's most challenging objects because of its low surface brightness. A few observers have seen it without optics, usually by holding an H-beta filter in front of their eye. The Loop is the remnant of a supernova explosion about 2 million years ago. The gases fluoresce because of hot young stars in and near the Orion Nebula (M42).

If you head about 9° southeast from Betelgeuse in Orion, and you'll see a glow in the Milky Way. Train a rich-field telescope or binoculars on it and the **Rosette Nebula**, an 80'-wide star cluster and emission nebula, will appear. The Rosette is part of the Monoceros OB2 molecular cloud. At 5,000 light-years away, the star cluster at its center is magnitude 4.8, easily bright enough to see with the naked eye.

Another option is the **Lambda Orionis Nebula**, also referred to as the Lambda Orionis Ring. Your best chance to catch it is by taking a piggyback image of Orion, which will easily show a large faint circle of nebulosity around the star Lambda (λ). The nebula is a real challenge to observe visually, but it can be glimpsed through large binoculars — especially those equipped with light pollution filters.



CHRIS SCHUR



ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

IZED

These objects look best through small scopes — or none at all. **BY KEVIN RITSCHER**



Virgo Cluster

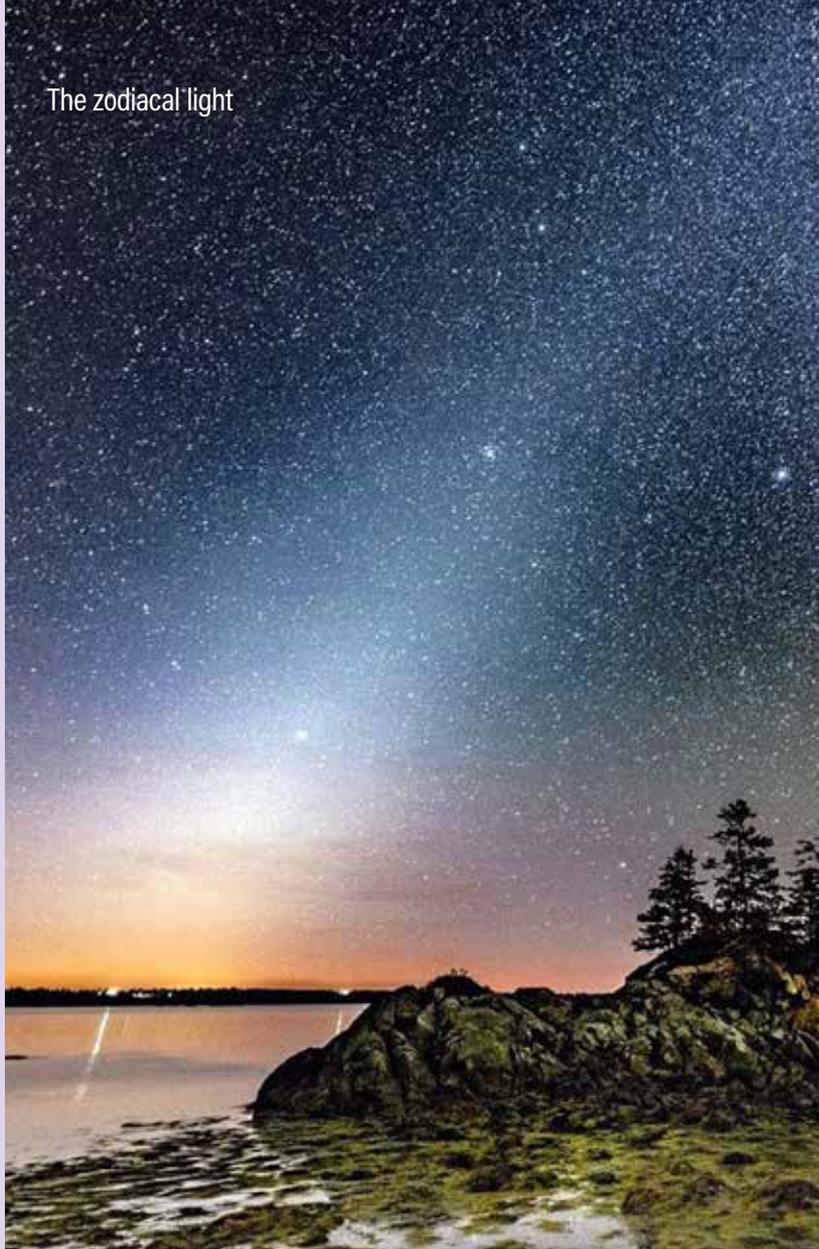
BERNHARD HUBL

SPRING

South of the Big Dipper's handle is the **Coma Star Cluster**, part of the constellation Coma Berenices. It has about 40 members and is only 280 light-years away. This cluster shines at magnitude 1.8 and covers over 5° of the sky.

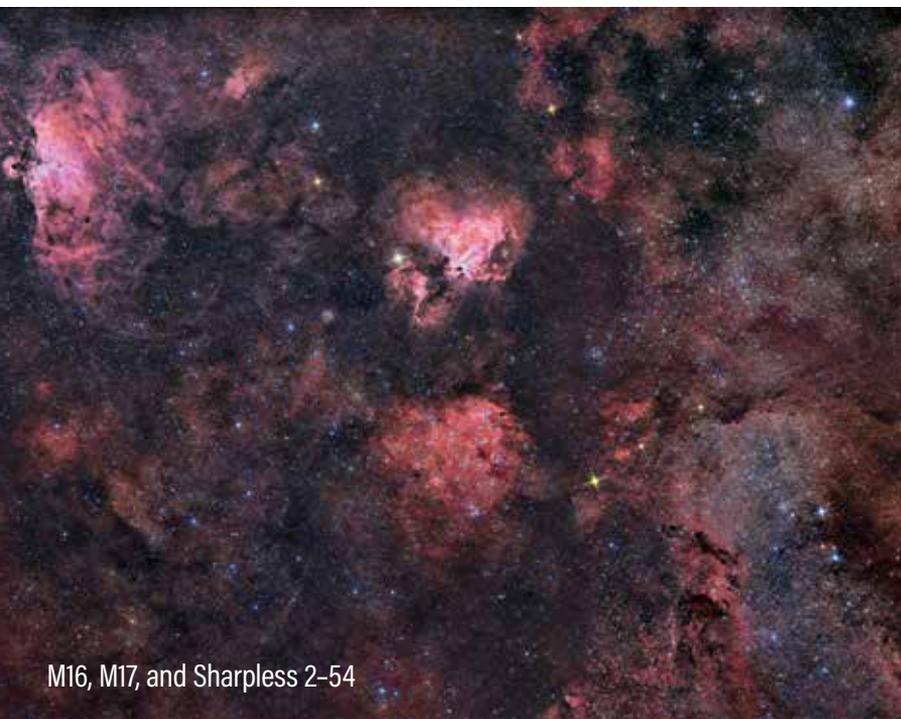
The brightest galaxies in the **Virgo Cluster** are visible through binoculars, but a 6-inch scope will let you examine more than 100 members of this cluster, which spans 8°. Centered on the giant elliptical galaxy M87, whose supermassive black hole was the first ever imaged, the center of the cluster is about 54 million light-years from Earth and is the most distant object on our list.

Also on your to-view list should be **the zodiacal light**, which is often visible after sunset in the spring and before sunrise in the fall (in the Northern Hemisphere). It's a large triangle-shaped glow emanating from the horizon and caused by the scattering and reflection of sunlight by interplanetary dust. The zodiacal light will usually be visible to an altitude of 20°, but in dark skies you can track it a lot higher.



The zodiacal light

BARRY BURGESS



M16, M17, and Sharpless 2-54

TERRY HANCOCK

SUMMER

The **Serpens-Aquila rift** starts west and slightly north of Altair and flows south, broadening to the west toward Serpens. This dark area obliterates the stars on the west side of the Milky Way. The creamy band of stars reclaims dominance in Serpens before submitting to the dust clouds in Sagittarius.

Also along the Milky Way's band but in the central rift, roughly between Antares and the Lagoon Nebula (M8), the unaided eye can pick up a dark zone, oriented east-west and thicker on the east end. Its outline, much clearer through binoculars, has the shape of a smoking pipe. The **Pipe Nebula** spans 8° and is made of dark dust clouds between us and the center of our galaxy. The Pipe is part of the even larger Dark Horse Nebula, which is more easily seen from southern latitudes.

In northern Sagittarius spreading north into Serpens is a 6°-wide vista of three major emission nebulae: **M17, M16, and Sharpless 2-54**. This is a



Pipe Nebula

GIANNI TUMINO

massive region of new star formation in the general direction of our galaxy's center. You can easily see all three nebulae through binoculars from a dark sky, and even a 4-inch telescope will reveal a wealth of rich detail.

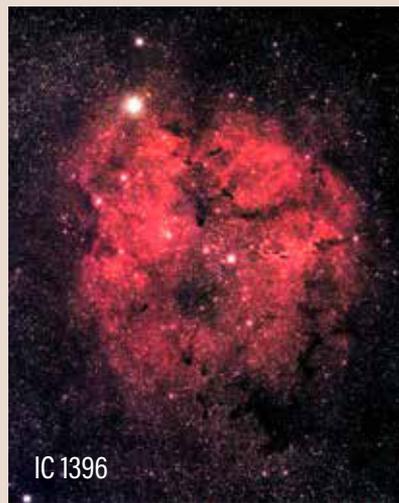
FALL

The star Eta (η) Persei, the Double Cluster (NGC 869 and NGC 884), and the **Heart and Soul nebulae** (IC 1805 and IC 1848) form a square in northern Perseus and southwestern Cassiopeia. The Heart and the Soul create a rich vista spanning some 5° and contain more than a dozen cataloged objects. You will see several bright spots if you track down these objects, but to observe their nebulosity is a challenge.

Another object that is hardly visible as a soft, barely-there glow to the naked eye but easily seen through binoculars at a dark site is the large emission nebula **IC 1396** in Cepheus. It holds several dark nebulae, the most famous being the Elephant Trunk (van den Bergh 142). To spot this through a telescope, you'll need at least a 3° -wide field of view.

I'll end my top 12 with the **Andromeda Galaxy (M31)**, a classic that covers more than 3° of the sky. Bright enough to spot with naked eyes, it's one of the few galaxies large enough to be on our list. Binoculars and telescopes will reveal its two satellite galaxies, M32 and NGC 205.

The other 38 objects that made my list will be featured on *Astronomy's* website. Scan the QR code below and explore them online — and in the sky.



JASON WARE



BOB FERA

Kevin Ritschel *previously worked at major telescope companies and has loved watching the night sky since the third grade.*



Scan the code to see the full list of 50 wide-angle objects online.



Eclipse viewing made simple

With some dollar-store reading lenses and a cardboard box, you can easily make your own solar viewer. **BY PHIL HARRINGTON**

Excitement is building for the total eclipse of April 8, 2024. Viewing such solar eclipses is great fun; however, looking at the Sun must be done cautiously. Many use special solar filters to reduce the Sun's energy to safe levels before it enters a telescope or binoculars. But how can those without access to either view the eclipse safely?

Terry Richardson, an astronomer and faculty emeritus of the College of Charleston in South Carolina, came up with an ingenious gadget before the 2017 total eclipse, one that can be easily made in an afternoon. He calls it the Safe Solar Viewer (SSV). It's not a telescope for viewing the Sun directly; instead, it projects sharp, enlarged views of the solar image onto a screen — and it far outperforms the common cardboard pinhole viewer.

The best part might be the low cost. Terry designed two versions. The simpler one uses optics that cost about \$1. The more advanced version's optics cost \$5.

 The author's grandchildren view the partial phases of the 2017 eclipse with a homebuilt Advanced Safe Solar Viewer. HELEN PARTLOW

Simple SSV

Let's look at the Simple SSV first. The lens comes from a pair of +1 reading glasses. You can buy these from a dollar store for, well, a dollar (or \$1.50 in some cases these days). Since you only need one of the lenses from the reading glasses, you can give the second lens to a friend.

Each lens has a focal length of about 39.4 inches (1 meter). To confirm your lens' focal length, let light from a room lamp shine through it onto a wall. Move the lens back and forth until the projected image is sharp, and then measure the distance from the lens to the image. That's how long your SSV needs to be.

Terry notes that you can use up to a +2 reading glass lens for a shorter focal length, but it will produce smaller images.

Besides the lens, you will need a long three-sided cardboard box measuring

about 4 by 4 inches (10.2 by 10.2 centimeters) across and about 6 or 7 inches (15.2 or 17.8 cm) longer than the lens focal length. Leave one long side of the box open for viewing.

Cut about 4 inches off from the front of the box to make the focuser. At the opposite end of the long box, glue a white card to serve as the projection screen.

Before mounting the lens to the outside of the focuser box, cut a small, round hole in the end's center (see opposite page, middle). Do not make the hole the same size as the lens. Terry warns, "In practice, a better image is formed if the hole is kept to about ¼ inch [about 0.6 cm] or a little more in size. A large hole makes an image that is too bright and indistinct for the best viewing."

Place the eyeglass lens over the hole in the focuser box and secure it using masking tape, duct tape, or glue. Just keep the center of the lens clear. With that set, slide the focuser into the open end of the long box (see opposite page, bottom).

Advanced SSV

The Advanced SSV uses two lenses — an objective lens and a Barlow lens — to project an image onto a white screen. It's best to assemble most of this SSV from plywood rather than cardboard, to keep the lenses aligned.

The objective lens should have a focal length between 400 and 600mm, while the Barlow is best between 18 and 30mm.

Terry bought his optics from Surplus Shed (surplussed.com). Thanks to the SSV's popularity, Surplus Shed now sells an SSV lens set for only \$5 plus shipping.

On Terry's advice, I used ½-inch plywood for my own Advanced SSV (top):

- Support rail: 32" x 3½" (A)
- Focuser upright: 3¾" x 3½" (B)
- Focuser foot: 2" x 3½" (C)
- Barlow upright: 3¾" x 3½" (G)
- Screen holder: 4½" x 3½" (H)

In addition, two focuser slide guides (D) are needed to keep the focuser from shifting along the support rail. These can be easily made by cutting a 6-inch (15.2 cm) tongue depressor in half. Finally, cut two 3-by-3-inch (7.6-by-7.6 cm) pieces of cardboard (E and F) to hold the optics in place.

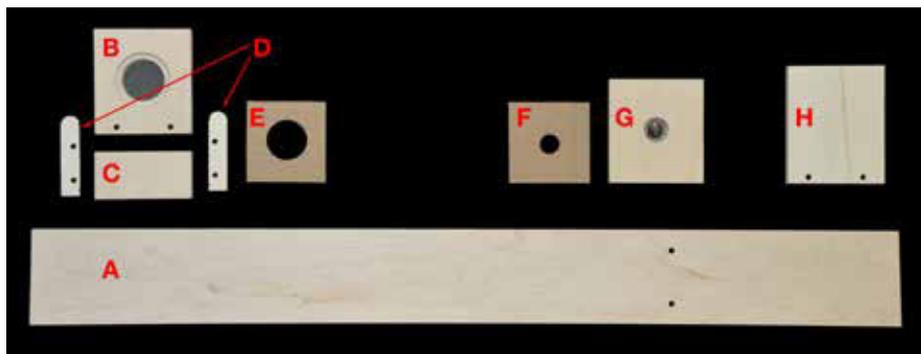
Begin by attaching the screen-holder (H) to the end of the support rail (A) with carpenter's glue and finishing nails, taking care not to crack the plywood. Then glue a white card onto the front of the screen holder.

Next, drill concentric pilot holes through the centers of the focuser (B) and Barlow (G) uprights, to ensure that both lenses will be on the same optical axis when completed. Then, open up the pilot hole in the focuser upright to match the outside diameter of the objective lens. Do the same to the Barlow upright to match that lens's outside diameter.

Finish off the focuser by nailing and gluing the foot (C) to the upright, and add the two focuser slide guides (D) to the foot's two sides.

Carefully insert the lenses into their respective supports. Check that they are square to the uprights. Hold them in place with the cardboard lens holders (E and F). I used duct tape to seal them tightly.

The exact spacing of the lenses and screen-holder is not super-



🔗 For a sturdier frame, the Advanced SSV can be made out of plywood. TR RICHARDSON

critical, but plan on positioning the Barlow about 11½ to 12 inches (29.2 to 30.5 cm) from the screen. Before you commit to anything, though, do a test. Bring the SSV outside on a sunny day and tilt it sunward. Mark about 12 inches in front of the screen and hold the Barlow in place. Next, slide on the focuser, aim at the Sun so that it shines through both lenses and onto the screen, and move it back and forth until you see a sharp image. **Do NOT look through the SSV's lens to aim at the Sun.** The Sun should always be at your back.

If the image isn't sharp, nudge the focuser toward or away from the Barlow.

If need be, also move the Barlow slightly toward or away from the screen. Once you get a reasonably good image, mark where the Barlow upright is along the support beam. Make sure it's square to the support beam, then drill two pilot holes through the beam and into the Barlow upright. Use carpenter's glue and finishing nails to secure the upright.

Final focusing

Once everything is assembled, it's time to focus your SSV. Regardless of the version, lean it against a chair or other support, shifting it until the Sun is shining through the lens. Again, **do NOT look through the SSV's lens to do this.**

After the Sun is projected onto the screen, and without moving the SSV's aim, slide the focuser back and forth until the projected image is sharpest. Once it's set, you should never need to refocus it. To keep the Simple SSV's focuser in place, Terry suggests using four binder clips. The Advanced SSV's focuser is best held in place with one or two strong rubber bands.

For more information on the SSV, visit Terry Richardson's website: richardson.people.cofc.edu/safe_solar_folder.

Making the SSV is a simple but very effective STEM project for parents, science classes, clubs, and Scout groups. And once it's done, it's sure to be a hit. My grandchildren loved using the SSV that I made for the 2017 eclipse, and we will certainly have it with us again for the next. ☺

Phil Harrington is a longtime contributor to *Astronomy* and the author of many books. He has observed the Sun for decades.



The Simple SSV makes use of a lens taken from a pair of reading glasses taped over an aperture. To avoid producing too bright an image, the aperture should be smaller than the lens itself. TR RICHARDSON



A cardboard box makes the perfect frame for the Simple SSV. One end of the box is used as a sliding focuser, held in place by binder clips. The lens is taped to the front of the focuser. A white card serves as the projection screen.

TR RICHARDSON

VAONIS' NEW SMART SCOPE

REVIEWED

The Vespera combines ease of use with complex technology in a lightweight package.

STORY AND PHOTOS BY RAYMOND SHUBINSKI



Vaonis' Vespera is a portable smart scope that can be used for night — or day — sky viewing.

Astronomical equipment has come a long way in the first two decades of the 21st century, and Vaonis provides an instrument that sets a new standard for observing and astrophotography.

Its name, *Vespera*, derives from the Latin *vesper*, meaning “evening.” This little instrument is the sister to Vaonis’ larger flagship scope, *Stellina*, which was built to work on the same design principles. As with the *Stellina* scope, which I reviewed in the August 2020 issue, the *Vespera* is meant to provide smart imaging and is not equipped with eyepieces.

Tech insights

The product design is elegant and simple. When the scope first came out of the box, my grandson said it looked like a giant earbud case. Weighing only 11 pounds (5 kilograms) and measuring 15 inches long and 8 inches wide (40 centimeters by 20 centimeters), this instrument is incredibly portable. There are several accessories available, including a custom-built backpack. For this review, Vaonis also sent three filters that easily snap in place on the telescope’s objective lens: a light-pollution filter, a dual-band filter, and a solar filter. (These filters are normally sold separately.) The dual-band filter is a narrowband interference filter that improves images of nebulae, and the solar filter provides an excellent white-light image of the Sun.

Also provided for the review was a hygrometer sensor. This tiny, 0.5-inch (1.3 cm) device screws into a slot next to the objective lens. When temperature and humidity reach a critical point, the sensor will activate a heating ring around the objective lens to prevent dewing. This is a very important accessory, since the telescope has no dew cap. The telescope comes with a USB charger, a bubble level, and a tabletop tripod that screws into the base of the instrument.

The telescope is equipped with a 50mm apochromatic objective that, according to Vaonis, has a “unique quadruplet lens, formed by two groups of two lenses made of lanthanum glass.” Lanthanum is a rare Earth element that helps reduce light dispersion when used in optical systems. As a result, the telescope provides extremely sharp images. The *Vespera* also produces a chromatic aberration- and astigmatism-free image. With a focal ratio of $f/4$, a focal length of 200mm, and a magnification of 30x, the *Vespera* functions as a high-tech rich-field telescope.

At the heart of the telescope is a Sony IMX462 sensor. This technology provides a compact low-light-sensing device. It’s easy to capture most extended objects with 8 megapixels of resolution and a 1.6° by 0.9° field of view. Mosaic mode, which can be accessed in Vaonis’ Singularity app, will allow for a wider field of view. The *Vespera* is also waterproof, which is great when dew starts to settle on the telescope.

Loading the sky

Getting ready to observe with the *Vespera* is uncomplicated and

intuitive. The unit has a small disk at the bottom of the telescope where three 8-inch (20 cm) legs can be attached to create a sturdy tabletop tripod. The USB charger magnetically snaps into place. On a full charge, the telescope can operate for eight hours, or about a full night of imaging. All that must be done for the physical setup is to ensure the scope is sitting level. The included bubble level attaches magnetically to the side of the telescope. The tripod legs can be adjusted a bit to level the instrument.

The Vespera is operated entirely from a phone or tablet. The Singularity app, developed by Vaonis, is available on both the App Store and Google Play. Simply download the app to your preferred device — I chose to use an iPad Pro for the large screen. When the app is first opened, information about your local weather conditions, Moon phase, and suggested objects for viewing appear. The Vespera has its own Wi-Fi transmitter, which allows it to connect with your device. Once the scope has been initialized, you can start observing.

Version 1.18.2 of the app provides more than 4,500 objects for viewing. It is also possible to input right ascension and declination to observe objects not in the catalog. The Vespera has perfect tracking, which is essential for long exposures. Once in operation, the scope can be left completely unattended. Images can be saved as JPG, FITS, and TIFF files. The images can also be further processed later using the app or other available software.

Choosing a target

I wanted to photograph the Orion Nebula (M42) first. I simply chose M42 from the list of recommended objects and watched as the scope started to capture the image.

You can watch the image “build” on your device’s screen. The longer the exposure, the more detailed the image will become. This is accomplished by stacking the images. Within seven minutes, I had a wonderfully detailed image of the Orion Nebula from my backyard. The Singularity app even provides the number of stacked images for each object — in this case, only 42 were required.

Next up was the Whirlpool Galaxy (M51). I let the Vespera track M51 for 17 minutes, stacking 101 images. The results were amazing, with the bright



M13 is a globular cluster in the constellation Hercules and an easy target for the Vespera scope.



The pink glow of the Orion Nebula (M42) is a beautiful sight with Vaonis’ Vespera scope.

PRODUCT INFORMATION

Vaonis Vespera

Lens: Apochromatic Quadruplet 50mm

Field of View: 1.6° x 0.9°

Focal Ratio: f/4

Battery life: 8 hours, extendable

Dimensions: 15 inches by 8 inches by 3.5 inches (38 cm by 20 cm by 9 cm)

Weight: 11 pounds (5 kg)

Price: \$1,499

Contact: Vaonis

+1.646.956.5933

<http://vaonis.com>

galactic center and dust lanes in the spiral arms clearly visible. Each of the images can be downloaded immediately and shared with others quickly.

Throughout this observing session, I chose each object manually. Alternatively, if you want to take a break, the “Plan My Night” feature allows you to set up an observing list in advance. Once you have input your desired object and the length of each exposure, the scope can be left unattended to capture the images you have chosen. I used this feature to allow me to visually observe with some of my other telescopes while the Vespera was working away on its own.

The Vespera is not just for nighttime observation. With the solar filter, it is possible to acquire high-definition images of the Sun. The scope will also find and track the planets and the Moon. However, because of the short focal ratio, planetary images are less than impressive.

Good with the bad

I found very few drawbacks to this instrument. One issue, however, was dealing with the wind. The arm that contains the optics tends to vibrate when a strong breeze kicks up. This can affect the quality of the final image.

When I showed the Vespera to friends and told them it costs about \$1,500, the usual reaction was, “That’s a lot for a little telescope you can’t look through.” But in my opinion, the Vespera is a bargain for the advanced technology available at your fingertips and as an aid for providing beautiful images that can easily be shared with others.

Based in Montpellier, France, Vaonis is a small company with the motto “Take people on a journey through space.” The founder, Cyril Dupuy, formed his company in 2016. Working with the French design firm Ova, Dupuy and his staff have created not only the Vespera, but the Stellina and Hyperia as well. A visit to the famous Nice Observatory sparked his lifelong passion for astronomy. Now Dupuy says he wants to “make astronomy accessible to everyone.” His goal is to provide high-quality and beautiful instruments that are easy to use and deliver outstanding results.

From what I have experienced, the Vespera is an aesthetically pleasing scope that you can take anywhere to view the wonders of the universe. ☺

Raymond Shubinski is a contributing editor of *Astronomy* who loves using new astronomical equipment under clear desert skies.

A stellar colossus

VY Canis Majoris is a behemoth hidden in a nebula of its own making.



An artist's impression of hypergiant star VY CMa shows the star's vast convection cells and violent ejections. VY CMa is such a behemoth that if it replaced the Sun, it would swallow Jupiter. NASA, ESA, AND R. HUMPHREYS (UNIVERSITY OF MINNESOTA), AND J. OLMSTED (STSCI)



There is a nebula visible through small telescopes that has long evaded attention. Despite occasional outbursts of intense interest, the nebula's time in the visual observer's limelight, for some unknown reason, ultimately fades. Recent observations by the Hubble Space Telescope, however, have spurred renewed interest in this remarkable object. This nebula belongs to VY Canis Majoris, a red (spectral type M3) hypergiant variable star whose face is masked by a red nebula that tightly surrounds it.

When we peer at VY CMa through our telescopes, we are not seeing the star itself but rather dense envelopes of knotty debris ejected from and illuminated by it. The star's dusty mass-loss episodes have no parallel among known nonexploding stars. And among stars in its class, its nebula has no equal in brightness and clarity — not even fellow hypergiant Eta Carinae reveals its nebulous secrets so readily.

A curious history

French astronomer Jérôme Lalande first recorded VY CMa's variability in 1801. It was well observed throughout the 19th century. Curiously, no observations were recorded for 17 years until 1917, when Luís Guérin of the Argentine National Observatory discovered that this star was in fact a nebula. As observatory director Charles Perrine later wrote, Guérin described its apparent size as 8" by 12", with an appearance "tending toward dark red or scarlet."

According to Perrine, Guérin also noted the nebula contained three nuclei and had an overall shape similar

to a comet. At a magnification of 220x, an "excessively faint" tail extended to the east. But at 500x magnification, the tail was "seen prolonged in a sinuous form to the south to a length of 2'."

When Perrine viewed the nebula through the observatory's 75-centimeter reflector on April 12, 1918, he saw its color as "a deep orange or brick red." The seeing was so poor that Perrine could not distinguish any nuclei. Nevertheless, he measured its disk to be roughly 3" or 4" in diameter and added that the edges seem to be a deeper red than the center.

A red surprise

In April 2022, Scott Harrington from Evening Shade, Arkansas, shared his sighting of VY CMa with me. He began by using his 10-inch Schmidt-Cassegrain at a magnification of 260x to acquire a tight focus on the nearby white variable star NN Canis Majoris before swinging 15' north-northeast to find 8th-magnitude VY CMa. Harrington reported that with direct vision, VY CMa appeared sharp and pointlike, except for its western edge. At 400x, it took on the appearance of a "tight double star" of equal magnitude, but the western component appeared "nonstellar." With averted vision through his 16-inch Dobsonian at 440x, VY CMa looked swollen, whereas direct vision showed it lodged in the east-northeast side of a "small, bright glow."

The following May, I used my 3-inch Tele Vue refractor to observe VY CMa. While the object gave a stellar impression at low power, I was surprised to see it appear definitely swollen at a 300x magnification, especially when compared to stars of similar magnitude. The nebula had a reddish-orange color, reminding me of IC 418, the Raspberry Nebula — a red 9th-magnitude planetary nebula in Lepus with a carbon-rich shell.

It's 300,000 times more luminous than our Sun.

Today, we know that the obscured star of the VY CMa nebula is a true colossus, up to 40 times more massive and 300,000 times more luminous than our Sun. It sheds mass

100 times faster than Betelgeuse. Roberta Humphreys of the University of Minnesota said in a 2021 NASA press release: "VY Canis Majoris is behaving a lot like Betelgeuse on steroids." She also noted that VY Canis Majoris may have already shed half of its mass. "Rather than exploding as a supernova," she continued, "it might simply collapse directly to a black hole."

If you see this remarkable red nebula masking one of the largest stars known in our galaxy, then send in your reports, along with any details about the appearance of its nuclei to sjomeara31@gmail.com, keeping in mind they are ephemeral. ☛



BY STEPHEN JAMES O'MEARA
Stephen is a globe-trotting observer who is always looking for the next great celestial event.



BROWSE THE "SECRET SKY" ARCHIVE AT
www.Astronomy.com/OMeara

Safe solar observing

Here's how to view April's entire eclipse while protecting your eyes.



ABOVE, LEFT AND CENTER: The pinhole effect is visible through tree leaves and hole-punched paper in these shots from the 2017 total solar eclipse.

MOLLY WAKELING

ABOVE RIGHT: A homemade offset filter cell of cardboard, gaffer's tape, and Seymour Solar filter film is fitted to the author's Celestron 8-inch Schmidt-Cassegrain.

MOLLY WAKELING



BY MOLLY WAKELING

Molly is an avid astrophotographer active in STEM outreach. She is pursuing her Ph.D. in nuclear engineering.



The April 2024 total solar eclipse across North America is fast approaching! Being in the shadow of the Moon and taking in the incredible view of the Sun's corona is an unforgettable experience. Totality is just a few minutes of the whole experience, however — watching the Moon taking a larger and larger bite out of the Sun during the partial phases is also exciting.

Besides eclipses, observing sunspots and solar activity all year long is a joy in itself. But caution must be taken when viewing the bright Sun: Safety is essential!

Solar glasses and filters

The simplest way to enjoy observing the Sun is with a pair of solar glasses. The filters in proper solar glasses not only dim the Sun's bright light, but also block the harmful invisible ultraviolet and infrared light as well. Solar glasses that meet the international standard of safety will be labeled with ISO 12312-2 or ISO 12312-2:2015. If this label is not present on the glasses, don't use them. Several websites publish lists of reliable vendors. Don't use the glasses if there are any scratches or holes, as these can allow light through and damage your eyes. Regular sunglasses, neutral density filters for cameras, unexposed film, and other items that might seem like they darken the Sun are not safe and should not be used — don't risk permanent damage to your eyesight!

If you plan on using binoculars or a telescope for the eclipse, a solar filter that securely covers the objective is essential for safe viewing. Various kinds of glass and film filters in different sizes are available from astronomy-gear vendors, and they should be rated ND 5.0, meaning they block 99.999 percent of the Sun's light. The filter itself and surrounding opaque material must block the telescope's entire objective lens. Be sure to cover finder scopes and guide scopes as well, with lens

caps, cardboard, or other opaque materials. Filters at the eyepiece alone are not safe, as heat can build up inside the telescope and break the telescope or the filter. And make sure that solar filters are securely attached with nylon screws, tape, Velcro, or other means to keep the wind or a passerby from accidentally knocking it off, blinding the observer.

During a solar eclipse, solar glasses and filters must be used during all phases except totality. Once the Sun is fully obscured (between second and third contact), you can safely remove your glasses and filters and bask in the ethereal light of the corona. Just be sure to put them back on when totality ends.

Telescope solar projection

An exciting and public event-friendly way of viewing the partial eclipse phases and sunspots is with solar projection through a telescope. Instead of using a solar filter, sunlight is allowed through the telescope and is projected out of the eyepiece onto the ground or a white sheet or board. To focus the image, move the screen closer to or farther from the telescope. A low-power eyepiece, about 15–20mm, and a short-focal-length refractor are ideal.

In order to prevent heat buildup, you need to make an aperture mask that blocks the telescope's objective except for a round hole about $1\frac{3}{4}$ inches (45 mm) or smaller across. It is important to not look through the telescope's eyepiece! Set up the telescope and board in such a way that prevents anyone from looking into the eyepiece and be sure someone is constantly present to supervise.

Solar glasses and filters must be used during all phases except totality.

Pinhole projection

During the partial phases of an eclipse, shadows take on strange shapes as the Sun becomes more of a crescent. You can see the crescent shape using anything with a small round hole, or even by overlapping your fingers in a grid pattern. A kitchen colander, perforated serving spoon, or hole-punched stiff paper are great for seeing this pinhole effect.

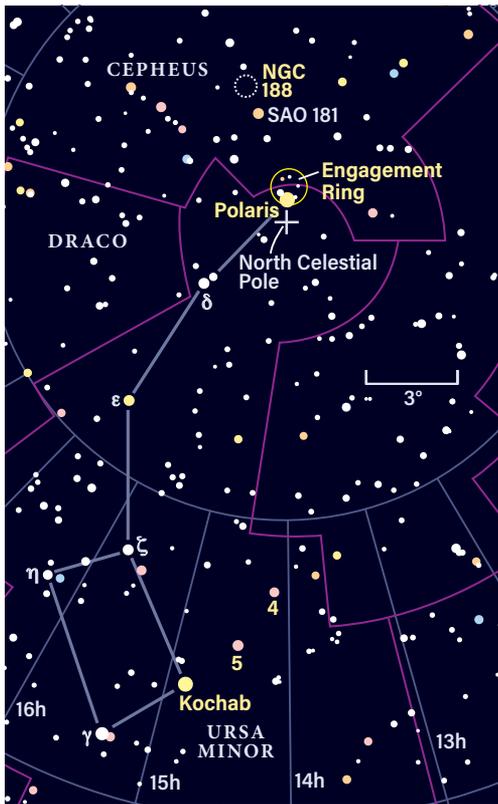
Observing the Sun during the partial phases of a solar eclipse, or even on any ordinary day, can be fun and rewarding — but remember that safety is imperative. Using proper solar glasses and filters and supervising telescope use will protect everyone's eyes from permanent damage. There is always something exciting for an astronomer to see, day or night! ☽



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Northward bound

Find the subtle boreal targets of Ursa Minor.



Polaris lights up the Little Bear in the north. *ASTRONOMY: ROEN KELLY*



BY PHIL HARRINGTON
Phil received the Walter Scott Houston Award at Stellafane 2018 for his lifelong work promoting and teaching astronomy.

Most of us pay much less attention to the far northern night sky than we should because it lacks bright stars and Messier objects. However, that inattention causes us to miss out on some interesting targets every night, year-round. Here are a few to tempt you to look north.

We can't go farther north than **Polaris** [Alpha (α) Ursae Minoris] at the tip of the Little Bear's tail — or the end of the Little Dipper's handle, if you prefer. Many people are familiar with Polaris, although some incorrectly believe it's the brightest star in the night sky. That designation belongs to

Sirius (Alpha Canis Majoris), while Polaris is 48th brightest. What makes Polaris so famous is its position, just 0.7° from the North Celestial Pole, earning it the nickname the North Star.

Because Earth's rotational axis wobbles, that star is getting closer: Polaris and the North Celestial Pole will continue to close to within some 27' of each other in the year 2100 before beginning to separate again.

If you aim your binoculars at Polaris, you will notice that it is the brightest member of a cirlet of stars about half a degree across. At 2nd magnitude, Polaris really stands out among the others, which shine between 7th and 8th magnitude. The late Robert Burnham, Jr., was the first to notice this asterism. In his classic *Burnham's Celestial Handbook*, he describes it as the **Engagement Ring**, with "Polaris itself sparkling as the celestial solitaire of the ring."

Next, shift from Polaris to **Kochab** (Beta [β] Ursae Minoris) at the outer rim of the Little Dipper's bowl.

Kochab is a type K star, giving it a yellowish tint through binoculars. Then glance 2° to its northwest to see a second, fainter yellow star. That's 4th-magnitude **5 Ursae Minoris**. In his voluminous (and free) online tome, *2000+: The Advanced Amateur Astronomer's Field Guide to Deep Sky Observing Database & Sky Atlas* (www.1000plus.com/2000plus), the late North Carolina observer and author Tomm Lorenzin described the golden pair as "a double 'caution light' in binoculars." Look carefully with averted vision and you just might notice that 5 UMi also has a faint companion.

Actually, there are three caution lights if we include 5th-magnitude **4 Ursae Minoris**, found 2° farther northwest. If you defocus your binoculars slightly, the colors may be accentuated.

Ready for a challenge? While most open star clusters lie along the plane of our Milky Way, northernmost Cepheus holds an out-of-place cluster that is barely visible through my 16x70 binoculars on the clearest, darkest nights. I imagine that John Herschel, son of William Herschel, was quite surprised to discover this rogue object on Nov. 3, 1831. Now cataloged as **NGC 188**, this lonely cluster resides just over 4° from Polaris and only 1° south-southwest from the 4th-magnitude star SAO 181.

Some 130 stars ranging from 10th to 17th magnitude call NGC 188 home. Together, they blend into an 8th-magnitude glow spanning about ¼°. The cluster's low surface brightness, however, makes it a difficult challenge in binoculars and smaller telescopes alike. If I aim my 25x100 binoculars its way, a couple of its dim stars pop into view.

NGC 188 is also noteworthy for its age. Formed at about the same time as our solar system, it is the second oldest open star cluster north of the celestial equator. Only NGC 6791 in Lyra is older.

As you can see, there are a variety of binocular targets that are up every night of the year, lying in wait in the north circumpolar sky.

I am sorry to say that this is my final Binocular Universe column in *Astronomy* magazine. I hope you have enjoyed the journeys that we have shared over the past eight years, and that you will continue to tour the universe through binoculars far

into the future. Let's keep in touch. Drop me a line through my website, philharrington.net, or join me on Facebook (@phil.harrington.author). And until we meet again, always remember that two eyes are better than one. ☺

Many people are familiar with Polaris, although some incorrectly believe it's the brightest star in the night sky.



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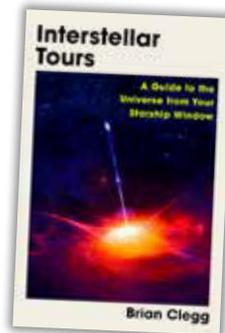
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Bob's Knobs	53
Celestron.....	60
DayStar Filters.....	6
Metamorphosis Jewelry Design.....	53
NEAF DEALER PAGE.....	60
Observer's Handbook.....	59
Scope Buggy	11
Sky Instruments	11
Solar Eclipse Products	59
Technical Innovations	53

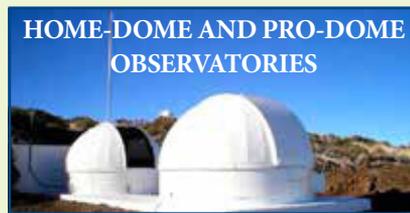


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Radio telescopes, such as the dishes of the Very Large Array in New Mexico, can observe during daylight hours.

ALEX SAVELLO/NRAO

Daytime astronomy

Q | CAN WE STUDY THE UNIVERSE IN THE DAYTIME? IT SEEMS ASTRONOMICAL OBSERVATIONS USUALLY HAPPEN AT NIGHT.

*Rishi Vardhan
Patna, Bihar, India*

A | The first thing you likely think of when you imagine studying astronomy is looking through a telescope at night. The light from planets, stars, and galaxies is faint compared to the nearby Sun, so ground-based observatories do have to wait until nighttime to see them.

But there are other ways to study the universe, and not all of them require darkness. For example, scientists studying the Sun itself use specially constructed solar telescopes during the day when the Sun is visible. Satellites in space also observe our star 24 hours a day. Additionally, some astronomical signals are not affected by sunlight or clouds. Ground-based radio observatories, gravitational-wave observatories, neutrino observatories, and many dark matter experiments can gather data at any time. Some types of gamma-ray observatories can also operate during the day.

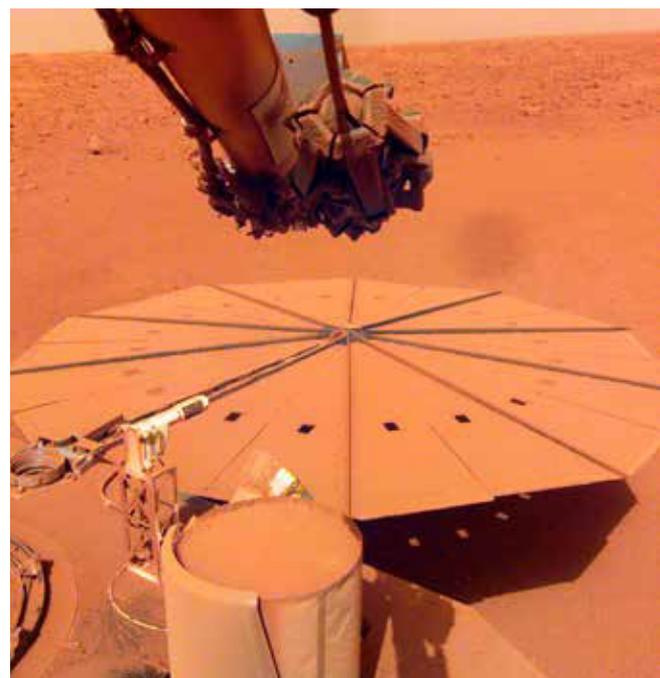
It's worth noting as well that many observatories aren't on the ground but in space: the Hubble Space Telescope, James Webb Space Telescope, Chandra X-ray Observatory, and more. These can take observations that are not affected by the time of day at a given scientist's

location. They can point at a range of objects with only some limitations based on their current position in space. And the spacecraft we have sent to explore the planets of our solar system — including the many Mars rovers and orbiters, BepiColombo, Juno, and even New Horizons and the Voyagers — constantly send back data, regardless of the time here on Earth.

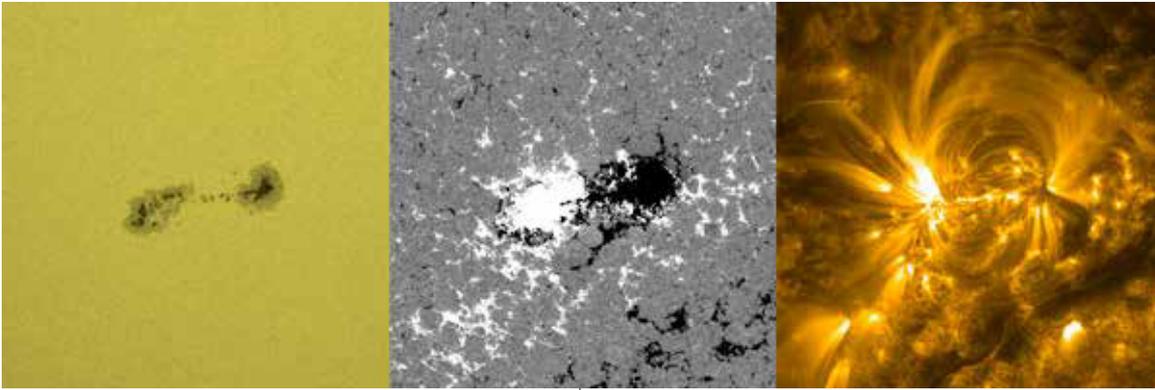
*Alison Klesman
Senior Editor*

Q | INEVITABLY, MARS ROVERS OR LANDERS GET COVERED WITH DUST AND THE SOLAR PANELS NO LONGER FUNCTION, ENDING THE MISSION. WHY DOESN'T NASA BUILD IN A MECHANISM TO CLEAN THE SOLAR PANELS?

*Mike Hunnicutt
Woodridge, Illinois*



NASA's Mars InSight lander was powered by two solar panels, one of which is imaged here. The mission ended when the panels became so dust-covered that they could not generate sufficient power to sustain the craft. NASA/JPL-CALTECH



These three panels show Active Region 13055 on the Sun on July 11, 2022. The same region appears in visible light (left), as a magnetic field measurement (middle), and in extreme ultraviolet light (right).
LISA UPTON, COURTESY OF NASA/SDO AND THE AIA, EVE, AND HMI SCIENCE TEAMS

A | This is a great question and to me, at least, the answer is not at all obvious.

It's not that NASA engineers can't design a brush or a wiper or an air-blasting system to clean dust off solar panels or other Mars rover or lander parts — that kind of engineering isn't rocket science! The issue really is about the constraints on deep-space missions; many engineers refer to these constraints as the "resource box." That is, all missions are constrained to fit into a metaphorical box defined by resources like mass, physical dimensions, power, schedule, data volume, and cost. The size of the box depends on many factors, like which rocket will launch the mission and what budget is available to the team. And while the resources can be moved around and traded inside the box, the whole system can't go "out of the box."

So, for example, if a team wants to add a dust wiper blade to a rover solar panel, the engineers will say, "Sure, we can do that! But what do you want to trade to accommodate the mass, volume, power needs, and cost of that wiper system?" Hmm... Would the team be OK, for example, trading a backup radio transmitter for that wiper system? Or dropping one of the science instruments for it? In my experience, we've decided not to make such trades because we felt confident that the rovers could survive their required minimum lifetime even with dusty solar panels. And, while debatable, to most of us involved that appears to have been an acceptable trade for missions like Spirit, Opportunity, Insight, and others.

We often hear about people or groups being praised for thinking "outside the box." But in deep-space mission systems engineering, the key is actually to try to maximize science while staying *inside* the (resource) box!

Jim Bell

Principal Investigator for Mars 2020 Mastcam-Z, Deputy Principal Investigator for Science for Mars Science Laboratory Mastcam, Arizona State University, Tempe, Arizona

Q | WHAT CAUSES SUNSPOTS? DO THEY FORM ON THE SURFACE OF THE SUN OR WELL UP FROM BELOW?

Gil Roscoe
Valley Village, California

A | Sunspots are dark regions on the Sun that are about the size of Earth. They are caused by strong magnetic fields that emerge through the photosphere, or surface, of the Sun. The spots themselves don't exactly well up from below, but are a visual effect caused when heat is *prevented* from doing so.

Our star is so hot that it undergoes convection in the outer third of its interior, causing the surface to boil like a pot of hot water (seen as tiny bubbles in the visible-light image on the left, above). At these temperatures, the matter is converted to a plasma — an ionized gas — in which the electrons and protons are free to move separately.

Magnetic fields within the Sun's convective interior are transported by plasma flows that stretch and amplify the fields' strength. When they grow stronger, these magnetic fields become buoyant and rise up, emerging through the photosphere. The effect is like pulling on a bundle of ropes with weights on both ends: The field lines remain anchored to the surface in two places, creating a loop. The places where they emerge from the surface are called footpoints. The field that comes out of the surface at one footpoint has a positive magnetic polarity and the field that goes back in at the other footpoint has a negative polarity (shown in the middle image with the positive/negative field represented by white/black).

The magnetic field lines above the surface are filled with plasma and are heated in the corona, forming beautiful glowing ultraviolet arches known as coronal loops (shown in the extreme ultraviolet image on the right). These stunning arches are invisible in the white-light spectrum that we see with our eyes. But we *do* see the footpoints of the arches, where the magnetic field emerges through the photosphere. These are the sunspots! They appear dark relative to the surrounding plasma on the solar surface (as seen in the visible-light image on the left) because they are cooler. This is because the intense magnetism at the footpoints slows convection, preventing heat from welling up from below.

Lisa Upton

Solar Physicist, Space Systems Research Corporation, Boulder, Colorado

SEND US YOUR QUESTIONS

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Cosmic portraits



1. EDGE OF THE TRUNK

Emission, reflection, and dark nebulae — this scene in Cepheus has it all. The region lies just north of the oft-imaged Elephant's Trunk Nebula in IC 1396. This Hubble-palette image represents 174 hours of exposure with a 2.4-inch f/4.9 scope. • *Jeffrey Horne*

2. WHAT HAPPENED HERE?

The giant elliptical galaxy Fornax A (NGC 1316) lies 60 million light-years away, accompanied by the smaller spiral NGC 1317. Although the pair appear to be interacting, Fornax A's distorted nature is likely due to previous encounters, including the merger of gas-rich galaxies that produced it. This LRGB image was taken over 22 hours on a 17-inch scope. • *Vikas Chander*





3

3. SPECTACULAR STEVE
An example of the auroralike phenomenon known as STEVE (strong thermal emission velocity enhancement) cuts across the sky above Edmonton, Alberta, intersecting the Pleiades (M45). The 15-second exposure was taken with a Sony a7R II at ISO 1200 and a 24mm f/1.4 lens.
• *Ray Wiens*



4

4. ECLIPSE OVER KUKULCÁN
The archaeological site of Chichén Itzá on Mexico's Yucatán Peninsula lay just outside the path of annularity of the Oct. 14, 2023, solar eclipse. The photographer used a Canon 6D and a wide-angle lens at 15mm and f/4.5 to capture the famed Temple of Kukulcán and a 135mm prime lens at f/2.8 to image the eclipse above it.
• *Amir Shahcheraghian*



5

5. TWIN TANTRUM
At the center of planetary nebula Sharpless 2-71 lies not one star, but a white dwarf with a binary companion, from which it is stealing material. That interaction is likely what has created the chaotic appearance of the nebula, which lies roughly 5,200 light-years away in Aquila. • *Kfir Simon*



6

6. CRAWLING IN THE DARK
The Gecko Nebula (LBN 437) is located 1,200 light-years away in — where else? — Lacerta the Lizard. The object is a reflection nebula, lit by young stars within. It overlaps the red strands of the much larger emission nebula Sharpless 2-126. The photographer used a 2.8-inch f/5.6 refractor, a cooled one-shot color camera, and two filters: 14 hours of exposure with a UV/IR filter to capture the Gecko, plus eight hours with a dual-band H α /OIII filter to capture the emission nebula. • *Katelyn Beecroft*

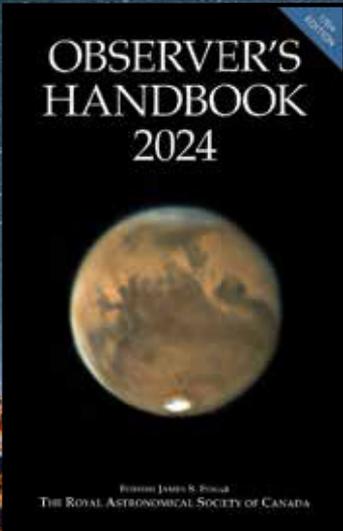


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Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures.



RIPE FOR HARVESTING

Although winter may not be prime time for picking raspberries, it's the best time for viewing the Raspberry Nebula (LBN 867). Located in Orion the Hunter just 2.2° north-northwest of 2nd-magnitude Bellatrix (Gamma [γ] Orionis), this colorful nebula shows a dual personality. Its most conspicuous segment is the emission nebula Sharpless 2-263. The bright star SAO 112667 at the center of this image ionizes the surrounding hydrogen, causing it to glow with a characteristic reddish color. Below Sharpless 2-263 lies the blue reflection nebula vdB 38, whose hue comes from dust scattering the light from this same hot star. KPNO/NOIRLAB/NSF/AURA/T.A. RECTOR (UNIVERSITY OF ALASKA ANCHORAGE/NSF'S NOIRLAB)



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